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Quantifying disparities in access to recreational opportunities by alternative modes of transport

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ABSTRACT

The paper draws upon open-source technologies to present methods of incorporating multiple travel modes into GIS analyses of cumulative opportunity and proximity-based metrics of accessibility. Two case studies are undertaken. The first uses isochrone analysis to evaluate national access to sport facilities expected to appeal to a broad range of ages and abilities. Predictably, urban areas and private car travel record the highest levels of access, but the revelation of geographical patterns in disparities between travel modes may allow transport planners and national and regional sporting bodies to identify where further investment in facilities and transport infrastructure might best be targeted. The second case study uses network tracing of shortest time pathways to consider city level access to greenspaces. Findings here suggest that cycling may offer similar access levels as private car travel, with much poorer outcomes for walking and public transport. Such studies demonstrate how active travel and public transport might be included in holistic GIS analyses to aid policy makers, and those who plan and monitor provision of sporting opportunities, to promote improved levels of access to, and participation in, physical activities within disadvantaged communities. They may also have value in cross-sector approaches that promote the wider health and environmental benefits of using active travel and public transport to access neighbourhood facilities.

1. Introduction

Larsson et al. (2022) have recently suggested three trends that have become evident in accessibility and land use studies – firstly, the incorporation of alternative means of transport other than the car, secondly, the use of novel open sources of data that enable greater spatial and temporal analysis of patterns and thirdly, an extension of research to consider activities other than access to employment opportunities. This paper continues these themes by demonstrating how active modes of travel (i.e., walking and cycling) and public transport schedules can be used as part of an overall evaluation and analysis of spatial variations in access to sports facilities and greenspace (i.e., vegetated land such as parks, playing fields and grassed areas located within an urban area) or blue space (i.e., natural or artificial environments that prominently feature water) at both national and city level. Previous research has been concerned with examining potential associations between the spatial distribution of sports facilities or green/blue spaces and participation in physical activities (Deelen et al., 2017; Elme, et al., 2017; Hallmann, et al., 2012). In addition, there is a relatively large literature base concerned with deriving objective measures of both the numbers and types of neighbourhood-based sporting opportunities that enable an understanding of variations in physical activity levels, utilisation patterns and physical and mental health outcomes (see for example, Van Den Eeden et al., 2022; Liu et al., 2022a; Liu et al., 2022b; Mears et al., 2019; Karusisi et al., 2013; Macdonald, 2019; Mulligan et al., 2017; Wendel-Vos et al., 2007).

Jones and Panter (2010) reviewed much of the early research of the use of both perceived and objective measures of accessibility to explore the provision of free-to-use and commercial facilities in different socio-economic contexts. More recently, the impacts of the COVID-19 pandemic have focused attention on the availability of opportunities for physical activity within 'reachable' distances and the potential health impacts of access to '*x-minute*' amenities from peoples' home residences (Logan et al., 2022). An early study of such factors for example has found widening disparities between disadvantaged and affluent areas in their levels of access to recreational walking and outdoor recreational facilities (Lee et al., 2022). This study responds to such debates by developing spatial approaches that incorporate active travel

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and public transport schedules within the types of accessibility measures that have been widely used by decision-makers to plan service provision. Such an approach could be used to encourage active travel and the associated benefits of healthy activities by both transport authorities and sporting bodies.

The key focus here is on measures that proxy for the ease in which people can reach an indoor/outdoor sports facility or access a neighbouring area of greenspace. Such sites are considered to offer 'recreational opportunities', a term that is used here to imply engagement with physical exercise, although more sedentary activities such as sports spectating and relaxing might arguably be included too. In the case of sports sites, this includes access to a range of facility types such as football pitches, tennis courts and swimming pools within reach of an estimate of population demand via alternative means of transport. Typically, past approaches have been based on the use of drive times as proxy measures of accessibility, assuming access is via private transport. Such metrics may not be appropriate in circumstances where active travel or public transport are the primary means of accessing indoor recreational facilities, swimming pools or public open space (Dong et al., 2022; Grow et al., 2008). The aims of this paper are thus to address gaps in the literature by drawing on open-source technologies to present methods of incorporating multiple travel modes into GIS approaches that adopt cumulative opportunity and proximity-based metrics and that permit access to be considered alongside the choice of facilities available within time or distance thresholds. By showing how potential accessibility can be calculated for user-defined distance/time thresholds, such an approach builds on previous findings to include active travel alongside public transport as means of accessing recreational opportunities and greenspaces.

By adopting techniques that identify areas that fail to meet a minimum set of proximity-based standards of service provision, these findings can be used by transport planners and national and regional sporting bodies to identify where further investment in facilities and transport infrastructure might best be targeted. This allows policy makers, and those who plan and monitor provision of sporting opportunities, to promote improved levels of access to, and participation in, physical activities in disadvantaged communities (Sport Wales, 2021). It can also be used in cross-sector approaches that promote the wider health and environmental benefits of using active travel and public transport to access neighbourhood facilities. The approach taken is described in more detail in section three following a summary of the literature concerned with measuring access to such opportunities.

2. Literature review

Several studies have been concerned with developing or improving perceived and objective measures of accessibility to sports facilities and other opportunities for physical activity, and with examining patterns of recreational provision in relation to socio-economic data (Ferguson et al., 2013; Higgs et al., 2015; Langford et al., 2018; Martori et al., 2020; Salze et al., 2011; Talen and Anselin, 1998). Cereijo, et al. (2019) for example used network distance to nearest facility as well as street network buffers around entrances to residential buildings in Madrid to examine potential disparities in exercise facilities. Such proximate and buffer catchment approaches have been extended to incorporate walking, cycling and private car travel modes, for varying catchment sizes that include improvements to demand measures by incorporating preferences for different age groups to a variety of sports facilities (Xiao et al., 2022). As demonstrated in the current study, this in turn can be enhanced by the inclusion of public transport schedules or by combining multiple transport modes to present a fuller picture of overall patterns of access using a combination of approaches.

A limitation of some studies has been the lack of consideration of the quality/size of the facility, which has significance because users may be prepared to travel further to reach larger amenities, those that possess a wider range of equipment, or where specialised coaching is offered. Coverage or so-called cumulative opportunity measures have been widely used to investigate access to a broad range of service types and consist of a count of the number of opportunities 'reachable' by a particular mode of transport within a predetermined time or distance (Handy and Niemeier, 1997; Talen, 2003; Wachs and Kumagai, 1973). To compute this requires the generation of catchment areas based either on straight-line buffers or ideally zones derived from network analyses that consider local road configurations and public transport availability. Several past studies use cumulative opportunity measures to examine the variety of local facilities and provide further insights into the choice of recreational opportunities. Billaudeau, et al. (2011) is one example, recording all services within 500 m of demand locations and showing how many facilities can be accessed in these catchments. Karusisi et al., (2013) used both proximity-based approaches and cumulative opportunity measures to draw attention to the advantages of methods that include the number of alternative facilities in an area rather than just identifying closest facilities. However, such studies are often confined to small study areas or only consider access to a limited number of facility types. Cutumisu and Spence (2012) used floating catchment area (FCA) techniques to examine spatial access to playing fields and potential associations with self-reported physical activity levels for a sample of almost 2900 adults in Edmonton, Canada. Better access was associated with higher levels of physical activity, at least for objective measures based on the equivalent of a 15-minute pedestrian trip to sports fields.

One particular and important drawback of studies to date, and thus a focus of this study, relates to assumptions regarding transport, which typically presume access is sought via a single mode such as by car or walking. Mode of travel will depend upon a host of factors that need to be considered when evaluating accessibility to sporting facilities, including the population age group commonly using different types of recreational activities, their socio-economic characteristics, and the broader environment (e.g., urban/rural area). Sports' governing bodies are charged with monitoring socio-economic variations in access and seek to encourage greater participation rates amongst minority groups or those living in deprived areas. The impacts of the COVID-19 pandemic led to a renewed interest in identifying inequalities in access to sports fields or recreational opportunities at neighbourhood levels as households were confined to their local areas during lockdown periods and indoor facilities temporarily closed in response to social distancing requirements.

During these lockdowns, reductions in public transport provision compounded changes in the availability of services with subsequent impacts for those reliant on these services to reach recreational opportunities. The COVID-19 pandemic also highlighted the importance of access to greenspace which permitted those unable to reach formal sporting facilities some degree of opportunity for engaging in physical activity during this period (Ha, et al., 2022; Heo et al. 2021; Geary et al. 2021). This has led to a renewed interest in investigating socioeconomic disparities in the availability of natural or greenspace within user-defined distance or time thresholds (see for example, Thornton et al., 2022; Capasso Da Silva, et al., 2020; Pozoukidou and Chatziyiannaki, 2021; Calafiore et al, 2022). This in turn builds on an extensive literature that has highlighted the wider physical and mental health benefits of urban parks and greenspaces (Bustamante et al., 2022).

Such approaches rely on GIS to generate catchments that then, for example, enable recreational opportunities to be assessed within a specified round trip of demand locations to gauge local service provision (Calafiore et al. 2022). Olsen et al. (2022) for example have explored the status of 20-minute neighbourhoods being promoted by the Scottish Government that incorporates potential access to recreational opportunities, sports pitches and facilities as part of domains of service types deemed important elements of provision. Staricco (2022) further examined the sensitivity of results to the catchment time thresholds adopted, examining the percentage accessible by walking in a case study based in Turin, Italy. Others have attempted to measure the number of reachable services within cycling neighbourhoods (McNeil, 2011),

examined patterns of access to workplaces via active transport modes (Both et al., 2022) or have explored socio-spatial variations in access to recreational facilities such as gymnastic facilities and swimming pools within walking or cycling distances (Dong et al., 2022; Ogilvie et al., 2011; Price et al., 2021). It remains an issue, however, that most studies include only a single mode of transport and thus tend not to compare outcomes with those derived from alternatives to provide a more holistic assessment of the role of transport infrastructure that includes for example active travel routes (Capasso Da Silva et al., 2020).

The potential benefits of active travel on both physical and mental health have been highlighted in a wide range of studies. Kroesen and van Wee (2022), for example, drew upon findings that show associations between walking and cycling modal shares and the proportion of those that were overweight or diagnosed with heart failure, diabetes, or other chronic illnesses, to highlight the importance of spatial characteristics of neighbourhoods. This current study is, to our knowledge, the first to examine the feasibility of including active travel into measures of accessibility to sporting and recreational opportunities at the national level for Wales. We suggest such an analysis could assist both in assessing the provision of active travel routes, a key policy focus of the current Welsh Government in encouraging modal shift (Welsh Government, 2021), and in helping to draw attention to the need to consider alternative transport options when planning the location of recreational facilities and greenspace. This in turn may impact on attempts to promote the use of such means of travel as part of the wider public health and environment agenda.

3. Data and methods

To illustrate how spatial variations in the potential accessibility of sports facilities and greenspace might be evaluated at both national (all-Wales) and city-wide (Cardiff) scale, three primary data considerations are needed. First, information regarding the supply of sports facilities and greenspaces as currently distributed across Wales is required. Second, to determine demand potentially placed upon such services, population counts at representative points are needed at an appropriate scale, as is discussed further below. Finally, data and software to model the connectivity between supply and demand sites and allow the subsequent calculation of transit times via alternative travel modes are necessary. Together, these facilitate the development of methodological approaches described below for measuring and monitoring accessibility at national and local scales.

3.1. Sports facilities and greenspace data

Individual sporting activities typically appeal to a distinct cohort in terms of their participants' age, gender, and ethnicity. The National Survey for Wales (Office for National Statistics and Welsh Government, 2016–2017) provides age profiles of participants in various sports and was used to help select the facility types included in this study. From a national comprehensive database supplied by Sport Wales, a subset of facility types was identified, selected on the basis that together they appeal to a broad range of age groups and sporting abilities:

- *Gyms / fitness suites* mostly used by younger adults aged 18–45 (390 sites).
- *Indoor swimming pools* popular with all age groups and sporting abilities (280 sites).
- *Outdoor tennis courts* appeal to relatively active participants of all ages (450 sites).
- *Outdoor basketball* includes both courts and single hoops (138 sites) that often attract younger participants, aged 8–18.
- *Outdoor multi-purpose pitches* supporting various team sports (e.g., football and rugby) often played in the context of formal leagues and tournaments, but also used informally by young friendship groups (2210 sites).

Fig. 1 illustrates the distribution of these sites across Wales, each represented by a single point location. In this exploratory study only site location and sport type were exploited, but in future analyses additional supply-side attributes could be added to develop a fuller understanding of variations in the overall quality of provision.

Information regarding greenspace, shown in Fig. 2, was derived from the Open Greenspace product (Ordnance Survey, 2022). Although available nationally, only the 5815 sites that fall within the limits of the City of Cardiff local authority (the Welsh capital) were utilised here as part of a city-wide analysis. As stated previously, access to greenspace is widely linked in the literature to enhanced physical and mental health and wellbeing, particularly in dense urban environments. Urban greenspace presents opportunities for all ages to participate in physical activities such as walking, jogging, and running, as well as offering informal playing fields and play spaces for younger members of society. Whilst many definitions of what constitutes greenspace exist, in this study it was important it should cater for sports activities or allow users to walk, cycle, or otherwise roam freely. This led us to only include those sites carrying the label "*Playing Fields*", "*Play Space*", "*Public Park or Garden*" or "*Other Sports Facility*". Unlike the previous sports facilities data, greenspaces typically cover an extensive area. Thus, polygons define their spatial extent while an associated set of points provided by the Open Greenspace dataset identify specific points of access.

3.2. Population demand

Potential demand placed upon sports sites and greenspaces was estimated from population totals recorded at representative points. Whilst aggregated counts are needed to ensure computations remain tractable, careful attention must be paid to the scale and resolution adopted. Many policy decisions in the UK are driven by information expressed spatially for units drawn from a geographical hierarchy used for reporting small area statistics. Output Areas (OAs) represent the finest spatial scale with a mean population of around 300 persons. OAs are clustered to create Lower Super Output Areas (LSOA, mean population 1500), which in turn are combined to form Middle Layer Super Output Areas (MSOA, mean population 7,200), and finally Local Authorities who are charged with the delivery of local government activities. Output Areas are themselves constructed from adjacent postcodes, each of which typically identifies 15 or so domestic properties and whose primary purpose is to facilitate postal delivery.

Both a representative point and associated polygon is available at each level in this hierarchy. Whilst statistical information for national and local studies is typically presented at LSOA and OA level respectively, using the single representative point of these units to compute an accessibility score would be an oversimplification of the true accessibility experienced amongst its contained population. Therefore, to maximise precision, provide a detailed granularity of analysis and maintain meaning this study computes all accessibility metrics using postcodes as representative points of population demand. Results are then aggregated to OA or LSOA level for reporting purposes, at levels familiar to planners and policy-makers, using population-weighted averaging whenever possible.

Based on the 2011 census, Wales is currently divided into 10,036 OAs and 1,909 LSOAs. Population counts were based on the national mid-year OA population estimates released in 2020. These counts were assigned to the 80,939 domestic postcodes identified as currently active (Doogal, 2022). Each OA mid-year count was distributed to its contained postcodes using their reported 2011 headcount to scale this amongst them proportionally.

3.3. Network times/distances

To determine travel time/travel distance between population demand centres and nearby sports facilities and greenspaces necessitates a suitable transport network dataset and associated routing engine. To

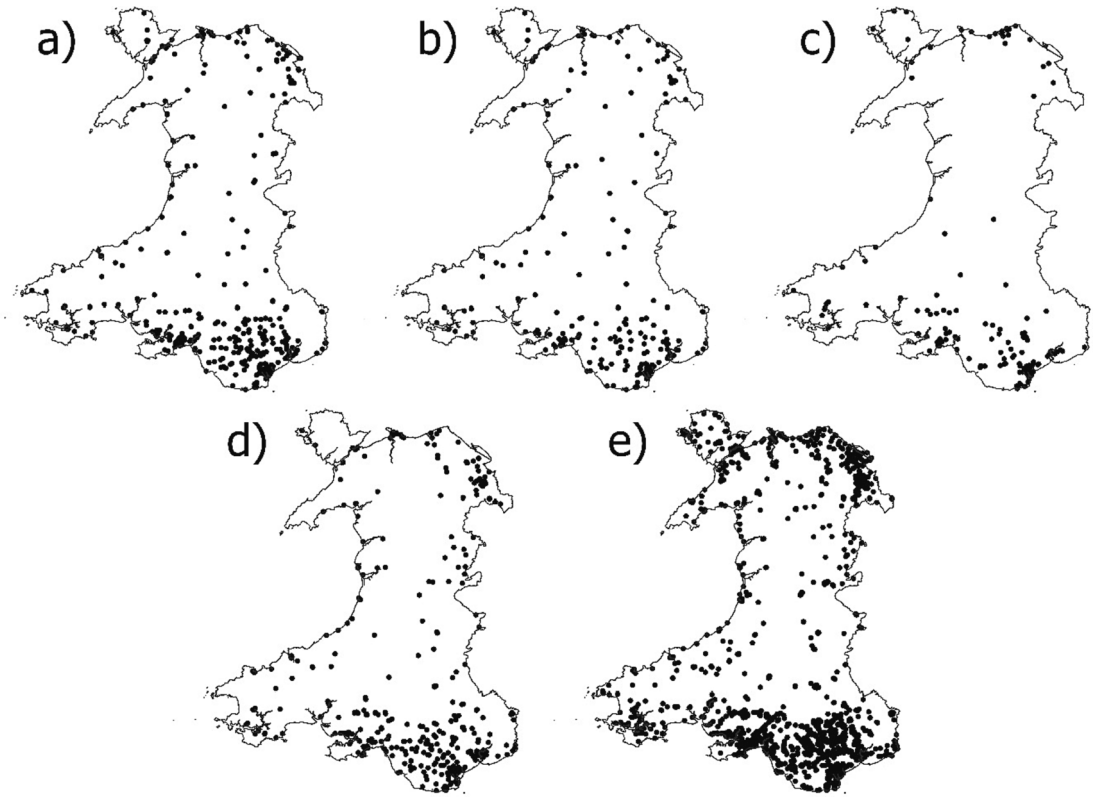

Fig. 1. The distribution of sports facilities across Wales: Gyms/fitness suites (a), swimming pools (b), basketball courts (c), tennis courts (d) and grass pitches (e). (Source: Sport Wales facility dataset).

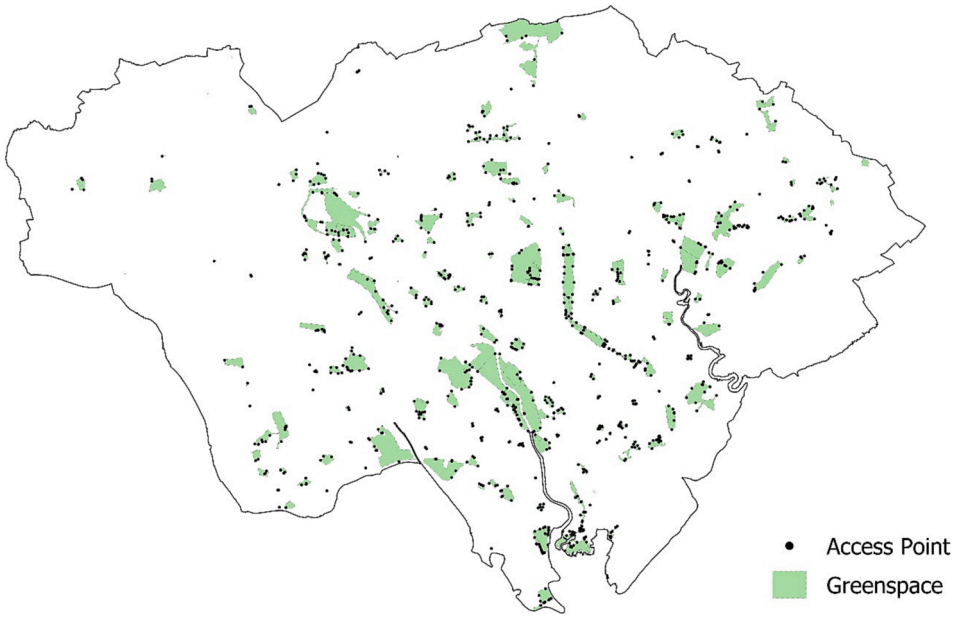

Fig. 2. Distribution of greenspace and its access points across the Cardiff local authority. (Source: Ordnance Survey Open Greenspace)

build on previous studies, a routing engine capable of computing routes via alternative travel modes was needed, leading to the adoption of OpenTripPlanner (OTP). OTP is an open-source routing engine (OpenTripPlanner, 2022) that uses a network graph based on OpenStreetMap (OSM, 2022) road and path network data, which themselves are continuously updated as a global community project. OTP can utilise public transport schedules supplied in General Transit Feed Specification (GTFS) format to allow routes to be computed using private (car), public (bus and train), cycling, and walking travel modes. Public travel routes can combine walking and bus/train elements and accommodate service interchanges to allow realistic solutions to be obtained. Public transport schedules were obtained from Traveline (Travelinedata, 2022) for information regarding bus services, and from Rail Delivery Group (Rail Delivery Group, 2022) for information regarding trains. Both were converted into GTFS format using an R package (UK2GTFS, 2022).

3.4. Measuring accessibility to recreational opportunities

Two case studies were undertaken. The first was a national level analysis whose outcomes were presented at LSOA level. OTP's isochrone calculation feature was deployed to calculate 20-minute travel-time catchments around each postcode, based on four modes of transport (car, bus, cycling, walking). OTP returns isochrones as polygons created by constructing a convex hull around the maximum points reached in the network from a given starting position over a given time. An example is shown in Fig. 3, where the consequences of adopting alternative travel modes is clearly demonstrated. The calculation for private car is based on national speed limits set according to road classifications. Calculations for cycling and walking use the same road network but extended to include cycle paths and walkways unavailable to motor vehicles and adopt recalibrated speeds (approximately 17 Km/h and 5 Km/h respectively). Calculations for public transport use supplied timetables to calculate intervals between bus stops, as well as adding walk times to/from a nearest bus stop to the actual journey start and end points. A user parameter affecting isochrones generated for public transport is the maximum walking distance allowed within any part of a journey. In this study we set this to be 400 m (about 5 min) because this value is widely adopted in previous studies to represent the maximum distance passengers might be expected to walk to reach a bus stop (see Murray et al., 1998; Ivan et al., 2019; Wu and Hine, 2003). The potential implications of this are further discussed in section 5 of the paper.

A Python script was developed to issue the necessary URL calls to OTP to generate isochrones for all 80,000 + postcodes, and to store the outcomes in a PostgreSQL/PostGIS spatial database (PostGIS, 2022; PostgreSQL, 2022). Thereafter analytical functions provided by the spatial database were used to determine which sport facilities were contained inside which isochrones (so called point-in-polygon analysis). Specifically, this information was first analysed to determine for each postcode and for each mode of travel whether any sports facility site of a specified type was reachable in the travel time constraint applied. The population counts of all postcodes in an LSOA able to access a site were then summed and expressed as a percentage of its total population. This yields an estimated percentage of the LSOA population able to access a given sports facility type via a stated transport mode within a 20-minute travel time.

For any given postcode and facility type, the total number of sites reached via a specific transport mode is also easily computable. If these scores are averaged over LSOAs, each being weighted by its corresponding postcode population, a cumulative opportunity measure is produced. This score represents the average number of opportunities that LSOA residents have to a particular service within the imposed travel time constraint. Returning to the first calculation, each LSOA is flagged to indicate if 50 % or more of its population can access a given facility type. Tallying these flags across all services produces a measure of diversity of sporting opportunity, with each LSOA scored 0 to 5 to reflect the number of sports activities determined to be readily available to its residents.

In addition to returning isochrones, OTP can compute a precise time/distance (and route details if needed) between specified start and end points. To demonstrate this flexibility, a proximity-based analysis was undertaken at the city level (Cardiff) by aggregating postcode scores across Output Areas (OAs) for multiple modes of transport. This second case study draws on the approach taken by Cereijo et al. (2019) in using network distances, but it extends their analysis by including multiple transport modes. When analysing accessibility to greenspace in an urban area the Output Areas is a more appropriate unit for the dissemination of results. First an origin to destination matrix is required in which distances from a postcode to its nearby greenspaces are recorded. Given the nature of greenspaces reported earlier, this may involve an assessment of several access points associated with any particular greenspace. Notwithstanding such complexities, the travel time to the nearest greenspace access point is computed for each postcode for each mode of transport. A population-weighted average was then computed for all postcodes falling in each Output Area to yield the final proximity-based accessibility metric.

4. Results

4.1. National level accessibility to sports facilities

The percentage LSOA population able to reach a service via each transport mode is presented in Fig. 4. This example maps information

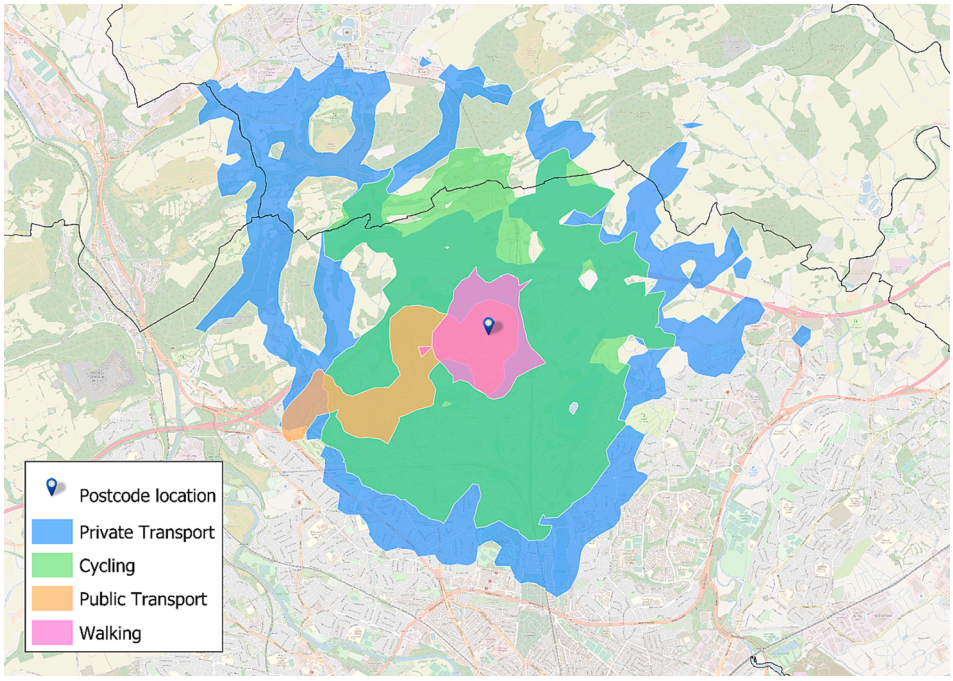

Fig. 3. 20-minute isochrones associated with alternative transport modes.

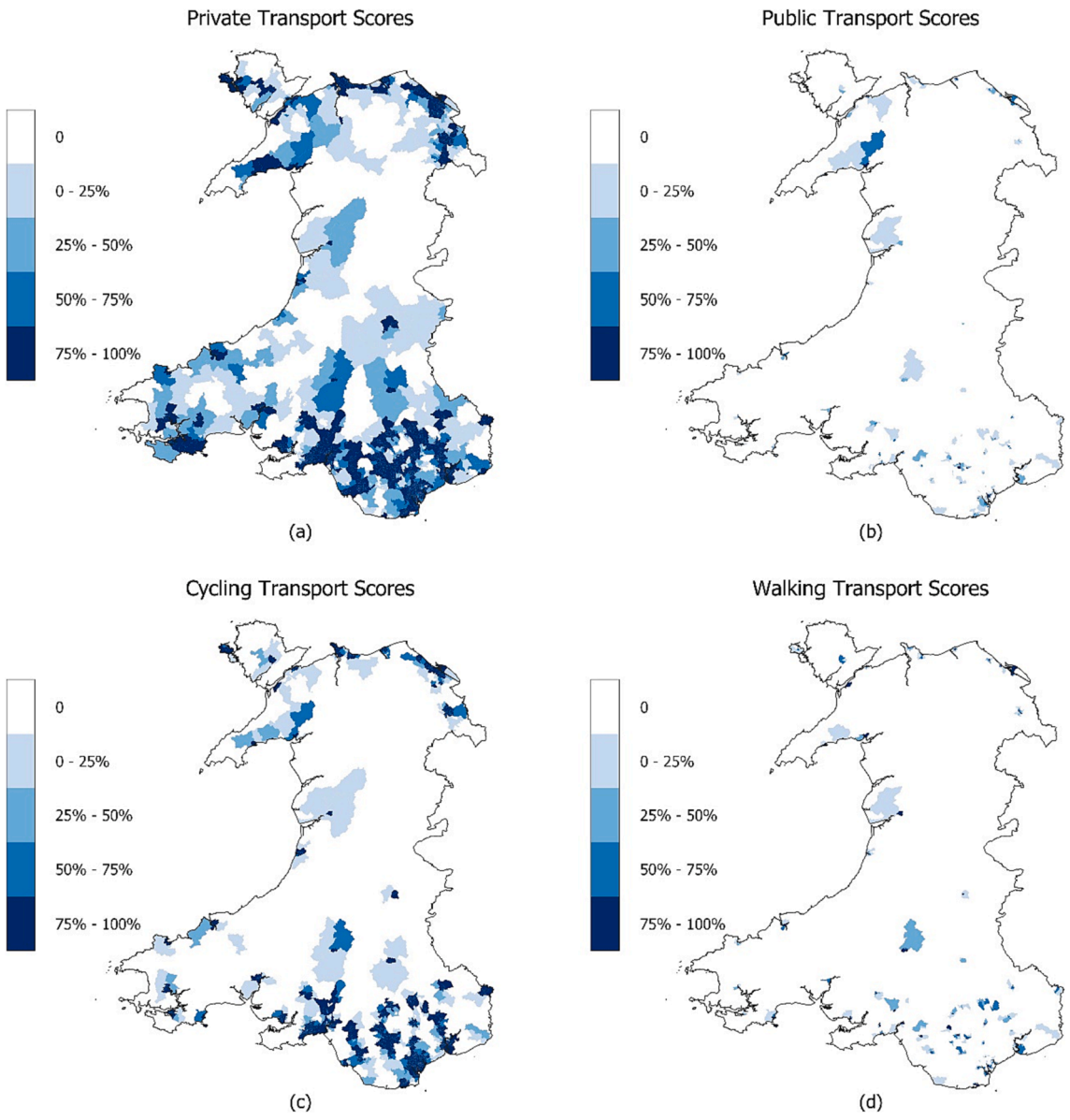

Fig. 4. Proportion of population with access to a swimming pool in a 20-minute travel time.

relating to access to swimming pools in a 20-minute travel time, with all other facility types also being available but not shown. Mapped patterns reveal that, as to be expected, private transport return the highest levels of overall accessibility. This is because private transport is unencumbered by the need to repeatedly stop to pick up/drop off passengers, or to make transfer between services on route. Furthermore, it mostly operates at higher travel speeds as compared to cycling and walking. Walking and public transport often resulted in similar scores overall. Although the accessibility patterns obtained for walking appear very similar to those for public transport, the averages for both rural and urban areas are actually higher for walking. This result may partially reflect the additional constraints imposed upon public transport trips, which assumed bus uses to be unwilling to walk further than 400 m to access a stop, as well as on the route limitations associated in general with public transport systems. For example, within the overall 20–minute time constraint a route consisting of, say, a 10-minute walk to a bus stop, 5-minute bus journey, and final 1-minute walk to a facility would not be picked up in this analysis. Yet it could still be quicker than the shortest travel time recorded for walking or identify an access opportunity available by bus when no opportunity was detected in the walking scenario. The 400 m constraint is very widely established in past literature concerning public transport analysis, and for this reason was adopted here, but a strong argument could be made for relaxing it in the context of access to sport facilities and greenspace where the primary journey objective is itself to engage in physical exercise.

Cumulative opportunity scores, reporting the average number of facilities of a specific type reachable from the contained postcodes within a 20-minute travel time are shown in Fig. 5. Once again, the maps shown here relate specifically to the instance of swimming pools although maps for all the other services were similarly constructed. The reason why multiple choice of facilities represented at this level is important relates to the preferences individuals may have for facility characteristics such as (in the case of swimming pools) the size of the pool, the quality of changing facilities or the availability of diving facilities, which may influence their selection. In such instances, the location of facilities is important, but choice can also be influenced by the mode of transport used to access sites. It is evident from the variations in access across Wales that the chosen mode of transport influences the numbers of facilities that can be accessed, re-iterating the importance of considering both the location of facilities and the impacts of

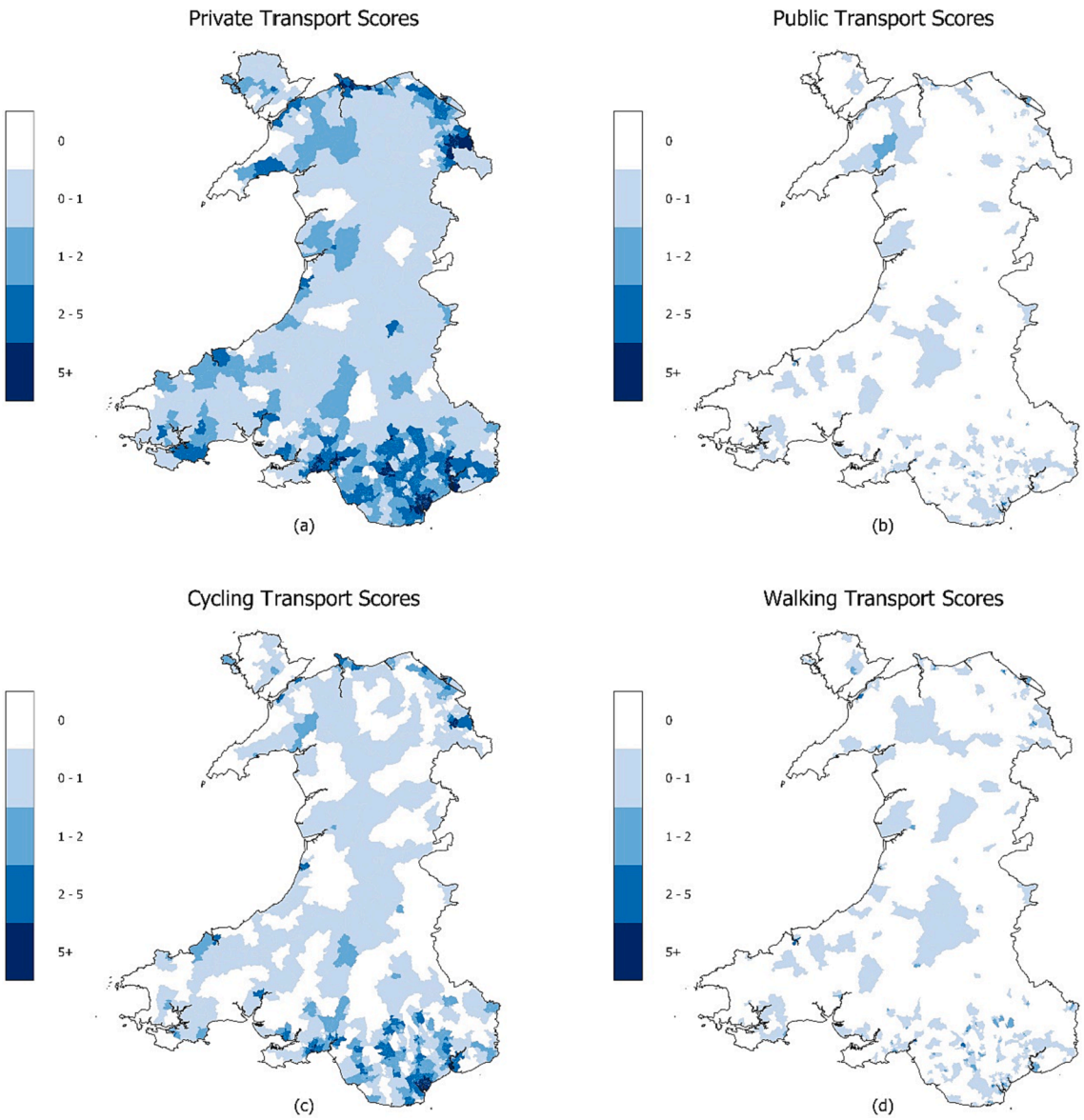

Fig. 5. Mean cumulative opportunity to a swimming pool within a 20-minute travel time.

public transport networks when planning provision.

The metric representing the diversity of sports regarded as being available within a 20-minute travel time are represented in Fig. 6. This shows the extent to which alternative activities might be able to be undertaken, thus providing options for increasing the levels of physical activity undertaken or encouraging a wider cohort of the population to engage with a sporting opportunity. It is evident, as expected, that urban areas are prominent in terms of higher levels of accessibility for most modes of transport. From these maps we can see the range of unique types of sport that could cater to different demographic groups in alternative age ranges for example. The results for the three different measures of accessibility displayed in Figs. 4–6, illustrate the importance of considering the availability of services in relation to prevailing population demand by different transport modes.

4.2. City-wide accessibility to greenspace (Cardiff)

Regarding the findings from nearest distance approach by transport modes, similar findings are seen in terms of those areas highlighted as having the higher levels of access to greenspace through shortest mean travel times from each postcode at the Output Area level (Fig. 7). However, access via public transport appears to be worse than for walking alone, whilst the cumulative opportunities results show roughly the same opportunities exist within the catchment. This again may be a result of methodological constraints mentioned previously in that people are assumed to walk a lot further than 400 m in 20 min, but the public transport option caps this at a 400 m maximum walking distance. It should also be noted that the 400 m 'rule' applies to any leg of the entire journey, so a walk between stops, or from the final stop to the facility must also fall within the 400 m distance in order for the route to be included.

When viewing the urban area within this case study, cycling tends to allow users to cover larger proportions of the research area, reaching further distances compared to public transport, and almost as much as private transport. This is likely due to the ability to travel on both roads and cycle paths that cut through areas which those using private or public transport cannot access. A limitation here however is that a computed shortest path may not necessarily be the most 'bike friendly' in terms of the terrain or road type.

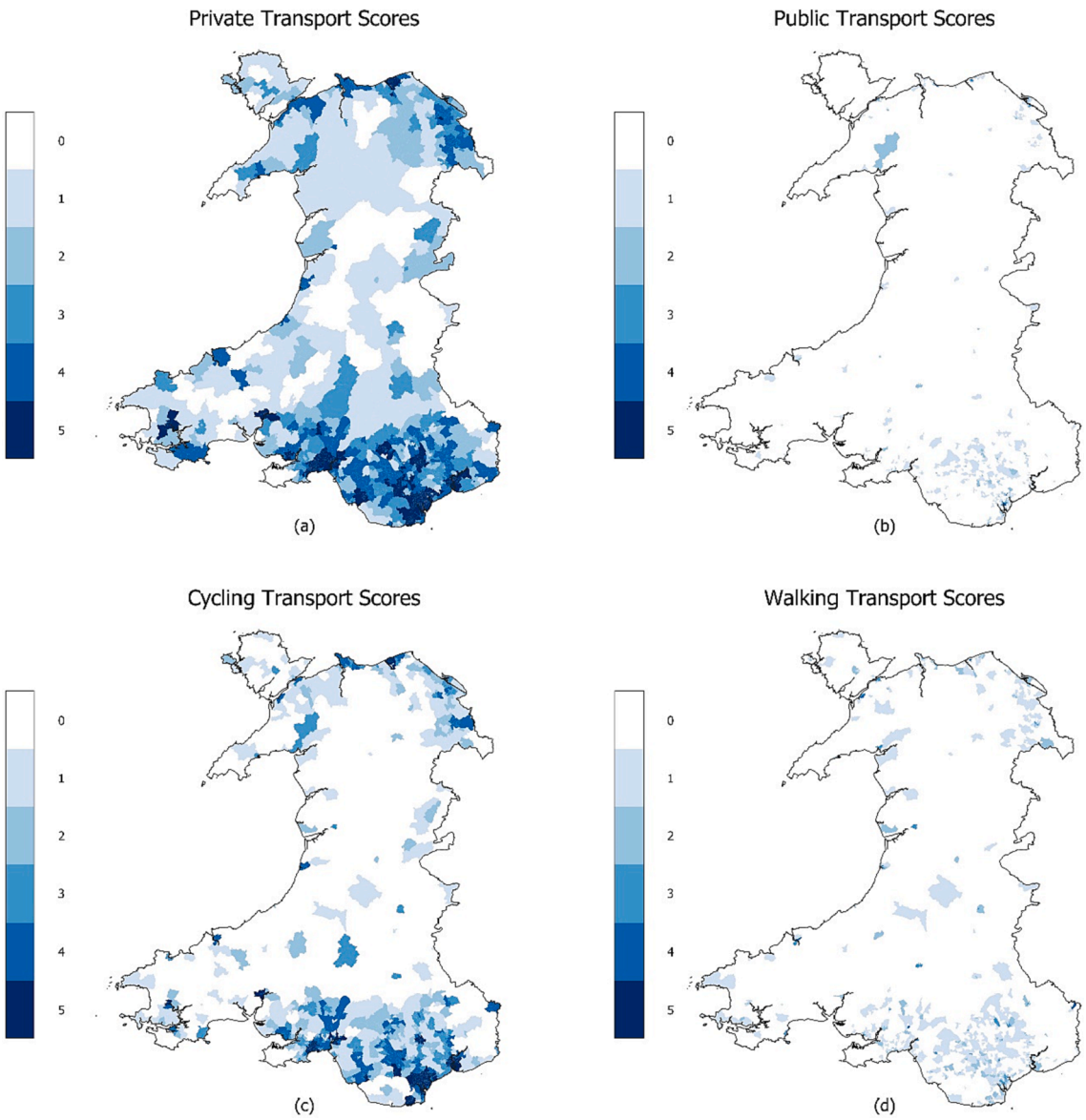

Fig. 6. Diversity of sports within a 20-minute travel time. Each sport is counted only if at least 50% of the Lower Super Output Area population are able to reach a facility of that type.

4.3. Summary

Previous studies have focused on a target of 20-minute neighbourhoods and predominately on walking and an all-round trip. This study has allowed multiple modes of transport including public transport, car, walking and cycling to all be included as part of an overall assessment of the implications of using different travel modes. As expected, maps by transport mode show car users to have the best access in terms of average closest proximity to greenspace. Analysis of those living in postcodes who utilise private transport, aggregated at the OA level, show that on average the closest greenspace is often less than 2 min away in this urban case study. The inclusion of public transport and walking modes highlighted areas where OAs had no identified greenspace within 20 min travel time, thus clearly signalling where an improvement in facility provision and/or transport availability may need to be addressed by relevant policy makers and planners.

5. Discussion and conclusions

5.1. Study findings

In this study both cumulative opportunity and spatial proximity methods for measuring spatial accessibility to recreational opportunities have been adapted to incorporate active travel routes and public transport schedules to develop more inclusive assessments of provision. The overarching aim has been to illustrate how mode of travel impacts on the geography of provision, using open-source data that could be exploited by sports organisations, local authorities, and educational establishments to plan the future siting of facilities. Maps at national (Wales) and city (Cardiff) level show considerable variation in access to sporting facilities and greenspaces using the approaches outlined in this study. The findings also draw attention to the need to consider the inclusion of sustainable modes of transport for accessing such facilities and to conduct sensitivity analysis using different time and distance thresholds where empirical evidence is available. Previous research has highlighted the importance of active transport on the frequency of use, particularly for adolescents accessing recreation sites, and has called for

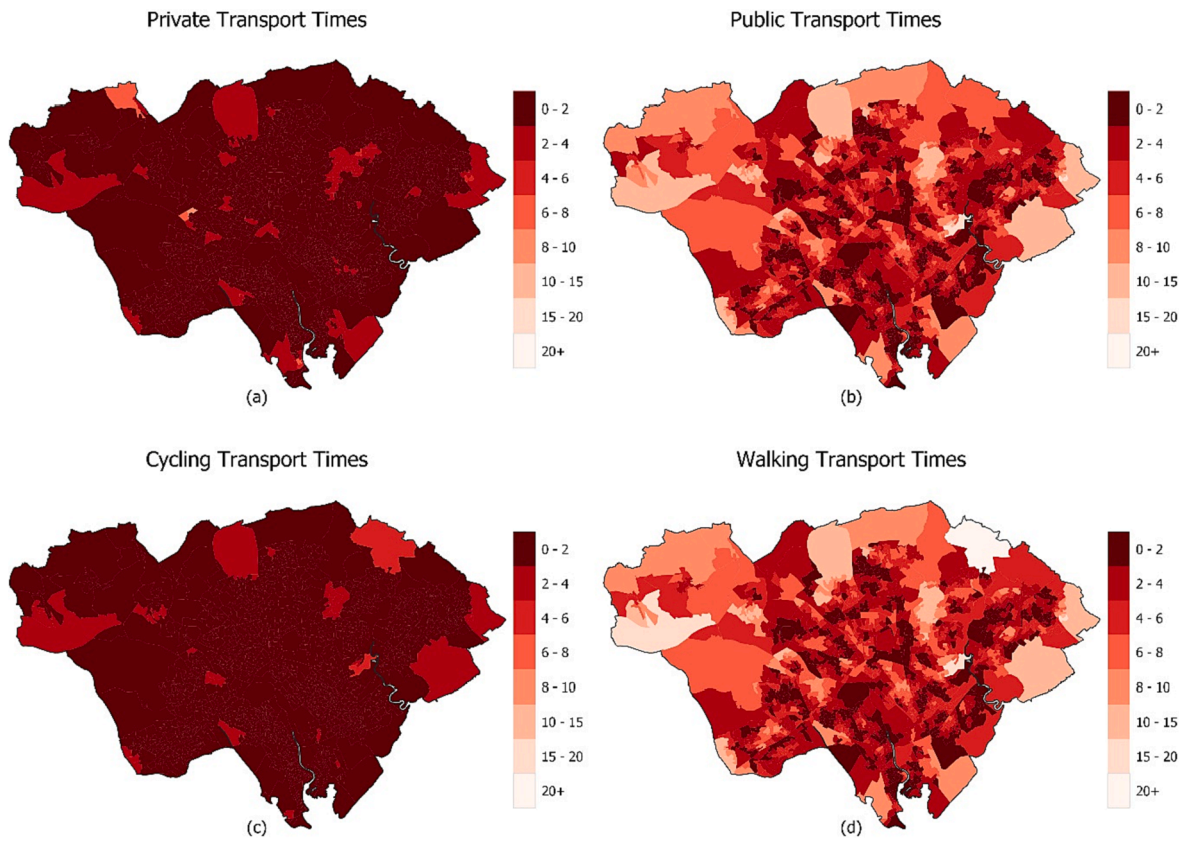

Fig. 7. Average time to nearest greenspace in minutes as reported by Output Area.

policies that facilitate safe opportunities for cycling/walking to encourage youth physical activity (Grow et al., 2008). At the same time, the possibility that 20-minute neighbourhoods based on access to services may be associated with walking for transport but not necessarily for walking for exercise/recreation purposes has recently been investigated in a couple of Australian cities (Ayala et al., 2022).

Cycling also provides a promising means of reaching sports and recreation facilities over shorter distances in urban areas when compared to 'traditional' car-based means of access. The patterns revealed within this study confirm some of the findings of the modal accessibility gap studies reviewed by Larsson et al., (2022) that could form the basis of standards across most urban areas as governing bodies implement better infrastructures for those who wish to travel via cycling. However, the same authors draw attention to the importance of geographical context and amenity type and in rural Wales, for example, means of active travel may not be available due to aspects such as the conditions of the road, "bike friendly" paths that run alongside these roads or changes in hill gradient which impact on overall access scores by both types of measure for different modes of travel.

Findings from such an approach provides insight into accessibility patterns using GIS-based networking tools using cumulative opportunity and proximity-based measures to provide a benchmark of the current levels of access to facilities. Such a framework can be used to monitor the impacts of planning new facilities as well as changes to the transport infrastructure to support policy makers planning provision in communities where traditionally there are fewer facility types or where there are greater travel distances to facilities. This can support policy makers when deciding the locations for new opportunities or attempting to improve current facilities within reach of the population.

5.2. Further research

The findings presented within this study provide a baseline for policy makers to monitor trends in accessibility and conduct follow-up analysis using a selection of demographic, health, social and economic indicators to perform a more extensive analysis for areas with low participation rates. This also enables the identification of areas with poor transport coverage and assists in planning the provision of active travel routes by highlighting areas where increases in public transport frequency or availability may have benefits in encouraging more engagement with sporting and environmental opportunities. This could also highlight areas where cycling and walking could be improved by the adoption of bike and or pedestrian friendly paths as part of the design of active travel routes. Such objective measures can be seen alongside the types of perceived barriers to access for recreational facilities that have been seen to influence the use of local sites (Harrington et al., 2017).

Although policy makers have targets to improve uptake of specific sports, it is also important to take into consideration a wider range of factors influencing the use of facilities to address accessibility concerns for different demographic groups. This can include characteristics of sports provision; in the case of swimming pools for example, the number and types of pools, the depth/dimensions, presence of diving boards, availability of coaches, or provision of changing rooms may impact on the "attractiveness" of the facility for potential users. Inevitably, given the ecological nature of the study, assumptions have been made regarding access parameters including the thresholds used for different types of sport facilities and greenspaces. These types of factors may impact on how far individuals are prepared to travel to access facilities and our future research will incorporate such "quality" attributes for each facility type where available. The inclusion of age ranges, income, the ability to pay and other demographic, socio-economic and cultural participation factors, alongside data on modal splits for different modes of transport, should enable policy makers to better understand patterns of provision under different policy scenarios. This could be informed by more research on how far individuals are prepared to travel, and by which means, to access such facilities.

A key strength of the approach taken in this study has been the granularity of the analysis that has permitted a degree of aggregation of the results computed at the postcode level to lower-level geographic areas at scales which are used to guide policies geared towards service provision. This in turn addresses concerns with the use of measures generated using centroids of areas which may be particularly problematic in rural areas where LSOA units tend to be larger. Whilst the use of 20-minute travel time catchments can be debated within such an approach, alternative threshold catchments can also be incorporated within the analysis depending on the mode of transport, the facility type and user preferences to examine the implications of varying accessibility catchment thresholds. For example, targets of 10 min may suit users who travel by car as they can travel longer distances within the city, their only concern then would be the competition between other car users and supply (supply-to-demand ratio). Public transport users may be prepared to travel for longer than 20 min to accommodate waiting times, transfers, and public transport stops. They may also be prepared to walk more than 400 m to access a bus stop, particularly if the purpose of the journey is itself to engage in physical activity. Other studies have highlighted the potential importance of demographic or attitudinal characteristics of individuals, the intervening topography between trip origins/destinations and public transport stops and factors such as the perceived safety around such stops as well as the weather conditions at the time of travel, all of which may impact on how far people are prepared to walk to access public transport (Chia et al., 2016; Hess, 2011; van Soest et al., 2019). The sensitivity of our current results to a potential relaxing of this constraint should thus be investigated as part of ongoing development. Public transport remains a necessity for those who lack the ability to walk for 20 min but who wish to access recreational activities. Alternatively, increasing public transport frequency, altering existing bus routes, or providing additional routes could enable the realisation of a 20-minute neighbourhood. Targets can then be set that encompass changes in both the siting of facilities as well as the increased provision of active travel routes and improvements in public transport management.

Future research can monitor such impacts for projected population counts, transportation modal splits and sporting facility locations to help further improve accessibility measurements and guide attempts to improve national health and wellbeing through the uptake of sports and recreational activities. The methods described within this study analyse variations at the postcode level, but further analysis is needed to investigate the sensitivity of findings to the spatial units used including the potential to drop down to individual household level analysis. Assumptions have been made regarding the origin of journeys which could be extended to include real-time distributions of populations during a typical working day or at weekends (Shrestha et al., 2019). There should be scope for extending this research to other national contexts where equivalent data sets are increasingly being made available to researchers including those emanating from crowd sourcing initiatives and new sources of data arising from GPS tracking or the use of social media. The type of tools described herein therefore have the potential to be applied in wider contexts utilising these datasets as they become available in developing countries. Finally, our future research will include a wider variety of indoor and outdoor recreational spaces used for day-to-day exercise and related health and well-being activities. Outputs can be further enhanced by including the capacity/quality of a facility via characteristics such as the number of tennis courts available, number of lanes in a swimming pool, availability of floodlighting in outdoor grounds, or length of opening hours. Factors that influence utilisation patterns extend beyond just the geographical proximity of sports facilities. Nevertheless, we contend that the types of analysis reported here can assist in developing a better understanding of the impacts of accessibility to recreational opportunities on local rates of sports participation and physical activity levels in diverse socio-economic contexts.

CRediT authorship contribution statement

Andrew Price: Data curation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **Mitchel Langford:** Conceptualization, Formal analysis, Software, Visualization, Writing – original draft, Writing – review & editing. **Gary Higgs:** Conceptualization, Project administration, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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