Bringing cities to life: The relationship between urban greenspace and mental wellbeing

by

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Table of Contents

List of Figures

List of Tables

Dedication

This work is dedicated first and foremost to *Libby Burton*, who inspired me to look at the built environment in a new way. I hope you would be proud of my work.

Second, to both *Granny* and *Grandma*, who showed such strength and taught me to be fearless.

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Declaration

The work presented in this thesis is entirely original and my own work, except where acknowledged in the text. I confirm that this thesis has not been submitted in any previous application for any degree, apart from some preliminary analyses in Chapter 4 which was previously submitted for the Dissertation for MSc Data Analytics at the University of Warwick in 2015.

Chapter 3 was published as:
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Abstract

This thesis aimed to deepen understanding of the potential health benefits of urban greenspace, by identifying associations between different greenspace characteristics and mental wellbeing. A systematic literature review revealed that, while local area greenspace is adequately associated with life satisfaction, evidence for other characterisations of greenspace (type, accessibility, etc) is less sufficient. Although findings are currently not specific enough to guide planning decisions, there is a need to examine multidimensional wellbeing measures and greenspace in detail.

A first study of local area greenspace and mental wellbeing in England, using data from 31,000 individuals in the UK Household Longitudinal Study survey and greenspace information (Generalised Land Use Database), found that Ordinary Least Squares associations between local prevalence of greenspace and multidimensional wellbeing could not be detected at census level, perhaps due to the imposition of arbitrary boundaries.

More detailed post code-level data was obtained for 25,000 London residents completing the Annual Population Survey 2012-2015, with greenspace shapefiles from the Greenspace Information for Greater London group. The amount of greenspace within a 300m buffer of individuals homes was positively and significantly associated with hedonic and eudaimonic wellbeing. Geographically Weighted Regression models, addressing spatial clusters within the data, revealed slight variation in the strength of these associations across the study space.

The final study, which characterised greenspace by type and accessibility on foot, found natural greenspace to be positively associated with hedonic wellbeing, but not eudaimonic wellbeing; associations with other types of greenspace were not significant. Spatial Error models allowed second-order processes within the structure of the data to be captured.
These contributions are the first to examine nature planning recommendations for potential associations with mental wellbeing, expanding the current knowledge of greenspace design. Informed design should consider both the characteristics of the greenspace and local residents, to benefit the mental wellbeing of individuals and society as a whole.

37,542 words

221 pages

List of Abbreviations

AFI	Attention Functioning Index
APS	Annual Population Survey
ART	Attention Restoration Theory
ASSIA	Applied Social Sciences Index and Abstracts
C	Regression Coefficient
CD	Census District
CI	Confidence Interval
CN-SI	Connectedness to Nature – Single Item
CNS	Connectedness to Nature Scale
CORINE	Coordination of Information on the Environment
FACE	Fascination, being Away, Compatibility, Extent
FCA	Floating Catchment Area
GDP	Gross Domestic Product
GHQ	General Health Questionnaire
GiGL	Greenspace Information for Greater London
GIS	Geographical Information System
GLUD	General Land Use Database
GPS	Global Positioning Satellite
GWR	Geographically Weighted Regression
IMD	Indices of Multiple Deprivation
KNN	*K* Nearest Neighbours
LISA	Local Indicators of Spatial Association
LSOA	Lower-Layer Super Output Area
MCS	Mental Component Summary
NDVI	Normalised Difference Vegetation Index
NOS	Newcastle Ottawa Scale
OLS	Ordinary Least Squares
ONS	Office for National Statistics
OR	Odds Ratio
PANAS	Positive and Negative Affect Scale
POMS	Profile Of Mood States
PPG17	Planning Policy Guidance 17
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PSU	Primary Sampling Unit
RoB	Risk of Bias
SAR	Simultaneous Autoregressive Model
SD	Standard Deviation
SE	Standard Error
SEM	Spatial Error Model
SHS	Subjective Happiness Scale
SRT	Stress Recovery Theory
SWEMWBS	(Shortened) Warwick-Edinburgh Mental Well-Being Scale
UKHLS	UK Household Longitudinal Panel Study
WHO	World Health Organisation
WHOQOL-BREF	World Health Organisation Quality of Life, Abbreviated
WEMWBS	Warwick-Edinburgh Mental Well-Being Scale
WOS	Web of Science

1.0 Introduction

"By discovering new synergies between nature and urban landscapes we can bring cities to life"

- Prof Tadao Ando Hon RA

Over half of the world's population today resides in cities, due to urban migration patterns and population growth; in the UK, this figure now exceeds 80% [1]. With urbanisation increasing, living patterns are changing around the globe. Land itself is at a premium, so policy makers and planners are increasingly challenged to accommodate new residents in effective and positive ways [2]. These changes may also have health and wellbeing consequences for those living in urban environments. Interest in the health effects of cities can be seen in early urban planning in the 19th century, when conditions were cramped, polluted and rife with disease [3]. While many contagious diseases have largely been eradicated or controlled, particularly in the developed world, chronic illnesses are becoming more prevalent in these settings, partly due to lifestyles and living conditions [4]. In particular, mental health issues are among the top contributors to the global burden of disease and have been projected to be (at least) the third most common cause by the year 2020 [5].

Healthy or unhealthy lifestyles may be affected by the economic, political and social aspects of urban environments. The 2015 Routledge *Handbook of Planning for Health and Wellbeing* has thus set out to address the epidemic of unhealthy lifestyles by putting human health at the heart of planning, covering aspects of physical, mental, social and cultural health. Contributors argue that healthy towns promote healthy individuals, so only through such informed design can a sustainable, global future be achieved [4].

In his book *Mental Health and the Built Environment: More than Bricks and Mortar?*, David Halpern argues that the field of urban planning needs to move away from an emphasis on aesthetics, towards 'potential social and behavioural consequences of design' [2][p10]; he highlights the need for researchers to ascertain which features of the urban environment are perceived as stressful, as well as which promote feelings of satisfaction. Halpern also believes that urban-rural inequalities in health require further investigation. While there is some evidence that mental health and wellbeing may be poorer in urban, than rural, areas [6], he suggests that the best aspects of each setting may be combined to create the optimal health-promoting environment.

More specifically, Charles Montgomery also aims to 'transform… lives through urban design' in his 2013 book, *Happy City* [7][p0]. His work encourages practitioners to change the way they think about urban life and consider how living in densely populated cities could in fact make individuals 'healthier, saner and happier people' [p0]. He argues that cities need to be reconfigured to focus on their residents, with urban planners forced to realign with the fact that, in his opinion, it is 'impossible to separate the life and design of the city from the attempt to understand happiness, to experience it, to build it for society' [7][p16].

Economic interest in designing health-promoting environments is also growing. Estimates suggest that mental illness is one of the leading components of years lived with disability, accounting for over 30% of the burden [5]. This is amongst the reasons provided for the creation of the new Beyond GDP initiative, an EU-level measure, designed to be more inclusive of environmental and social aspects of progress [8]. This programme has highlighted that, in addition to policy and direct input by health services and councils, there is a need for improvement at the social level, in order to promote wellbeing. Intervention is much more cost effective and widely available than active treatment for improving mental health. Environmental modifications may thus be a way to achieve healthier urban environments, by creating a positive landscape to benefit the urban population.

Political awareness of healthy urban design is also developing, with an increasing interest in the salutogenic (health-promoting) effects of greenspace (areas of grass, trees and other vegetation). The United Nations' Sustainability Goals (SDGs), announced in 2015, include both providing access to greenspaces, and improving health and wellbeing, in order to support healthy life for future generations [9]. Goal 11, which is focussed on sustainable cities and communities, specifically aims to 'provide universal access to safe, inclusive and accessible, green and public spaces' by 2030, in order to 'foster prosperity and quality of life for all', while Goal 3 focusses on ensuring 'healthy lives' and promoting 'well-being at all ages [sic]'. Further, the World Health Organisation, in the 2016 review of evidence on *Urban green spaces and health* also states that such spaces are a necessary component for delivering healthy, sustainable, liveable conditions [10]. This report emphasises the scope to use informed urban design to address major public health issues related to noncommunicable diseases. This idea of using urban planning to prevent against ill-health is also gaining prominence in the UK, being the focus of the recent Governmental white paper, *Spatial Planning for Health* [11]. This report covers several aspects of healthy developments, including housing, food and transport, with the authors arguing in particular that protecting the natural environment is vital for sustaining future human civilizations.

The question of how to design environments, particularly urban environments, not only to prevent illness, but promote health, has also become increasingly of interest to researchers over recent years. There is a growing body of evidence that places may influence how individuals feel, with many people able to relate to environments which causes stress and claustrophobia, as well as those which promote happiness, relaxation and comfort [2, 4]. Subsequently, research into health and wellbeing in the built environment is growing, as is an understanding of interactions between people and the spaces in which they live and work.

This expanding literature on the health effects of place has emphasised that local circumstances are important in understanding individual wellbeing outcomes. Drawing on research into neighbourhoods and health, Pearce proposes that consideration of where people live, in addition to who they are, is vital for understanding place as a component of a complex socio-spatial structure [12]. In a recent study of greenspace, social deprivation and mental illness, he suggests that place-based processes have helped to explain the growing divide in health inequalities within the UK, as the local environment has the potential to improve both health and healthy behaviours [13]. However, traditional research on health disparities has focussed on individuals, rather than the environments to which they are exposed, both physically and socially. Earlier research has, whether intended or not, often treated people and places as mutually exclusive and opposing explanations for health inequality, rather than seeking to identify the complexities of the interrelationships between them [14]. Studies which consider health effects of place therefore seek to untangle these aspects by examining both the individual and their surrounding environment, which is vital in understanding the subtle nuances of the processes by which context influences wellbeing [15]. Places are also related to each other and their broader surrounding area, and Cummins criticises studies which assume that the environment in each locality influences population health independently of neighbouring areas [14]. It is often the case that areas with similar environments are clustered together in space, and this clustering may in turn increase the positive or negative impact of local conditions [14]. Place effects on health are therefore more complex than simply the result of where people live, but may also reflect and exacerbate wider health inequalities.

Researchers also emphasise the necessity of taking advantage of the growing number of population surveys in the UK, which allow for larger scale analyses of individuals and their environment [16]. National coverage may also provide insight into local and regional variations, thereby capturing more complex interactions between people and the places themselves [14]. The increase in data availability also now provides a range of more specific health indicators, meaning that wellbeing outcomes may now be modelled directly, facilitating a move away from the traditional reliance on area-level proxies [17].

MacIntyre advocates directly studying features of the local social and physical environment which might promote or inhibit health, at a level specific to the individual. She argues that previous studies may have provided conflicting evidence on the extent and magnitude of area effects on health, due to differing operationalisations of local area [13, 15]. It is argued that local and individual associations with place may differ substantially; this is known as ecological fallacy, where area effects are assumed to reflect individual-level relationships [15]. Area-level differences in health therefore cannot necessarily be interpreted as place-base effects on individuals, and only by combining individual and area measures can the outcomes of residential environment and personal circumstance be separated [18]. MacIntyre goes on to suggest that improvements in public health may be achieved by focusing on specific features of both places and the people who inhabit them [17]. Furthermore, Cummins argues that studies should be hypothesis-driven in order to identify which specific features of places may be related to relevant health outcomes, thereby furthering understanding of how far relationships between people and places are generalisable, or indeed variable, across whole populations [14]. Identifying the specific mechanisms through which places affect health, as well as quantifying their impact, is important not only for strengthening causal inferences but also for identifying potential avenues for intervention, in order to design policies that improve public health [14]. Ascertaining which features of the built environment could be utilised to promote health, and mental wellbeing in particular, may further understanding of upstream components of health differences and thereby facilitate urban design which not only promotes health but reduces these inequalities.

It has long been established that people benefit from exposure to nature (physical features and processes of nonhuman origin [19]) in particular [20]; the theory of *biophilia*, first proposed by Wilson in the 1980s, literally means 'love of living systems' and as such proposes that humans have an innate desire to affiliate with the natural environment [20]. Wilson suggests that this may have an evolutionary advantage, with humans continuing the seek out the environments in which they evolved and as such are best adapted to. Greenspaces would have historically offered shelter, food and hence a best chance of survival; this may be why modern humans still experience positive feelings in natural environments [20]. This may also account (at least in part) for why people who live in urban environments without sufficient access to green landscapes [20, 21] may experience poor physical [22, 23] and mental health [19, 24], whereas greener environments may lead to salutogenic effects on mental health and wellbeing, such as increased attention, feelings of happiness and reduced stress [25, 26]. While these are important aspects of mental health, the relationship between greenspace and mental wellbeing (positive mental health) specifically remains relatively unexplored [16, 27-30].

Building on this evolutionary model, Prospect-Refuge theory suggests that an individual's benefit from environments may depend on their inclination towards either wide vistas offering the potential to discover resources and easily identify dangers (prospect) or alternatively a place to hide and recover from threats (refuge) [31]. This aesthetic preference may be due to psychological responses to stimuli which motivate environment-contingent behaviour, in order to maximise chances of survival. Individuals may therefore be particularly drawn towards certain natural areas when they are feeling cheerful or stressed [32]. Milligan argues, however, that this view is overly simplistic; she proposes that the relationship between nature and humans is innately complex, and relates to the interaction of physical, biological and cultural features of an environment [33]. Where these qualities combine, they may promote physical, mental and spiritual wellbeing in what can be described as a *therapeutic landscape*. While the theory of such landscapes continues to evolve, they are generally considered to have the potential to not only heal those experiencing ill-health, but have health-promoting effects on all individuals [34]. Although therapeutic landscapes may have individual meaning and form, the natural environment is thought to be particularly prevalent in these healing qualities, due to the combination of visual, social and cultural associations they provide [34].

Humans are at the heart of planning. Environments are designed and created for human activities: living, working and socialising. It therefore follows that design which aims to promote health and wellbeing may enhance the quality of people's lives and the effectiveness of the city. While current political interest in the provision of greenspace for health emphasises the importance of sustainable urban design, there is a need for robust evidence for the inclusion of such spaces, in order to guide urban planning decisions.

With urban land at an increasing premium, it is vital that this space be put to its optimal use. By investigating which aspects of greenspace are associated with mental wellbeing and generating new, robust evidence, this thesis emphasises the importance of well-designed greenspace to potentially benefit the mental health of the urban population.

1.1 Aims and objectives

The overall aim of this thesis was to investigate the complex relationship between greenspace and mental wellbeing, to improve the evidence base for the place effects of greenspace on mental health and wellbeing within the urban environment.

Previous research has established that the inclusion of greenspace in urban environments may be important for reducing symptoms of mental distress and promoting positive feelings, although the evidence for an association with a broader, multidimensional view of mental wellbeing (which includes both positive feelings and personal fulfilment) is less well established. The objectives of this research are therefore as follows:

- To undertake studies which test for associations between different characteristics of greenspace and multidimensional mental wellbeing (including: the amounts, types, and accessibility of urban greenspace)
- To develop a more detailed understanding of which characteristics of greenspace may be important for mental wellbeing
- To test government-recommended guidelines for the inclusion of greenspace within the built-environment, in terms of associations with mental wellbeing
- To examine the spatial nature of the association between greenspace and mental wellbeing, through application of analytical methods appropriate to the statistical and spatial structure of the data

1.2 Research questions

To achieve the aims of this work, the key research questions to be addressed are as follows:

Research Question 1 - How has greenspace been studied and conceptualised in previous research, and therefore what is the existing evidence for associations with validated mental wellbeing measures?

Research Question 2 - Is the quantity of greenspace in a local (census) area associated with multidimensional mental wellbeing?

Research Question 3 - Measuring the amount of greenspace within a radius of individuals' homes, do associations with mental wellbeing differ to what is detected at an aggregated, local area, level?

Research Question 4 - Are natural greenspaces more strongly associated with mental wellbeing than other, manmade, types of greenspace?

1.3 Overview of research

Theories suggest that individuals benefit from exposure to natural environments, which in urban areas is enabled through the provision of greenspaces. Previous research has demonstrated that living in a greener neighbourhood may improve general health and symptoms of psychiatric distress, but the evidence for associations with mental wellbeing (positive mental health) is much less conclusive. This thesis is therefore based around three contributions of original research, which are designed to address these knowledge gaps. By understanding which characteristics (for example, the type or amount) of greenspace may be important for mental wellbeing, it will be possible to design urban environments which benefit individuals, society and the economy.

Taking advantage of large-scale, population data sets, including the UK Household Longitudinal Panel Survey (UKHLS) [35] and the Annual Population Survey (APS) [36], it was possible to link land use data to both individuals' local geographic area (Lower Layer Super Output Area, LSOA) and then, more specifically, to their post code, to conduct large and robust analyses. The APS in particular is an ongoing data collection, which contains very detailed socio-economic and demographic variables, as well as full post code for all respondents. It measures mental wellbeing in three ways: life satisfaction, happiness and sense of worth, thereby addressing different aspects of wellbeing. Local, census area variables such as deprivation and population density are measured in the analysis; the spatial granularity of the post code also has the advantage of allowing the amount of greenspace available to each individual to be calculated, rather than assigning them to an arbitrary data collection boundary, which may not reflect their real-world neighbourhood, as well as missing important information on nearby greenspace, which may extend to that in neighbouring localities.

Detailed land use data were acquired from the Greenspace Information for Greater London group (GiGL), which aggregates the physical shapes, sizes and locations of all public open areas in London, also assigning them a type category based on UK Planning Guidance classifications. These are provided as GIS (Geographic Information System) shapefiles, thereby allowing the amounts and types of greenspace surrounding individuals' homes, either within a radius or set walking distance, to be accurately measured.

All analyses began by constructing linear regression models, to observe the associations between greenspace and mental wellbeing. However, by graphically plotting and spatially mapping the distributions of both the greenspace and mental wellbeing indicators, it was possible to identify appropriate modelling techniques which reflect both the spatial structure of the data itself, as well as any geographical clustering in the residuals (error terms) of the preliminary analyses. The linear regression calculation assumes that observations are statistically independent; spatial autocorrelation is common in studies relating to land and people when they are clustered in different areas, meaning that survey participants are likely to be more similar than would be expected by chance. Therefore, spatial modelling techniques (including Geographically Weighted Regression and Spatial Error Models) were applied to adjust for these spatial patterns and allow a statistically sound association between greenspace and mental wellbeing to be estimated. These methods also specify the amount of geospatial variation within the data, which provides further context for interpreting these results.

By investigating sizes, types and accessibility of greenspace, the studies within this thesis have been able to examine associations between different greenspace characteristics and multidimensional mental wellbeing (including aspects of positive affect and self-fulfilment) on a large scale for the first time. The findings reveal that greenspace should best be studied at the individual, rather than local area, level, in order to detect associations; further analyses show that natural greenspace may be most important for mental wellbeing. These results also highlight the necessity of considering the structure of the data, in order to model these relationships in the most appropriate way.

1.4 Structure of this thesis

This thesis is structured by chapters designed to address the specific research questions outlined above. Here in Chapter 1, the introduction has described the concept of healthy urban design and the current interest in creating greener cities to promote mental wellbeing.

Chapter 2 introduces and defines concepts of greenspace and mental wellbeing and discusses how these have previously been conceptualised and measured. Background about the existing evidence for the association between greenspace and mental wellbeing is presented, including a reflection upon current gaps in knowledge and the consequent challenges posed by undertaking this type of research.

Chapter 3 is designed to address Research Question 1 (How has greenspace been studied and conceptualised in previous research, and therefore what is the existing evidence for associations with validated mental wellbeing measures?) and comprises a systematic literature review, titled 'The Relationship Between Greenspace and Mental Wellbeing of Adults', undertaken in line with the PRISMA protocol, the results of which were published in PLoS one in September 2018 [37]. This includes a narrative review of 52 studies, stratifying by the 6 ways in which greenspace was assessed: the amount of local area greenspace, land cover type, views of greenspace, visits to greenspace, greenspace accessibility, and subjective connection to nature. Results suggest a potential association between different greenspace characteristics and mental wellbeing measures, though further research is required to implement validated, multidimensional wellbeing indicators.

This lack of evidence for multidimensional wellbeing (including personal fulfilment) was addressed in Chapter 4, by means of a cross-sectional analysis of local area greenspace and mental wellbeing in England, using neighbourhood proportion of greenspace and the 7-item Warwick-Edinburgh Mental Well-Being Scale. In testing Research Question 2 (Is the quantity of greenspace in a local (census) area associated with multidimensional mental wellbeing?), the linear association between greenspace prevalence and mental wellbeing was confounded by individual level factors and urban-rural location. The analysis suggests that the association between greenspace and mental wellbeing may be more complex than can be detected using arbitrary boundaries, which impose unrealistic restrictions on the individuals. This study was published in BMC Public Health in May 2017 [38].

Chapter 5 builds on the findings of Chapter 4, reporting on individual-level greenspace, measuring the amount available within a radius of individuals' homes; this research thereby investigated Question 3 (Measuring the amount of greenspace within a radius of individuals' homes, do associations with mental wellbeing differ to what is detected at an aggregated, local area, level?). Prevalence of greenspace was positively and significantly associated with measures of multiple dimensions of wellbeing in linear models. Geographically Weighted Regression, used to account for spatial clusters within the data, revealed slight variation in the strength of the association across London. While providing evidence that associations can be detected at the individual level, this opens up questions regarding which additional characteristics of greenspace, such as usage, types and accessibility, may contribute to this spatial variation. This study has been accepted for publication in Applied Geography [39].

To further investigate these differences, as set out in Question 4 (Are natural greenspaces more strongly associated with mental wellbeing than other, manmade, types of greenspace?) the amount of greenspace accessible based on street network distance was calculated in Chapter 6, then stratified into 4 types: natural greenspace (for example, nature reserves and woodland), formal parks and gardens, outdoor sports facilities and other. Linear regression models revealed that access to greater amounts of natural greenspace had a positive association with life satisfaction and happiness, while the amount of parks was associated with increased sense of worth. Spatial Error Models were then calculated, to adjust for clustering in the linear model residuals. Results revealed that natural greenspace was positively and statistically significantly associated with life satisfaction and happiness, but not sense of worth. These results emphasise the potential importance of nature and begin to provide some evidence that natural greenspace may be more important for some aspects of mental wellbeing than others. Further investigation into greenspace usage patterns, quality and causality in the relationship between greenspace and mental wellbeing are recommended, in order to make more specific recommendations for planning policy.

Finally, Chapter 7 concludes this thesis by summarising and reflecting on the findings of each of the preceding chapters, both individually and in summation. Considering the specific types of greenspace and how these relate spatially to the locations of individuals seems to reveal the strongest associations with mental wellbeing. Implications for urban science, urban planning and policy and the wider contribution to the field of health and wellbeing in the built environment are discussed. Limitations of the existing work lead into recommendations for future research, which should include further detailed characterisation of greenspace, larger scale studies and longitudinal analyses in particular.

2.0 Background of greenspace and mental wellbeing

"We do not need magic to transform our world. We carry all the power we need inside ourselves already: we have the power to imagine better"

- J K Rowling

2.1 Defining greenspace

Research on greenspace, in the context of healthy cities, has expanded greatly over the last few decades. However, descriptions of greenspace itself vary considerably; in a review of evidence, the World Health Organisation (WHO) concludes that there is no universally accepted definition of urban greenspace, with regard to its health and wellbeing impact [10]. Another review, by Lachowycz and Jones, argues that the constitution of greenspace may be subjective, though the most commonly studied features include publicly accessible areas of natural vegetation, such as grass, trees and other plants [40]. The most popular definition applied in Europe derives from the European Urban Atlas, which describes the term generally as 'public green areas…used predominantly for recreation'. These may therefore include formal parks and gardens, forests and natural areas [41]; and whereas some authors also include private gardens [16], others restrict their studies to just formally designated open spaces [42]. Some bodies further refine their terminology to only include spaces in urban environments [43].

While most definitions refer to environments which are specifically green (comprised of plants), the World Health Organisation argues that availability of water bodies is a key component of access to nature in urban areas, as these can provide 'attractive features for people to use and enjoy' and are often part of urban greenspace [10][p3]. The European Health Atlas, on the other hand, explicitly excludes any areas of such 'blue space' from their description [41].

This lack of consensus reflects similar difficulties in respect of 'nature', as many studies of greenspace are concerned with the benefits of exposure to nature within urban environments [19]. The term 'nature' has been used variously to describe environments dominated by water and vegetation [26], spaces with minimal evidence of human intervention [25], or, more broadly still, plentiful biodiversity [44]. However, features that may appear ‘natural’ are often artificially constructed [19]. Hartig et al. provide the most descriptive definition of nature:

‘Physical features and processes of nonhuman origin…, including the ‘living nature’ of flora and fauna,…still and running water…and landscapes that comprise these’ [19][p208].

This definition will be used to describe the term throughout this thesis. This terminological uncertainty is exacerbated by the interchangeable use of ‘nature’ and ‘greenspace’ in the literature [28, 45-48]. However, ’greenspace’ is more inclusive and refers to areas of grass, trees or other vegetation [49] and makes no assumptions about origin, biodiversity or other content of the space in question. Hence greenspace can be used to describe, for example, both surrounding greenness in the countryside, and spaces managed, or reserved, in urban environments [50]. Although many theories focus on aspects of nature as the basis for potential improvements to mental health and wellbeing, the term greenspace will be used throughout this thesis, and is defined for this purpose as follows:

Any area of grass, trees, or other vegetation, which, particularly in urban areas, is deliberately reserved for recreational, aesthetic or environmental purposes; this term therefore covers a range of green urban features, including parks, sports pitches and streetscape greenery.

2.1.1 Greenspace policies

With a growing understanding of the potential benefits of exposure to greenspace, governments and non-governmental organisations (NGOs) in the UK and elsewhere are increasingly advising on the incorporation of greenspace into urban environments. A recent UK Government White Paper, entitled ‘*Spatial Planning for Health’*, informed by a review of existing literature, emphasised the importance of access to, and engagement with, the ‘natural environment’ but did not make any specific recommendations for the promotion of health [11]. The World Health Organisation also maintains that, while urban greenspaces are a ‘necessary component for delivering healthy, sustainable, liveable’ cities, the required ‘dose’ and proximity to greenspace for health benefits is still to be determined [10].

Despite these unknowns, both the UK Government and the European Union recommend that all residents should have greenspace provided within 300m of their home, to ensure that individuals can access the ‘natural environment’, although this is based on the creation of environments 'where people want to live and work', rather than being specifically for health promotion [50][p9]. No research has yet examined whether this distance is optimal in providing potential mental wellbeing benefits [51]. The UK guidelines focus on the importance of 'natural' greenspace in particular (defined generally as areas where a feeling of 'naturalness' is allowed to predominate) and make recommendations for 'nature nearby'; this is called the Accessible Natural Greenspace Standard, designed to promote and improve access to greenspace in the UK. This Standard also advises on the types and sizes of greenspace which should be provided at different scales, based on acceptable walking distances and small surveys in England. Specifically, they recommend that all residents should have an accessible natural greenspace [50]:

- of at least 2 hectares in size, no more than 300 metres (5 minutes' walk) from home;
- of minimum 20-hectare site within two kilometres of home;
- one accessible 100-hectare site within five kilometres of home;
- one 500-hectare site within ten kilometres of home; and
- a minimum of one hectare of statutory Local Nature Reserves per thousand population.

Despite these recommendations, current planning policy does not include any specific requirements for building green areas into new developments, or outline any legal requirements. Further research is therefore required to provide evidence on the amounts, types, and accessibility of greenspaces, in order to inform more specific planning guidance. A more detailed discussion of the current standard of greenspace characterisation within the literature can be found in Chapter 3.

2.2 Mental Wellbeing

The World Health Organisation, since its inception in 1946, defines health as, 'a state of complete physical, mental and social well-being [sic], not merely an absence of disease or infirmity' [52][p10]. Mental wellbeing is therefore a measure of positive mental health, distinct from mental illness, and comprises two domains: the hedonic dimension, which includes pleasure and life satisfaction; and the eudaimonic dimension, which is concerned with self-realisation, purpose and fulfilment [53, 54].

Hedonic wellbeing has its origins in Greek philosophy, with philosophers generally equating wellbeing with the positive emotional states that accompany satisfaction of desire; therefore, experiences of pleasure, enjoyment, and cheerfulness were considered reflective of wellbeing. Simply, they theorised a subjective pursuit of wellbeing, whereby humans seek to maximise their experience of pleasure and to minimise pain, with the individual themselves best able to report on their own experience of wellbeing [54]. Interestingly, the perspective of eudaimonic philosophers directly opposed the hedonic tradition. Aristotle, in particular, defined eudaimonia as acting virtuously, behaving in a way that is noble and is worthwhile for its own sake, specifically emphasising the importance of fairness, kindness, and honesty. He also suggested that developing one's potential, by pursuing meaningful goals, was what distinguished eudaimonia from hedonia, which he believed was selfish and vulgar [54, 55].

Modern researchers, however, generally consider hedonia and eudaimonia to be two domains, or components, of more complex mental wellbeing [53]. Huta and Ryan argue that in seeking hedonic and eudaimonic pursuits, each may contribute to wellbeing in its own way, by providing a sense of pleasure and comfort, as well as enabling individuals to develop the best in themselves [56]. In an international validation study, Delle Fave et al. highlighted the relationship between happiness, meaningfulness and satisfaction with life, concluding hedonic and eudaimonic dimensions to be different and complementary contribution' to mental wellbeing [57]. Ryan and Deci conclude that wellbeing is best conceived as a multi-dimensional phenomenon that includes aspects of both the hedonic and eudaimonic perspectives; these components are at once overlapping and distinct and as such, an understanding of wellbeing may be enhanced by measuring both [53].

Therefore, rather than just an absence of symptoms of distress, mental wellbeing encompasses aspects of positive affect, relaxation, functioning, personal relationships, satisfaction and general happiness [52, 58, 59]. As a multi-faceted concept, scales have been developed for measuring individual mental wellbeing, although these have only been studied in detail within the last decade [59, 60].

The Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS) is a 14-item validated questionnaire, designed to cover both hedonic and eudaimonic wellbeing. WEMWBS was developed to facilitate the monitoring of mental wellbeing in the general population, as well as the evaluation of interventions to improve mental wellbeing. It asks the individual how they have been feeling over the past two weeks, using a Likert-style response to positively-worded questions such as, 'optimistic about the future', 'close to other people' and 'dealing with problems well'; it therefore addresses both hedonic and eudaimonic aspects of personal wellbeing [59].

Similarly, the UK's Office of National Statistics developed their own Measuring National Wellbeing questionnaire, designed for application in larger populations. It is part of a broader wellbeing evaluation which also covers more objective life evaluation questions such as income and general health, alongside traditional indicators of national progress such as GDP. The mental wellbeing questions measure personal life satisfaction and sense of worth, as well as how happy and anxious the individual felt 'yesterday', on a scale of 0 ('not at all') to 10 ('completely') [36]. While anxiety is more accurately a measure of mental distress rather than wellbeing, it is included within the original questionnaire to capture 'affective wellbeing' alongside happiness, although it is not used for the studies within this thesis. The items therefore address both hedonic and eudaimonic wellbeing, while allowing individuals to decide which of these aspects is most important to them; the questions aim to maximise scope while minimising question lengths, which in longer surveys may be an issue. Despite this questionnaire being briefer than the scale in WEMWBS, it has been shown to be effective in capturing the mental wellbeing of populations [61].

At the optimum level, individuals may be described as 'flourishing', where they reside within an optimal state of human function, both psychologically and socially. People whose multidimensional mental wellbeing is flourishing experience positivity, emotional resilience and personal growth; conversely, those at the lowest end are said to be 'languishing', who may feel demotivated, less resilient to common life stressors and may experience more negative emotions [62]. In a 2017 UK population sample, it was observed that approximately 13% of individuals may be described as flourishing, with a very high average mental wellbeing score between 9 and 10 on the ONS scale [36, 63].

Validation studies of measures such as WEMWBS demonstrate that the distribution across a population generally approximates a normal distribution (Figure 2.1), with most people experiencing 'moderate mental health' [59, 64]; the dotted line in the graph represents how a shift in distribution may appear in response to a population-level increase in mental wellbeing.

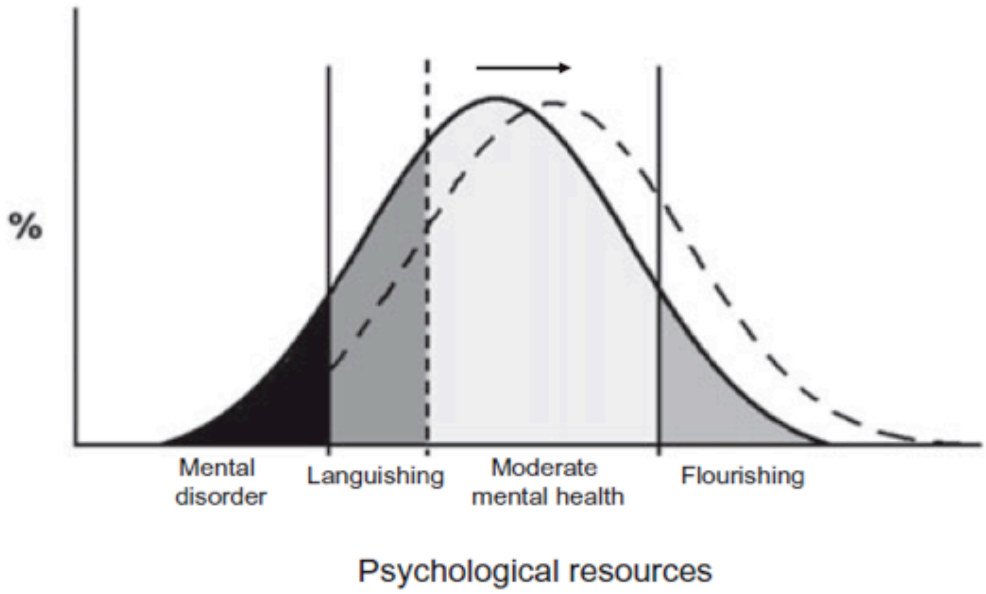


Figure 2.1 Approximate mental wellbeing population distribution [64]

For individuals, the traditional ‘hedonic treadmill’ theory proposes that people have an inherent ‘set-point’ of wellbeing, around which their mental health will oscillate over time, within a specific range that is different for each person [65]. This may be due in part, to the fact that personality traits (which are stable throughout life course) are thought to be strongly related to mental wellbeing [66, 67]. After a particularly positive or negative life event, wellbeing may improve or decrease beyond an individual’s normal range respectively, but will adapt and return to their set point after a short time [29, 68, 69]; this set-point cycle is visualised in Figure 2.2. However, Diener et al. propose that set points can be changed, and that individuals only ‘partially adapt’ to positive changes, with their wellbeing remaining stable at a slightly higher level than before; this is known as the ‘shifting baseline’ hypothesis. In particular, he proposes that interventions to increase happiness can be effective, for changes targeted at the individual, organisational, or even societal level [65], as conceptualised in Figure 2.3. In relation to cities, this therefore implies that, in understanding how to design urban environments to promote mental wellbeing, it may be possible to improve the set point of wellbeing, at a societal level.

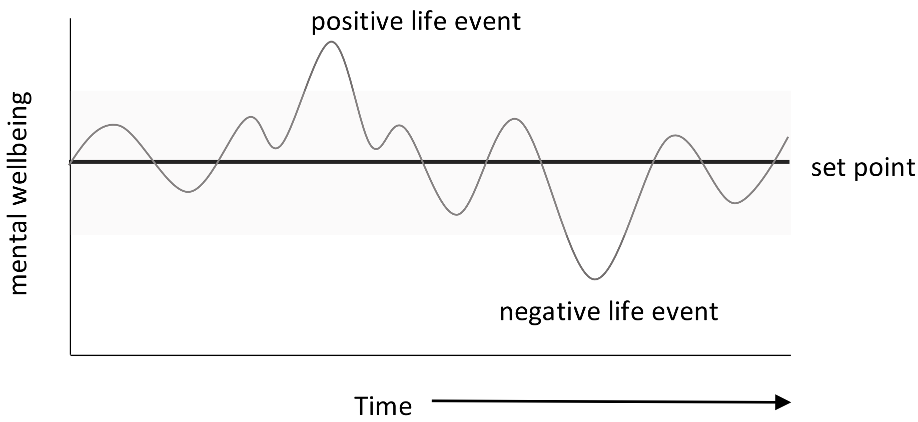


Figure 2.2 Mental wellbeing set-point [65]

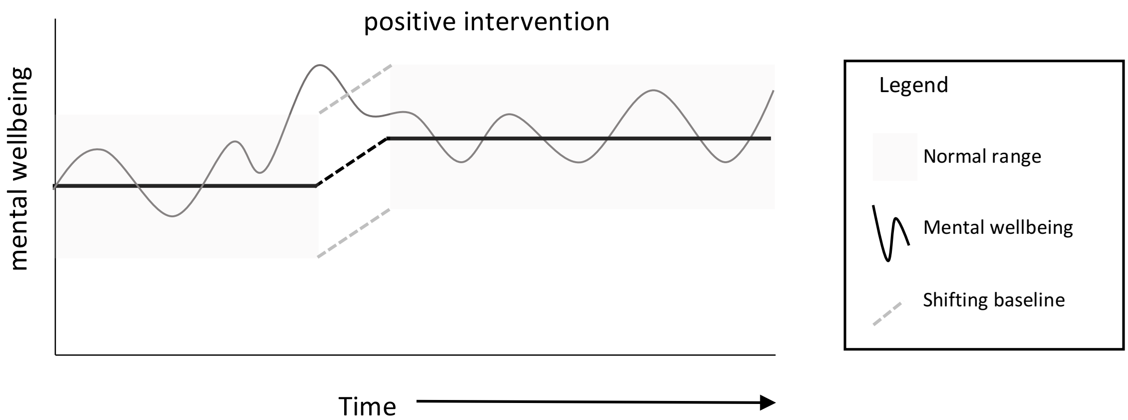


Figure 2.3 Mental wellbeing shifting baseline [65]

Mental wellbeing is evidently important for individuals, with those with better mental wellbeing demonstrating improved attention, intuition and creativity, while physically improving faster after cardiovascular exertion and displaying increased resilience to both stress and pain [62, 70]. In the UK, results from the 2015 Annual Population Survey showed that, while mental wellbeing had on average increased over recent years, the divide between those rating their personal wellbeing at the highest and lowest levels had also grown, indicating a wellbeing inequality which needs to be addressed [71]. At a population level, improved average wellbeing may increase life expectancy, productivity and prosperity [62]. Therefore, it may be theorised that improving the country's mental wellbeing through population-level interventions may be beneficial to individuals, but could also have wider implications for society and the economy.

2.3 The relationship between greenspace and mental wellbeing

Emerging evidence suggests that aspects of the physical environment, and exposure to nature in particular, are often associated with improved indicators of mental wellbeing, such as higher levels of happiness and life satisfaction [16, 27, 28]. Hartig et al. argue that research increasingly reflects concerns that urbanisation, environmental degradation, and lifestyle changes are restricting human contact with nature [19]. Lachowycz and Jones state that greenspace is an especially important feature of the built environment, because of its multi-faceted potential to influence health, both physical and mental [40]. Studies have shown that those who reside in areas with more greenspace may have better life satisfaction [16, 29], and people feel more relaxed, less stressed, happier and able to concentrate better, following exposure to green environments [19, 40, 72]. However, the association between greenspace and a more multi-dimensional view of mental wellbeing remains relatively unexplored [16, 27-30].

Several studies have sought to understand why greenspaces seem to be beneficial for health and wellbeing. Exposure to nature might enhance wellbeing by providing mental escape and restoration from fatigue, which is the focus for two key theories. Attention Restoration Theory (ART) proposes that individuals have two kinds of attention: the effortful, directed attention required to undertake everyday tasks, and the involuntary fascination captured by interesting things, including nature, which provides an opportunity to rest the brain, reflect and restore concentration [25, 73-75]. *Fascination* is the key feature of ART, being necessary for recovering directed attention. Restorative environments require 4 key features: *Fascination, being Away, Compatibility* and *Extent*, forming the acronym 'FACE'. *Being 'away'* requires separation from mentally taxing activities, hence freeing up directed attention to enable rest, while *compatibility* describes the match between the environment and one's inclinations, be it to sit, explore, or engage in an activity. As described in Wilson's Biophilia theory, humans are inherently attracted to the natural environment and, to this end, greenspaces may provide this compatibility [20]. Finally, there must be sufficient *extent*, to be a rich and coherent environment for the individual to explore, physically or visually [75]. Kaplan argues that urban greenspaces can provide restorative experiences to counteract the stresses of urban environments [25], which demand directed attention to process high levels of information [72, 73]. A systematic review and meta-analysis of 31 studies investigated the validity of attention restoration in natural versus non-natural settings [76]; the majority of studies provided significant evidence that exposure to nature improved concentration more than non-natural counterparts.

An alternative but similar concept, the Stress Recovery Theory, argues that views of nature improve mental health by helping stressed individuals recover a relaxed emotional state [26, 77], rather than directly restoring attention. Ulrich based his theory on the human preference for natural, rather than built, landscapes, in particular those with a wide vista, sufficient complexity, and low perceived levels of threat [77]. In testing this theory, Ulrich compared responses to images of natural and urban landscapes, finding that exposure to natural scenes had a positive influence on emotional and psychological states, which was most pronounced for those experiencing stress and anxiety. Interestingly, although urban environments were found to be less preferable, responses improved if trees or other vegetation became visible in the same landscape [77]. Ulrich therefore also emphasised how designated greenery is important in built-up areas, to break up the monotony and add interest, hence helping to reduce stress. Further validation studies have shown that prevalence of local area greenspace may act as a buffer between stressful events and health, with individuals living in greener neighbourhoods reporting less stress after a major life event, compared to those in less green areas [78], while individuals may actively seek out greenspace to help alleviate stress [79]. Both of these theories suggest that exposure to nature may promote a positive mental state, which is a key component of hedonic wellbeing in particular [53]. Further, the effects of improved concentration and reduced stress levels may help improve productivity and achievement, hence contributing to an individual's sense of purpose [80].

Greenspaces may also act as a facilitator for therapeutic activities known to improve mental wellbeing [33]. Particularly in urban environments, greenspaces may provide a destination in themselves, within which to perform physical activity, such as running, cycling or playing sport, or otherwise by creating an attractive environment which promotes ease of walking [81, 82]. In general, individuals have been shown to be more physically active if they reside in a greener environment [83-87]. In particular, those who live in areas with more greenspace surrounding their home (within 300m) are more likely to engage in moderate to vigorous physical activity during their leisure time, than those who do not, as well as being less likely to have a BMI categorised as 'obese' [85]. Further, those who cycle for commuting purposes are likely to spend more time on their journey if they have a greener living environment [82], although it is worth noting that those in more suburban areas are likely to both have a greener neighbourhood and further to travel to work. In addition, a study in Bristol, England, showed that individuals were more likely to meet weekly recommendations for levels of physical activity if they had greater amounts of accessible greenspace nearby, and that reported frequency of greenspace use for physical activity declined with increasing distance to the nearest greenspace [88]. While physical activity is known to reduce stress, encourage feelings of happiness and promote mental wellbeing [89], studies differ as to whether exercising itself is a mechanism which facilitates the association between greenspace and improved mental health and wellbeing [83, 86, 90]. Despite this, studies which directly compare the benefits of exercising indoors versus outside in greenspace have demonstrated that the latter may more greatly benefit health. One systematic review concluded that, compared with training indoors, exercising in natural environments was associated with greater feelings of revitalisation and positive engagement, decreases in tension, confusion, anger, and depression, and increased energy, while participants also reported greater enjoyment and satisfaction with outdoor activity and declared a greater intent to repeat the activity at a later date [91]. As exercise can improve both physical and mental health, it may be theorised that the positive feelings which physical activity release may promote hedonic wellbeing in the short term, while Ryan and Frederick speculate that, more generally, those with better physical health and energy levels are also likely to have higher eudaimonic wellbeing [92].

Greenspace may also foster a sense of community and cohesion, by providing areas for social interaction and hence increasing levels of social support [40, 93]. There is much evidence that having good social connections is beneficial for mental wellbeing [94] and a growing body of evidence that this may mediate associations with greenspace [19]. Cattell et al. argue, from findings in their qualitative study, that social interaction in greenspaces can provide escape from daily routines, improved sense of community, opportunities for sustaining bonding friendships or making new acquaintances and, more broadly, can influence tolerance and raise people's spirits [95]. Less greenspace in people's living environment has been shown to coincide with feelings of loneliness and a perceived shortage of social support, with results suggesting that such issues may partly mediate the association between greenspace and wellbeing [93], with loneliness in particular negatively related to positive affect and life satisfaction [96]. From an individual-level perspective, Sugiyama et al. found social coherence and interaction to be related to the perceived greenness of a neighbourhood [97], while de Vries et al. demonstrated a relationship between greener streets and social cohesion in a neighbourhood, both for the quantity and, stronger still, for the quality of the streetscape greenery [87]. Positive interactions with others promote feelings of happiness and therefore can promote better hedonic wellbeing [98], while Ryff and Singer view that positive relations with others are essential for human flourishing [99].

In a review of the literature on nature and health, Hartig et al. also suggested that trees within greenspace can reduce some pollutants and particulates, which improves ambient air quality and hence may support human health and wellbeing [19]. Vegetation may additionally help to mitigate the urban heat island effect, as well as to elevate temperatures during cold weather, thereby helping maintain a comfortable environment and facilitating outdoor activity [19]; both of these processes are likely to promote positive affect and hence hedonic wellbeing [92].

Lachowycz and Jones also theorise a number of other potential mediators, through which provision of local greenspace may either encourage individuals to engage in healthy behaviours, or enable them to feel more positive about their neighbourhood environment [40]. These authors derived a detailed theoretical framework, based on an in-depth review of literature, to better understand and visualise the relationship between greenspace and health, in particular the pathways through which the association may operate. Their conceptual diagram is presented in Figure 2.4, simplified to represent the characteristics of greenspace and individuals relevant to this thesis. This demonstrates how having access to greenspace increases exposure, while individual characteristics, as well as those of the greenspace itself, may moderate the exposure, through opportunity, personal motivation and ease of use. In this way, moderating factors can affect the strength or direction of the association; for example, greenspaces that are easy to use may encourage visitors and thereby increase the benefits of exposure. Using the greenspace may then lead to improved perceptions of the local environment, promote aesthetic pleasure, as well as the benefits described above of activities such as relaxing, exercising and socialising. Other pathways may lead straight from exposure to mediating factors, or alternatively directly to the outcome, for instance, simply knowing that local greenspace is available may lead to positive emotions. Lachowycz and Jones propose that through this process, individuals obtain physical and mental health benefits, including improved mental wellbeing. The arrows in Figure 2.4 further demonstrate how each of these stages may be additionally interrelated [40].

Research also suggests that residing in a greener location may simply promote satisfaction in itself, by creating a more aesthetically pleasing, positive environment [4, 40, 100]. Studies have additionally demonstrated that individuals have greater wellbeing if they live in more 'scenic' environments, which are often characterised by open spaces with minimal evidence of human intervention [30]. However, very urban environments may be improved with the addition of greenery, reinforcing the importance of greenspace provision in the urban landscape [30].

The relationship between greenspace and mental wellbeing is therefore complex, and may depend not only on the individuals and their surrounding environment, but also the potentially mediating effects of patterns of physical activity, social support, restoration and relaxation, air quality, perception and aesthetics.

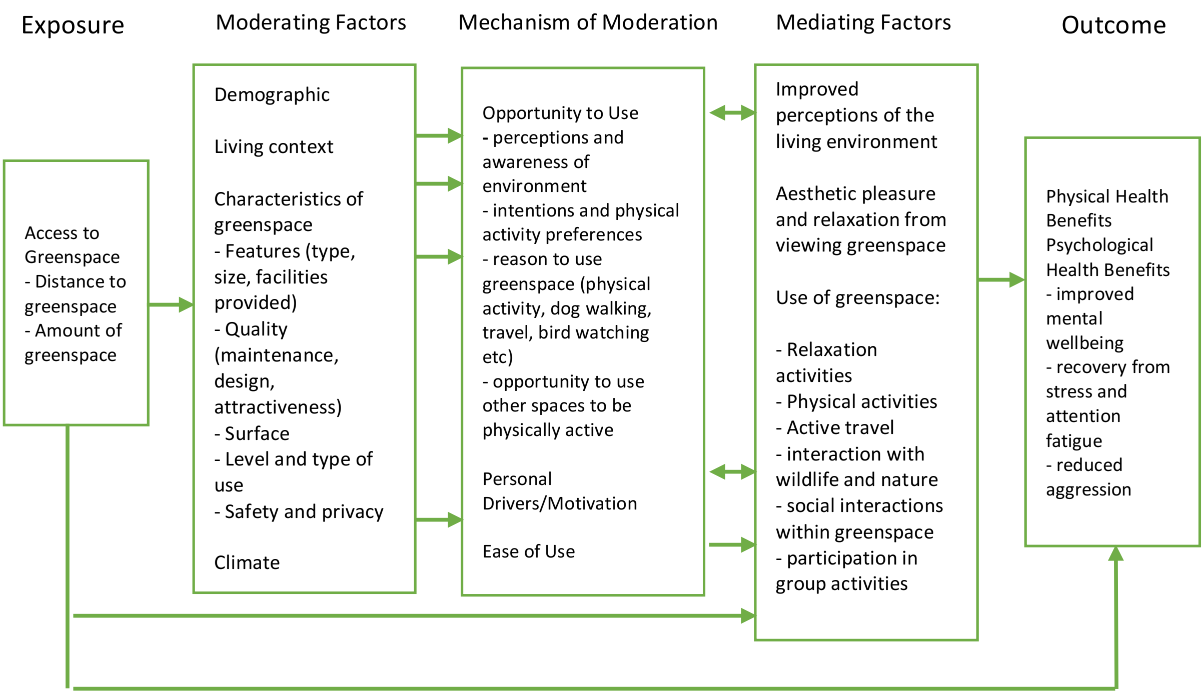


Figure 2.4 Adapted and simplified from Lachowycz and Jones' theoretical framework for the relationship between greenspace and health [40]

2.4 Challenges of studying greenspace and mental wellbeing

With a growing body of evidence supporting the importance of urban greenspace for general health [19], establishing the association with mental wellbeing in particular is made more challenging by the common misunderstanding of the complexities of multi-dimensional mental wellbeing, with most studies focusing just on hedonic wellbeing, as well as the variety of ways in which both of these concepts are operationalised in the literature.

Mental wellbeing, specifically comprising both hedonic and eudaimonic dimensions, is a fairly recent area of study within the field of health and wellbeing in the built environment. As demonstrated by Hartig et al., the body of research is expanding, with only 2 papers on 'nature and health' published in the 1990s, growing to 34 between 2000 and 2009 [19]. Studies of mental wellbeing often rely on subjective measures of the built environment, rather than the more robust evidence found in the fields of health or applied geography [4]. Burton suggests that this may be due, in part, to the disciplines of architecture and urban planning being traditionally based more on creativity than empirical evidence, therefore feeding the increasing recommendations and guidelines for healthy urban design, rather than specify any policy or design protocol [4].

2.4.1 Complexities of terminology

The nature of mental wellbeing is often simplified or misunderstood in the literature, where studies, which focus on mental illness or hedonic wellbeing only, sometimes describe their results in terms of mental wellbeing, or make claims regarding 'improved mental health'. For example, the General Health Questionnaire (GHQ) is a validated mental health evaluation tool, designed to measure individuals' symptoms of psychiatric distress. Although mental wellbeing is much more complex than merely the absence or improvement of symptoms of distress, studies using this tool are often incorrectly cited as investigations of mental wellbeing [101, 102]. This makes establishing existing evidence for associations between greenspace and mental wellbeing all the more challenging.

This may be partly caused by the lack of consensus in defining both greenspace and mental wellbeing in the literature. While an internationally established definition of greenspace is yet to be agreed, studies will continue to conceptualise the term in different ways, making comparisons and aggregation of results more challenging; it is also difficult to generate the robust evidence required for urban planning guidance while the existing literature is so varied [101, 102].

2.4.2 Data availability

While a number of population studies measure general, or mental, health (for example the census, mental health trusts survey, national health survey, British Household Panel Study, etc), surveys which include items on multi-dimensional mental wellbeing are much less common. Therefore, conducting analyses on mental wellbeing is limited by current data availability, or alternatively researchers having the means to implement large scale surveys themselves. However, both the UK Longitudinal Household Panel Study (since 2005) and the Annual Population Survey (began in its current form in 2011) contain multi-dimensional wellbeing measures, creating an opportunity for researchers to conduct studies at a national level.

Similarly, the additional greenspace data that is required for such research is also difficult to obtain. Only in 2017 did Ordnance Survey, the largest mapping organisation in the UK, provide a map describing greenspace across the country, with a detailed outline of the types of, and access to, these spaces still only available via an academic license [103]. Prior to this, greenspace charts were only available for individual regions, provided by local boroughs and councils, for example in London [104], or alternatively spatially aggregated to local geographic (LSOA) level [105], which significantly limits the granularity, and therefore the level of detail, which can be obtained through analysis.

2.4.3 Methodological challenges

The study of greenspace and mental wellbeing faces further challenges. Some are standard considerations common to observational research, such as chance, confounding, bias and reverse causality, while the spatial heterogeneity of individual-level survey and greenspace data adds an additional level of analytical complexity.

2.4.3.1 Chance

As with all cross-sectional research, there is always a risk that outcomes may in fact be the results of chance, rather than real, statistical differences. This may be mitigated by ensuring a large sample size for all analyses and considering coefficients to be significant if there is a 95% chance that the value is a true representation of the phenomena ($p < 0.05$) in a sufficiently large and representative sample. All coefficients should be interpreted with caution, and in the context of a wider, more complex environment.

2.3.4.2 Confounding

Potential mediators (such as physical activity, social support and restoration) as well as the consideration of potentially confounding factors (including demographic, socioeconomic status, and lifestyle) may complicate the analytical process and limit the generalisability of findings. In addition, particularly when applying data from national surveys, the robustness of research outcomes is restricted by the individual-level questionnaire data available. Therefore, it is important to adjust for as many potentially confounding factors as possible to minimise the risk of overestimating the real association between the dependent and independent variables. Throughout this thesis, such factors were identified from the existing literature, and estimates calculated before and after adjusting for these, in order to observe the effects of potential confounding.

Although interactions for individual demographics were not a focus of these analyses, there may potentially be more complex or diverse relationships between greenspace and mental wellbeing within certain subgroups of the population.

2.4.3.3 Bias

The issue of self-selection into an area must not be overlooked. While cross-sectional studies allow for observations of greenspace prevalence and mental wellbeing, they are not able to account for where individuals themselves choose to live, or how this may be related to their mental wellbeing. Halpern argues that urban-rural difference in health outcomes may, in particular, be partially driven by those with poorer mental health choosing to reside in cities, where support services may be more easily available, while those who prefer a more relaxed pace of life migrate towards the countryside [2]. In terms of exposure to greenspace, those who prefer living in a greener environment, or even value greenspace more highly, may choose to live in areas with more greenspace [106], for example. Similarly, those with better mental wellbeing may self-select into greener neighbourhoods, while people with lower wellbeing may not. People with poorer mental health might also be more deprived [107, 108], meaning that they may not have the means to reside in an area with more greenspace, where house prices and living costs may be higher [109]. However, a longitudinal study by Alcock et al. demonstrated that symptoms of mental distress were reduced for those moving to a greener area [29], which provides some evidence that, while the issue of selection is important, associations between greenspace and health may at least be partly driven by the environment. While self-selection may be a potentially confounding factor, this therefore highlights the importance of controlling for socioeconomic factors in cross-sectional analysis, in order to begin accounting for selection bias.

2.4.3.4 Reverse causality

Reverse causality refers to the direction of association; in this context, it is assumed that greenspace may lead to improvements in mental wellbeing scores; therefore, reverse causality would mean that those with better mental wellbeing are likely to live in areas with higher amounts of greenspace. Here, this also overlaps with the issues of selection bias and potential confounding factors. While longitudinal research may provide an opportunity to examine cause and effect (for example, by observing whether mental wellbeing increases after the living neighbourhood becomes greener, either through an intervention or relocation), the risk may be reduced in cross-sectional research by again accounting for a wide range of potentially confounding factors, such as income and local area deprivation in particular, which may influence whether an individual is likely to be moving to a greener area.

2.4.3.5 Spatial heterogeneity

Individual and land use data are both spatial in nature, and therefore studying these phenomena is inherently complex [14]. Spatial heterogeneity occurs where such features are unevenly distributed across space, which adds an additional level of complication to analyses where variation and clustering is discovered at a statistically significant level, hence observations become non-independent. Methods which account for both the physical attributes and the spatial nature of these processes may allow the compositional and contextual factors in these relationships to be disentangled, where composition relates to specific properties of the physical environment at the individual level, while context focuses on social and economic nuances [17, 110]. Throughout the studies in this thesis, the geographical structures of datasets are examined, so that methods which allow for the underlying spatial patterns within the data may be accounted for, revealing more accurate estimations of the associations between the independent and dependent variables.

3.0 The relationship between greenspace and the mental wellbeing of adults: A systematic review

"I *firmly believe that nature brings solace in all troubles*"

- Anne Frank

3.1 Introduction

Urbanisation is increasing at an unprecedented rate [111], so many people may not have access to the green landscapes in which the human species evolved [20, 21]. In the UK, local authorities are responsible for providing access to the natural environment [112], and guidelines recommend that all residents should live within 300m of at least 2 hectares of greenspace [50, 51], despite limited evidence for the wellbeing benefits of these recommendations. One of the reasons for this dearth of evidence is the lack of consensus regarding the definition of the terms 'nature' and 'natural' [26, 44], and features that may appear 'natural' are often artificially constructed [19]. Furthermore, the terms 'nature' and 'greenspace' are often used interchangeably [28, 45-48]; 'greenspace' is more inclusive, referring to areas of grass, trees or other vegetation [49], and can be used to describe both surrounding greenness in the countryside, and spaces managed or reserved in urban environments [50]. It was decided not to include studies of water (blue space), as this is generally considered separately to greenspace [16, 22, 113, 114].

While theories suggest that mental wellbeing may be improved by exposure to greenspace, there is limited evidence for clear benefits; many studies use unvalidated measures or proxies such as mental distress or quality of life, rather than considering mental wellbeing as a multidimensional concept with hedonic and eudaimonic dimensions [24]. Additionally, measures of nature and greenspace vary widely [10, 19, 49]. In order to appraise the existing evidence for associations between greenspace and mental wellbeing, a systematic literature review was undertaken, thereby identifying gaps in current knowledge and contributing to the development of further research questions; these questions are then investigated in Chapters 4-6, to address these unknowns.

Previous reviews have examined the relationship between greenspace (/nature) and general health [10, 19, 24], or mental health [101], although the latter has generally been defined in terms of mental distress, rather than mental wellbeing. While Douglas et al. describe their recent scoping review as focussing on 'green space benefits for health and well-being', they include no studies measuring mental wellbeing per se, but provide further evidence for reduced mental distress in greener neighbourhoods [24]. Similarly, Gascon et al.'s review of 'Mental Health Benefits' of long-term greenspace exposure includes some studies of aspects of mental wellbeing, but focusses mainly on measures of mental distress, rather than positive mental health [101]. It is therefore believed this is the first review to examine greenspace associations specifically with mental wellbeing in adults. This review was designed to address the first research question:

Research Question 1 - How has greenspace been studied and conceptualised in previous research, and therefore what is the existing evidence for associations with validated mental wellbeing measures?

The aim of this review was therefore to synthesise quantitative evidence for associations between greenspace and mental wellbeing. The research identified varying evidence for associations between different characterisations of greenspace and mental wellbeing, while highlighting key areas for future research, as well as subsequent implications for policy and practice.

3.2 Materials and methods

3.2.1 Search strategy and selection criteria

The review was registered with PROSPERO, an international register of systematic reviews (available online at https://www.crd.york.ac.uk/prospero/, ID: CRD42016041377) and followed guidance from York's Centre for Research and Dissemination and the Cochrane Handbook for Systematic Reviews [115, 116]. A search strategy was developed with an information specialist, undertaken by one reviewer, supported by a second, independent reviewer. The following databases were searched: Applied Social Sciences Index and Abstracts (ASSIA), American Psychological Association (PsychInfo), National Center for Biotechnology Information (PubMED), Elsevier's Scopus, and Web of Science (WOS). Common keywords relating to greenspace and mental wellbeing were derived from the literature, refined following a trial search in each database; this created a final set of terms for greenspace (greenspace(s), green space(s), open space(s), green, greener, nature, natural, landscape) and mental wellbeing (wellbeing, well-being, wellbeing, happiness, happy, happier, life satisfaction, satisfaction with life). Searches were restricted to studies in English, relating to humans, published after 01/01/1980. Searches were run from 07/07/2016 to 31/01/2018. The full electronic searches are shown in Table 3.1.

Database	*Search*
ASSIA	ti(green?space OR ‘open space’ OR green* OR natur* OR landscape) AND ti(wellbeing OR well?being OR ‘mental health’ OR happy OR happi* OR life NEAR/5 satisfaction)
PubMed	(((((((greenspace[Title] OR ‘green space’[Title] OR ‘open space’[Title] OR green*[Title] OR nature[Title] OR natural[Title] OR landscape[Title])) AND (well-being[Title] OR wellbeing[Title] OR ‘well being’[Title] OR ‘mental health’[Title] OR happy[Title] OR happier[Title] OR happiness[Title] OR ‘life satisfaction’[Title])) AND (‘1980/01/01’[PDat] : ‘2018/01/31’[PDat]) AND Humans[Mesh] AND English[lang])))
PsychInfo	ti(green?space OR ‘open space’ OR green* OR natur* OR landscape) AND ti(wellbeing OR well?being OR ‘mental health’ OR happy OR happi* OR life NEAR/5 satisfaction) AND la.exact(‘English’)
Scopus	((TITLE: (greenspace OR (open space) OR (green space) OR green OR greener OR nature OR natural OR landscape) AND TITLE (well?being OR wellbeing OR (mental health) OR happy OR happier OR happiness OR (life W/5 satisfaction)))) AND PUBYEAR > 1979) AND ORIG-LOAD-DATE AFT 1529266261 AND ORIG-LOAD-DATE BEF 1529871076 AND (LIMIT-TO (LANGUAGE , ’English’))
WOS	TITLE: ((‘green space*’ OR greenspace* OR ‘open space*’ OR greener OR green OR nature OR natural OR landscape)) <i>AND</i> TITLE: ((well?being OR wellbeing OR ‘mental health’ OR happy OR happiness OR happier OR life NEAR/5 satisfaction)) Refined by: *LANGUAGES:* (ENGLISH)

Table 3.1 Database search strategy

Using the in-built database functions, an auto-search was timed to re-run each query on a weekly basis to detect any further publications within the review duration. All articles recovered from initial searches were recorded in Endnote, and duplicates removed. Titles and Abstracts were screened for potential relevance by two reviewers independently, and full texts of shortlisted studies retrieved for formal inclusion/exclusion. It was agreed that any disputed studies would be cautiously retained for full text evaluation.

3.2.2 Study eligibility criteria

Criteria for inclusion were: (a) Population: adults aged over 16 (or all ages, but not wholly or mainly children); (b) Exposure: any measure of greenspace, defined as areas of grass, trees or other vegetation. Studies measuring personal connectedness to nature were included. Due to interest in all greenspace characteristics, both urban and rural studies were included; (c) Control: Comparators must include a control group which differed in the type/degree of exposure to greenspace, or direct comparison before and after an intervention; (d) Outcome: mental wellbeing, ascertained using a validated measure of hedonic and/or eudaimonic mental wellbeing, or one or more aspects of these (e.g. life satisfaction, happiness, quality of life. The General Health Questionnaire (GHQ) is designed to measure psychological distress, but includes several positive items, and is prevalent in the literature; studies using this outcome were therefore included. Instruments designed to capture only symptoms of mental distress were not included; (e) No study designs were explicitly excluded.

3.2.3 Evaluation of evidence

After identifying eligible papers, study contents were evaluated by extracting: authors, publication date, country, study design, age of participants, sample size, greenspace measures, methods, outcomes, confounders, and a results summary, including effect sizes (regression coefficients/risk ratio and confidence interval/standard error).

For quality appraisal, risk of bias was assessed using Cochrane-recommended criteria [115]: the Newcastle-Ottawa Scale (NOS), adapted for longitudinal and cross-sectional studies, alongside the Cochrane Risk of Bias (RoB) tool for controlled studies [117, 118]. The criteria cover potential risk of bias arising from: representativeness of the sample, participant awareness of the intervention, control factors, and selection of reported results.

Established Quality Assessment thresholds were used to categorise each article [119]. For those assessed using the Cochrane RoB tool, a Good quality study met all criteria (low RoB), while those of Fair quality had moderate RoB not meeting one criterion; Poor quality studies had high RoB, not meeting multiple criteria. More complex scoring criteria were used for papers analysed using the NOS, across three domains: Selection (representativeness of sample, treatment of non-respondents), Comparability (between exposure groups) and Outcome (assessment, soundness). Good studies scored at least 3 for Selection, 1 for

Comparability and 2 for Outcome; Fair studies scored at least 2, 1 and 2, respectively. Poor papers scored 1 or less for each category. A final quality rating was given according to the lowest rating for any category.

3.2.4 Stratification by characterisation of greenspace

Six types of study were identified, according to the characterisation of greenspace: (a) amount of local area greenspace, most commonly the proportion of local areas covered by greenspace; (b) greenspace type; (c) views of greenspace; (d) visits to greenspace; (e) accessibility, in terms of proximity to greenspaces and self-reported 'access'; and (f) subjective connection to nature.

As methodological heterogeneity precluded meta-analysis, a narrative review of evidence was conducted. Evidence for associations between each type of greenspace characteristic and mental wellbeing was classified according to the consistency, strength and methodological quality of the findings, and study design. Evidence of association was categorised using established guidelines used by other studies in the field [120]: *Adequate* (most studies, at least one Good quality, reported an association between greenspace and mental wellbeing); *Limited* (more than one study, at least one Good, reported an association, but with inconsistent findings); *Inadequate* (associations reported in one or more studies, but none Good quality); and *No association* (several Good quality studies reported an absence of a statistically significant association between greenspace and mental wellbeing).

3.3 Results

Titles and abstracts of 485 records were screened, and 75 chosen for full-text evaluation; 42 were found to be eligible. During this process, 10 additional papers were found via Auto-Searching the databases and recommendations. Therefore, 52 papers were finally included in this review (Fig 3.1).

Among these, 4 were controlled case studies and a further 6 were longitudinal cohort studies; there was one ecological analysis, 4 uncontrolled case studies, the remaining 37 were cross-sectional surveys. Two studies were international, 31 were restricted to Europe, 15 just in the UK; 5 were based in the USA with another 6 in Canada, 10 in Australia. Analyses were confined to urban areas in 22 cases, 9 included only rural greenspace. Sample size ranged from 25 to 30,900 participants, but was not specified in 3 cases.

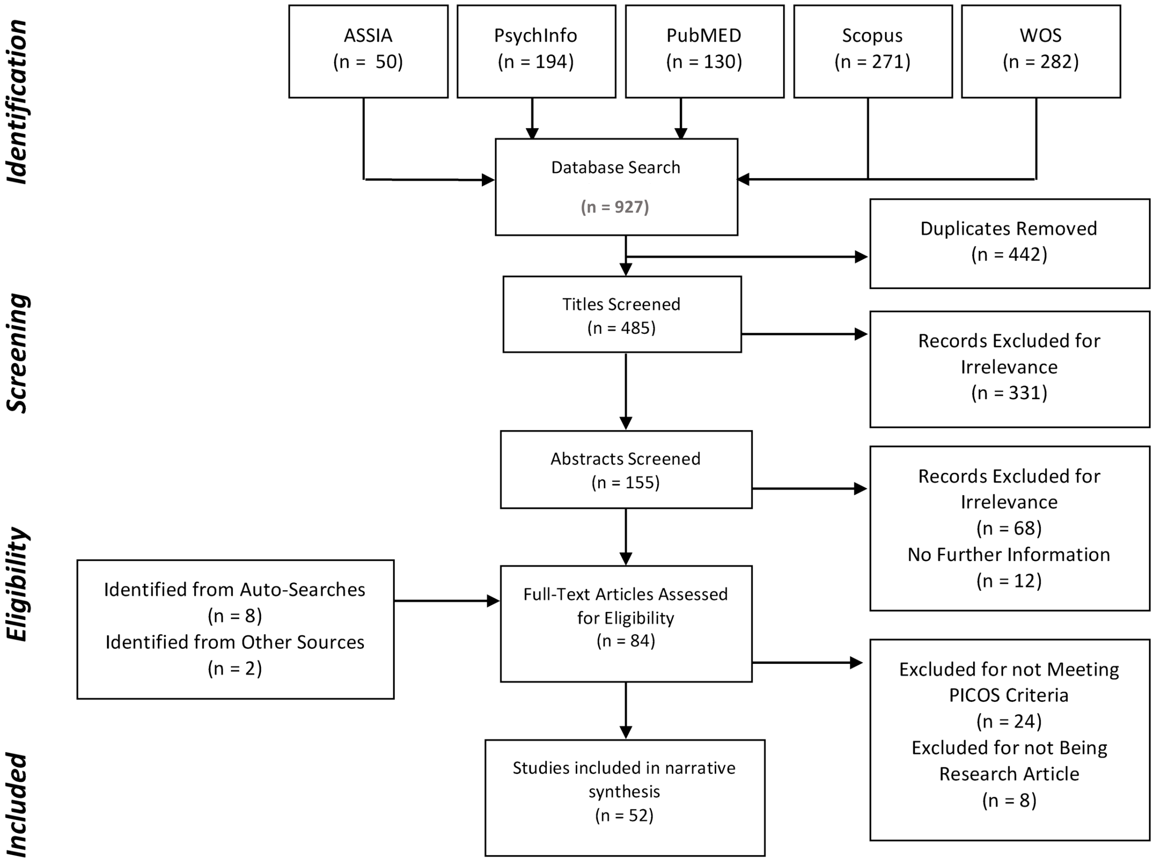


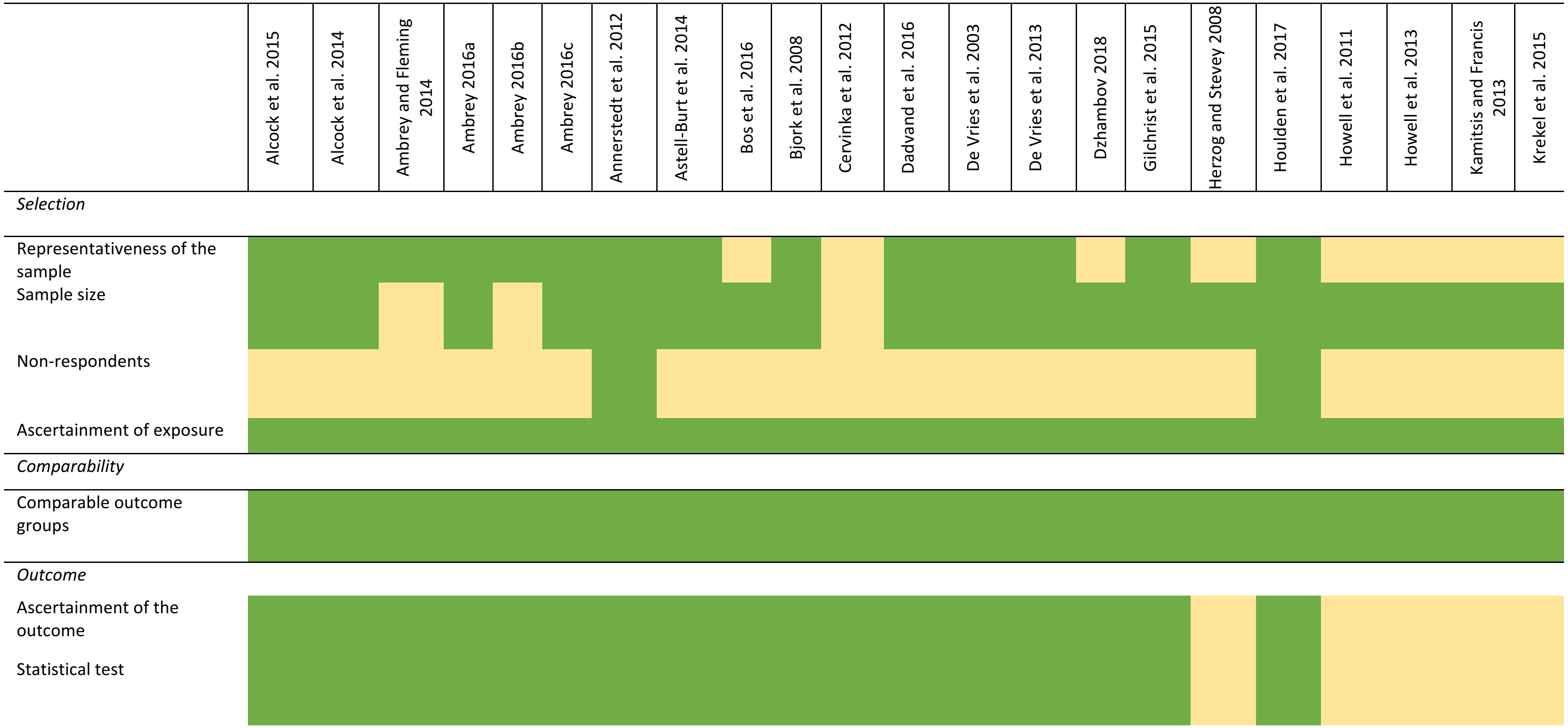
Figure 3.1 Study selection process

Age ranges were fairly consistent, covering young adults to past retirement age, although 1 focused on 'youths' (aged 16-25), 3 studies recruited university students and two included mainly people aged over 55; however, 11 studies did not specify participants' age. Full details of the risk of bias for each study are provided in the form of heat maps, presented in Table 3.2 for cross-sectional studies evaluated using the Newcastle-Ottawa Scale, with Table 3.3 for those analysed in accordance with the Cochrane Risk of Bias 2.0 tool.

After quality assessment, the majority of studies (*n*=27) were determined to be Good, 13 were Fair, and 12 Poor. For Poor studies, Table 3.4 provides further justification. This Table also includes summary data for each of the included studies, focussing on the measures included and the associations observed; effect sizes describe the strength of these associations, including correlation coefficients (C) and Odds Ratios (Odds) as well as the statistical significance indicators such as Confidence Intervals (CI) and Standard Errors (SE).

the specific mental wellbeing outcomes are described in more detail in section 3.3.1.

Table 3.5 then provides further detail on the typologies, measures, metrics and scales of greenspace implemented for each study. In particular, the measure type includes both objective (calculated) and subjective (individual self-reported) items. Objective greenspace measures include those derived from GIS (Geographic Information Systems, which store and analyse digitised maps; this format includes the CORINE land cover map, which features various land classes), land use databases (such as GLUD, the Generalised Land Use Database, which provide tabulated information for each locality in a region) and satellite imagery (including the Normalised Difference Vegetation Index, NDVI, which measures surface reflectance to identify areas of land covered by vegetation).


Alcock et al. 2015
Alcock et al. 2014
Ambrey and Fleming 2014
Ambrey 2016a
Ambrey 2016b
Ambrey 2016c
Annerstedt et al. 2012
Astell-Burt et al. 2014
Bos et al. 2016
Bjork et al. 2008
Cervinka et al. 2012
Dadvand et al. 2016
De Vries et al. 2003
De Vries et al. 2013
Dzhambov 2018
Gilchrist et al. 2015
Herzog and Stevey 2008
Houlden et al. 2017
Howell et al. 2011
Howell et al. 2013
Kamitsis and Francis 2013
Krekel et al. 2015
Selection
Representativeness of the sample
Sample size
Non-respondents
Ascertainment of exposure
Comparability
Comparable outcome groups
Outcome
Ascertainment of the outcome
Statistical test

	Luck et al. 2011	Maas et al. 2009	Mackerron and Mourato 2013	Marselle et al. 2013	Mitchell 2013	Nisbet et al. 2011	Panno et al. 2017	Sugiyama at al.L. 2008	Taylor et al. 2017	Triguero-Mas et al. 2015	Triguero-Mas et al. 2017	Van den Berg et al. 2016	Van den Bosch et al. 2015	Vemuri and Costanza 2006	Vemuri et al. 2011	Ward Thompson et al. 2014	Weimann et al. 2015	White et al. 2014	White et al. 2017	Wood et al. 2017	Zelenski and Nisbet 2014	Zhang et al.2014
Selection																						
Representativeness of the sample	Low	Low	Some	Some	Low	Low	Some	Low	Some	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Some	Some	Low
Sample size	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Some	Low	Low	Low	Low	Low	Low	Low	Low
Non-respondents	Low	Some	Some	Some	Some	Some	Some	Low	Some	Some	Some	Some	Low	Some	Some	Some	Low	Some	Some	Some	Some	Some
Ascertainment of exposure	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Some	Low	Low	Low	Low	Low	Low
Comparability																						
Comparable outcome groups	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Outcome																						
Ascertainment of the outcome	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Statistical test	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Some	Low	Low	Low	Low	Some	Low

Key: Low Risk of Bias; Some Risk of Bias

Table 3.2 Heat map of risk of bias for studies evaluated using the Newcastle-Ottawa Scale adapted for cross-sectional studies

	Duvall and Kaplan 2014	Jakubec et al. 2016	Marselle et al. 2015	Molsher and Townsend 2016	Nisbet and Zekenski 2011	Pretty et al. 2005	Richardson et al. 2016
Bias arising from randomisation process							
Was the allocation sequence random?	PN	PN	PN	N	PY	N	NI
Were there baseline imbalances that suggest a problem with the randomisation process?	NI	NI	NI	NI	NI	NI	NI
Bias due to deviations from intended interventions							
Were participants aware of their assigned intervention?	Y	Y	Y	Y	PN	PN	PN
Were personal aware of the participants' assigned intervention?	Y	Y	Y	Y	PY	PY	NI
Bias due to missing outcome data							
Was the outcome data available for all, or nearly all, participants randomised?	PY	PY	PY	PY	PY	PY	PY
Are the proportions of missing outcome data and reasons for missing outcome data similar across groups?	NI	PY	Y	NI	NI	NI	PY
Bias in measurement of the outcome							
Were outcome assessors aware of the intervention received by study participants?	Y	Y	Y	Y	Y	Y	Y
Bias in the selection of the reported result							
Are reported outcome data likely to have been selection, on the basis of results, from… multiple outcomes?	PN	PN	PN	PN	PN	PN	PN
… multiple analyses of the data?	PN	PN	PN	NI	PN	PN	PN

Y = Yes

PY = Possibly Yes — High Risk of Bias (blue)

PN = Possibly No — Some Risk of Bias (yellow)

No = No — Low Risk of Bias (green)

NI = No Information — No Information (white)

Table 3.3 Heat map of risk of bias for studies evaluated using the Cochrane Risk of Bias 2.0 tool

Authors, Year, Country	*Study Design*	*Age of Participants*	*Sample Size*	*Greenspace Measure*	*Mental Wellbeing Tool*	*Mental Wellbeing*	*Confounders*	*Methods*	*Statistically Significant Associations***	*Effect Size***	*Interaction Effects*	*Quality*
Amount of Local- Area Greenspace												
Alcock et al., 2015, England [121]	Longitudinal Cohort Study	under 25-over 75	2,020 214 movers	% area of each LSOA*, 10 land-cover types Rural areas only	GHQ-12	Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions, Health Commuting. Local: IMD	Multilevel Linear Regression	Cross-sectional differences: no association. Longitudinal differences for movers: significant, positive associations with increase access individually to Arable, Improved Grassland, Semi-natural Grassland, Mountain, Heath and Bog, and Coastal land cover.	C, SE: Within-individual: Arable: 0.083, 0.037 Improved Grassland: 1.351, 0.040 Semi-natural Grassland: 0.152, 0.062 Mountains/Heath: 1.667, 0.074	N/A	Good
Alcock et al., 2014, England [113]	Longitudinal Cohort Study	16-55+	1,064 residents of BHPS who relocated during survey	% greenspace in each LSOA, including private gardens, Urban areas only	GHQ-12	Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions, Health, Pre-move GHQ, Commuting. Local: IMD	Linear Regression	Movers to greener areas: significantly lower GHQ scores post-move. Movers to less green areas: GHQ decreased in year preceding the move but no significant difference post-move.	C, SE: Movers to greener areas T+1: 0.369, 0.152 T+2: 0.378, 0.158 T+3: 0.431, 0.162	N/A	Good
Ambrey and Fleming, 2014, Australia [122]	Cross-Sectional Survey	15-60+	NOT GIVEN	% public greenspace in each CD* Urban areas only	Life Satisfaction	Life Satisfaction	Individual: Demographic, Language, Marital, SES, Living Conditions, Health, Commuting, Hours Worked	Linear Regression	More greenspace: higher life satisfaction	C, SE: 0.003, 0.002	N/A	Good

Ambrey, 2016, Australia [123]	Cross-Sectional Survey	NOT GIVEN	3,288	Greenspace per capita, in each CD Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Physical Activity	Linear Regression	More greenspace: better mental health, only for those engaged in physical activity	C, SE: Greenspace Physical Activity Interaction: 4.392, 1.702	Positive interaction between greenspace and physical activity	Good
Ambrey, 2016, Australia [124]	Cross-Sectional Survey	NOT GIVEN	6,082	Greenspace per capita, in each CD Urban areas only	Life Satisfaction, SF-36	Life Satisfaction, Quality of Life	Individual: Physical Activity	Logistic Regression	More greenspace: better life satisfaction and quality of life	Odds, CI: Life Satisfaction: 0.942, 0.920-0.990. Quality of Life: 0.974, 0.912-1.039	N/A	Good
Ambrey, 2016, Australia [125]	Cross-Sectional Survey	NOT GIVEN	6,077	Amount of greenspace in each CD Urban areas only	SF-36	Quality of Life	Individual: Demographic, Ethnicity, Marital, SES, Free Time, Social Interaction, Household Members Engaged in Physical Activity, Personality. Local: Proximity to Lake, River, Coastline, SES	Linear Regression	More greenspace: better quality of life, only for those engaged in physical activity	C, SE: 0.553, 0.229	Positive interaction between greenspace and physical activity	Good
Astell-Burt et al., 2014, UK [45]	Longitudinal Cohort Study	15-75+	65,407 person-years	% greenspace in each ward, excluding water and private gardens Urban areas only	GHQ-12	Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions, Smoking	Linear Regression	More greenspace: lower GHQ scores among men. Variation in associations across life course and gender.	C, SE: 'High' Greenspace: 0.300, 0.370	Interactions for life course and gender	Good
Bos et al., 2016, The	Cross-Sectional Survey	18-87	4,924	% greenspace within 1km	Manchester Short Assessment	Quality of Life	Individual: Demographic, Country of	Linear Regression	More greenspace within 3km: better quality of life,	C, SE: 1km: 5.200, 5.500. 3km: 6.300, 4.500	Interactions for life	Poor

Netherlands [126]				and 3km buffers	of Quality of Life		Origin, Marital, SES		significant interactions for age and gender. For middle aged men, inverse association Greenspace within 1km: no association		course and gender	Limited Statistical reporting
De Vries et al., 2003, The Netherlands [22]	Cross-Sectional Survey	All ages (including children)	10,179	% greenspace in local area, % bluespace in local area, presence of a garden	GHQ-12	Psychological Distress	Individual: Demographic, SES, Living Conditions, Health Insurances, Life Events in Last Year	Multilevel Linear Regression	More greenspace: lower GHQ scores Access to agricultural space: lower GH Only for lower educated groups Results only significant for whole sample, not for individual urban categories Having a garden: significant only in very urban municipalities	C, SE: %green within 3km: -0.100, 0.003	Interaction with level of urbanity	Good
De Vries et al., 2013, The Netherlands [87]	Cross-Sectional Survey	NOT GIVEN	1,641	Quantity and quality of streetscape greenery, Urban areas only	SF-36	Quality of Life	Individual: Demographic, SES, Living Conditions, Health, Life Events in Last Year,	Multilevel Linear Regression	Higher amounts of greenspace: higher QOL, but not statistically significant after quality is added to the model. High quality of greenspace: higher quality of life.	C, SE: Quantity: 0.007 , 0.036 (not statistically significant) Quality: 0.0153, 0.069	Both Quantity and Quality show positive interaction s with stress, social cohesion, and green activity	Good
Dzhambov et al., 2018, Bulgaria [127]	Cross-Sectional Survey	15-25	399	Amount of green land within 500m of home, perceived neighbourh ood greenness and quality	GHQ-12	Psychological Distress	Individual: Demographic, SES, Living Conditions, Noise. Local: Population Density	Linear Mixed Models and Linear Mediation Models	Perceived greenness and quality: lower GHQ scores. No statistically significant associations for objective greenspace measures.	C, CI: Perceived greenness: -0.59, -0.85- -0.32 Greenspace quality: -0.08, -0.12 - -0.04	Higher perceived restorative quality was associated with more physical activity and social cohesion,	Fair

				Urban areas only							which was associated with lower GHQ scores. For objective measures, this held for all but the greenspace quality measure.	
Houlden et al., 2017, England [38]	Cross-Sectional Survey	16-65+	30,900	% greenspace in each LSOA, excluding gardens	SWEMWBS	Mental Wellbeing	Individual: Demographic, Marital, SES, Living Conditions, Health, Commuting. Local: IMD	Linear Regression	Greater amounts of greenspace: higher SWEMWBS scores. Reduced to null after adjustment	No statistically significant associations to report	N/A	Good
Maas et al., 2009, The Netherlands [93]	Cross-sectional Survey	12-65+	10,089	% greenspace within 1 and 3km buffers	GHQ-12	Psychological Distress	Individual: Demographic, Ethnicity, SES, Living Conditions, Health Insurance, Life Events in Last Year. Local: Level of Urbanity	Multilevel Linear Regression	More surrounding greenspace: lower GHQ score. Stronger association for 1km than 3km	C, SE: 1km: -0.005, 0.002 3km: -0.004, 0.002	N/A	Good
Taylor et al., 2018, Australia and New Zealand [128]	Cross-Sectional Survey	18-75+	1,819	Amount of greenspace in post code Urban areas only	WHO-5	Hedonic Wellbeing	NO	Linear Regression	Higher amounts of greenspace: higher WHO-5 scores. Only for 2 sample cities, remaining 2 insignificant	C: Melbourne: 1.410 Sydney: 2.470	N/A	Poor No controls
Triguero-Mas et al., 2015, Spain [129]	Cross-Sectional Survey	NOT GIVEN	8,793	Amount of greenspace within	GHQ-12	Psychological Distress	Individual: Demographic, Birth Place,	Logistic Regression	Higher amounts of greenspace: lower	Odds, CI: Males: 0.820, 0.700-0.980	Stronger association for males	Fair

				300m buffer Sensitivity analysis with other buffers			Marital, SES, Health Insurance. Local: SES		odds of higher GHQ score Consistent results for all buffers	Females: 0.770, 0.670-0.880	than females	
Triguero-Mas et al., 2017, Europe [130]	Cross-Sectional Survey	18-75	403	Amount of greenspace within 300m buffer, Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Demographic	Linear Regression	No association for surrounding greenspace.	No Statistical Results to report	Stronger association for males than females	Fair
Vemuri and Costanza, 2006, International [131]	Ecological Analysis	NOT GIVEN	172 Countries	Ecosystem services product (ESP), per square kilometre for each country, normalised. From amount of each land-cover and multiplied by ecosystem services per country.	Life Satisfaction	Life Satisfaction	NO	Linear Regression	Better natural capital: higher life satisfaction	Odds, SE: 2.453, 0.739	N/A	Poor No controls, high-level analysis
Ward Thompson et al., 2014, Scotland [132]	Cross-Sectional Survey	NOT GIVEN	305	Amount of greenspace 'around each home', perceptions of local greenspace Urban areas only	SWEMWBS	Mental Wellbeing	Individual: Demographic, Income, Deprivation	Linear Regression	Perceptions of having sufficient local greenspace: better mental wellbeing Satisfaction with quality: higher mental wellbeing	No Statistical Results to Report	N/A	Fair

White et al., 2013, England [16]	Cross-Sectional Survey	Under 25-over75	12,818 (GHQ) 10,168 (Life Satisfaction)	% greenspace in each LSOA, including private gardens, Urban areas only	Life Satisfaction, GHQ	Life Satisfaction, Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions, Health, Commuting. Local: IMD	Linear Regression	Higher percentage of greenspace: decreased GHQ, increased Life Satisfaction	C, SE: GHQ: -0.004, 0.001 Life Satisfaction: 0.002, 0.001	N/A	Good
White et al., 2013, England [114]	Cross-Sectional Survey	Under 25-over75	15,361	% greenspace in each LSOA, including private gardens	Life Satisfaction, GHQ	Life Satisfaction, Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions, Health, Commuting. Local: IMD	Linear Regression	Higher percentage of greenspace: decreased GHQ	C, SE: GHQ (reversed): Greenspace: 0.003, 0.001	N/A	Good
Wood et al., 2017, Australia [133]	Cross-Sectional Survey	NOT GIVEN	492	Amount and number of public greenspaces within 1.6km buffer, type of greenspace: sports, recreational, natural Urban areas only	SWEMWBS	Mental Wellbeing	Individual: Demographic, SES	Linear Regression	Number of parks: higher mental wellbeing. Strongest association for largest parks, decreasing with size. Greater area of parks: higher mental wellbeing scores Strongest association for sports spaces	C, SE: Number of parks: 0.110, 0.050 Hectare increase of park area: 0.070, 0.020 Number of sports spaces: 0.430, 0.210 Number of recreational spaces: 0.110, 0.050 Number of natural spaces: 0.110, 0.050	N/A	Fair
Greenspace Types												

Alcock et al., 2015, England [121]	Longitudinal Cohort Study	under 25-over 75	2,020 214 movers	10 land-cover types Rural areas only	GHQ-12	Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions, Health Commuting. Local: IMD	Multilevel Linear Regression	Cross-sectional differences: no association. Longitudinal differences for movers: significant, positive associations with increase access individually to Arable, Improved Grassland, Semi-natural Grassland, Mountain, Heath and Bog, and Coastal land cover.	C, SE: Within-individual: Arable: 0.083, 0.037 Improved Grassland: 1.351, 0.040 Semi-natural Grassland: 0.152, 0.062 Mountains/Heath: 1.667, 0.074	N/A	Good
Annerstedt et al., 2012, Sweden [134]	Longitudinal Cohort Study	18-80	7,549 residents who did not relocate during survey	Presence of 5 green qualities within 300m buffer: Serene, Wild, Lush, Spacious, Culture Rural areas only	GHQ-12	Psychological Distress	Individual: Demographic, Country of Origin, Marital, Financial Strain, Physical Activity	Logistic Regression	Presence of Serene: lower GHQ score, only for those engaged in physical activity Presence of Spacious: lower GHQ, only for women engaged in physical activity	Odds, CI: Women with Access to Serene: 0.200, 0.060-0.900	Positive interaction between being physical activity and serene greenspace Positive interaction between being physical activity and serene greenspace, for women	Good
Bjork et al., 2008, Sweden [46]	Cross-Sectional Survey	19-76	24,819	Number of 5 green qualities within 100 and 300m buffers: Serene, Wild, Lush,	SF-36 Vitality Component Survey	Vitality	Individual: Demographic, SES, Financial Strain, Smoking	Logistic Regression	More green qualities within 300m: better vitality, only for women More green qualities within 100m: no association Individual qualities: no association	Odds and CI, women with access to number of qualities: 4-5: 1.070, 0.880-1.290 3: 1.220, 1.060-1.410	Interactions with gender	Good

				Spacious, Culture Rural areas only						2: 1.060,0.940-1.190		
Luck et al., 2011, Australia [135]	Cross-sectional Survey	All ages	1,043	Residential neighbourhood greenspace aspects:, vegetation cover, vegetation density, Urban areas only	Subjective Wellbeing	Subjective Wellbeing	Individual: Demographic, SES, Living Conditions, General Activity	Multilevel Linear Regression	Higher levels of species richness, species abundance, vegetation cover, vegetation density: better subjective wellbeing, strongest for vegetation	C, SE: Vegetation Cover: 0.560, 0.260 Vegetation Density: 0.800, 0.390	N/A	Good
MacKerron and Mourato, 2013, UK [136]	Cross-Sectional Survey	All ages	21,947	Land cover types	Happiness	Happiness	NO	Linear Regression	All outdoor land cover types: better happiness than continuous urban areas. Marine and coastal areas have happiest scores.	C, SE: Mountains/moors: 2.710, 0.870 Woodland: 2.120, 0.340 Semi-natural grassland: 2.040, 0.350 Suburban/rural: 0.880, 0.160	N/A	Fair
Sugiyama et al., 2008, Australia [137]	Cross-Sectional Survey	20-65	1,895	Neighbourhood Environment Walkability Scale, Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Demographic, Marital, SES, Walking, Social Interaction	Logistic Regression	Higher reported greenness: better mental health	Odds, CI: High Perceived Greenness: 1.270, 0.990-1.620	N/A	Good
Van den Bosch et al., 2015, Sweden [138]	Longitudinal Cohort Study	18-80	1,419 residents who relocated during survey	Amount and presence of greenspace within 300m buffer: Serene,	GHQ-12	Psychological Distress	Individual: Deprivation, Marital, Education	Logistic Regression	Gained access to Serene greenspace: improved mental health among women. No other associations	Odds, CI: Access to Serene: 2.800, 1.110-7.040	Associations only for females, not males	Good

				Wild, Lush, Spacious, Culture, Rural areas only								
Vemuri et al., 2011, USA [139]	Cross-sectional Survey	18-65+	1,361	Neighbourhood satisfaction, quality of neighbourhood natural environment, amount of tree cover per census block, Urban areas only	Life Satisfaction	Life Satisfaction	Individual: Demographic, Ethnicity, Marital, Living Conditions, Social Capital	Logistic Regression	Stronger perceived environmental quality: improved life satisfaction Perceived shows stronger association than objective measures	C, SE: 0.276, 0.514	N/A	Good
Weimann et al., 2015, Sweden [140]	Longitudinal Cohort Study	18-80	9,444	Number of 5 green qualities within local 1km^2 area: Serene, Wild, Lush, Spacious, Culture	GHQ-12	Psychological Distress	Individual: Demographic, Marital, SES, Living Conditions BMI, Smoking	Multilevel Logistic Regression	Within-individual difference of higher neighbourhood greenness: lower psychological distress	Odds, CI: Within-Individual: 1.030, 1.000-1.160 Between-Individuals:1.070, 1.000-1.140	N/A	Good
Wood et al., 2017, Australia [133]	Cross-Sectional Survey	NOT GIVEN	492	Amount and number of public greenspaces within 1.6km buffer, type of greenspace: sports, recreational, natural	SWEMWBS	Mental Wellbeing	Individual: Demographic, SES	Linear Regression	Number of parks: higher mental wellbeing. Strongest association for largest parks, decreasing with size. Greater area of parks: higher mental wellbeing scores Strongest association for sports spaces	C, SE: Number of parks: 0.110, 0.050 Hectare increase of park area: 0.070, 0.020 Number of sports spaces: 0.430, 0.210 Number of recreational spaces: 0.110, 0.050 Number of natural spaces: 0.110, 0.050	N/A	Fair

				Urban areas only								
Views of Greenspace												
Gilchrist et al., 2015, Scotland [141]	Cross-Sectional Survey	16-55+	366	Workplace view naturalness, view satisfaction, extent of features in view Urban areas only	SWEMWBS	Mental Wellbeing	Individual: Demographic, Job Type, Greenspace Use in Leisure Time. Local: Location	Linear Regression	No association for view naturalness Satisfaction with view, views of trees/bushes/flowering plants: higher SWEMWBS score Types strongest predictors	C, SE: View of Trees: 0.616, 0.198 View bushes/flowers: 0.610, 0.312 View Satisfaction: 0.802, 0.215	N/A	Good
Pretty et al., 2005, UK [47]	Controlled Case Study	18-60	100	Running while exposed to photographs: urban/rural pleasant and unpleasant	Rosenberg Self-Esteem Questionnaire, Profile of Mood States	Self-Esteem, Mood	NO	N/A	Viewing pleasant scenes: increase in self-esteem	No Statistical Results to Report	N/A	Fair
Vemuri et al., 2011, USA [139]	Cross-sectional Survey	18-65+	1,361	Number of trees visible from residence Urban areas only	Life Satisfaction	Life Satisfaction	Individual: Demographic, Ethnicity, Marital, Living Conditions, Social Capital	Logistic Regression	Perceived shows stronger association than objective measures	No Statistical Results to Report	N/A	Good
Visits to Greenspace												
Duvall and Kaplan, 2014, USA [142]	Uncontrolled Case Study	20-50+	73	Wilderness Expedition, Rural areas only	AFI, PANAS	Attention, Affect	Individual: Demographic, SES, Physical and Mental Health History, Veteran History	Linear Mixed Models	Post expedition: more positive affect and better attentional functioning Follow-up: better positive affect	Score Change: AFI: 0.340 Affect: 0.270	N/A	Poor Small sample, allocation based on intervention
Dzhambov et al., 2018, Bulgaria [127]	Cross-Sectional Survey	15-25	399	Amount of green land within 500m of	GHQ-12	Psychological Distress	Individual: Demographic, SES, Living Conditions,	Linear Mixed Models and Linear	Perceived greenness and quality, and travel time to greenspace: lower GHQ scores.	C, CI: Perceived greenness: -0.59, -0.85- -0.32	Higher perceived restorative quality was	Fair

				home, Euclidean distance to nearest greenspace, perceived neighbourhood greenness and quality, travel time to and time spent in neighbourhood greenspace Urban areas only			Noise. Local: Population Density	Mediation Models	No statistically significant associations for objective greenspace measures.	<5min to greenspace: -2.54, -3.96 - -1.12 Greenspace quality: -0.08, -0.12 - -0.04	associated with more physical activity and social cohesion, which was associated with lower GHQ scores. For objective measures, this held for all but the greenspace quality measure.	
Gilchrist et al., 2015, Scotland [141]	Cross-Sectional Survey	16-55+	366	Workplace greenspace visit frequency, weekly use duration Urban areas only	SWEMWBS	Mental Wellbeing	Individual: Demographic, Job Type, Greenspace Use in Leisure Time. Local: Location	Linear Regression	No association for use frequency Time spent in workplace greenspace, satisfaction with view, views of trees/bushes/flowering plants: higher SWEMWBS score Types strongest predictors	C, SE: Use Duration: 0.431, 0.191	N/A	Good
Herzog and Stevey, 2008, USA [143]	Cross-Sectional Survey	University Students	823	Self-reported typical contact with nature	Ryff's Scales of Psychological Well-Being, Attention, PANAS	Mental Wellbeing, Attention, Affect	Individual: Sense of humour	Linear Regression	Greater contact with nature: better personal development, effective functioning.	C: Personal Development: 0.090 Effective Functioning: 0.230	N/A	Fair

Jakubec et al., 2016, Canada [144]	Uncontrolled Case Study	Adults	37	Visits to greenspace, Rural areas only	Quality of Life Inventory	Quality of Life	NO	Score Change	Post-Intervention: improved quality of life, not statistically significant	Score Change: Satisfaction with love: +1.000 Satisfaction with life: -1.000	N/A	Poor No controls, participants aware of intervention
Kamitsis and Francis, 2013, Australia [145]	Cross-Sectional Survey	18-69	190	Nature Exposure, CNS	WHOQOL-BREF	Quality of Life	Individual: Spirituality	Linear Regression	Higher nature exposure or connection to nature: better quality of life	C: Exposure: 0.280 CNS: 0.330	N/A	Poor Minimal controls
Marselle et al., 2013, UK [146]	Controlled Case Study	Adults, mostly over 55	708	Group walks in different environments: natural and semi-natural, green corridors, farmland, parks and gardens, urban, coastal, amenity greenspace, allotments, outdoor sports facilities, other	WEMWBS, PANAS	Mental Wellbeing, Affect	Individual: Demographic, Marital, Education, Deprivation	Multilevel Linear Regression	Walks in farmland: better mental wellbeing No associations with other greenspace types	C, SE: Walks in farmland: 2.790, 0.003	N/A	Fair
Marselle et al., 2015, UK [147]	Cross-Sectional Survey	Adults, mostly over 55	127	Walking: environment type, perceived naturalness, perceived biodiversity, perceived restorative	Happiness, PANAS	Happiness, Affect	NO	Multilevel Linear Regression	Perceived restorativeness, perceived walk intensity: positively associated with affect and happiness.	C, SE: Affect: 0.126, 0.014 Happiness: 0.029, 0.003	N/A	Poor No controls, participants aware of intervention

				ness, duration of walk, perceived walk intensity								
Mitchell, 2013, Scotland [28]	Cross-sectional Survey	16+	1,890	Frequency of use of different environment types for physical activity	WEMWBS, GHQ	Mental Wellbeing, Psychological Distress	Individual: Demographic, Income, Physical Activity. Local: Level of Urbanity	Linear Regression	Regular use of open space/park or woods/forest: lower GHQ score Regular use of natural environments: no clear association with mental wellbeing Regular use of non-natural environments: better mental wellbeing	Odds, CI: GHQ: Park >1 a week: 0.570, 0.369-0.881 Woods >1 a week: 0.557, 0.323-0.962 WEMWBS: Park <1 a week: 2.442, 0.769-4.115	N/A	Good
Molsher and Townsend, 2016, Australia [148]	Uncontrolled Case Study	14-71	32	Engagement with 10 week Environmental Volunteering Project, Rural areas only	General Wellbeing Scale, PANAS	Wellbeing, Affect	NO	Score Change	Post-intervention and Follow-up: improved wellbeing and mood state scores	Score Change: Wellbeing: +11.600	N/A	Poor No controls, participants aware of intervention
Nisbet and Zekenski, 2011, Canada [149]	Controlled Case Study	16-48	150	Walking indoors or outdoors in nature, Nature Relatedness Urban areas only	Happiness, PANAS	Happiness, Affect	NO	T-Tests	Walking outdoors: more positive affect, relaxation and fascination	T-Test: Outdoor Walk: Affect: 4.860 Relaxation: 4.570 Fascination: 4.800	N/A	Fair
Panno et al., 2017, Italy [150]	Cross-Sectional Survey	NOT GIVEN	115	Self-reported greenspace	WHO-5	Hedonic Wellbeing	Individual: Demographics, SES	Hierarchical Regression	Higher reported frequency of greenspace visits: greater wellbeing	No Statistically Significant Results to Report	N/A	Fair

				visit frequency					scores. Not statistically significant.			
Richardson et al., 2016, UK [151]	Uncontrolled Case Study	18-71	613	Nature in Self, Engagemen t with '30 Days Wild' Programme	Happiness	Happiness	NO	T-Tests	Post-intervention, increased nature connection, increased general happiness	T-Tests: 6.650	N/A	Fair
Triguero-Mas et al., 2017, Europe [130]	Cross-Sectional Survey	18-75	403	Frequency of contact with greenspace in terciles Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Demographic	Linear Regression	Lower frequency of greenspace visits: poorer mental health. Stronger associations for males	C, CI for 'low' contact Males: -9.140, -14.420 - -3.860 Females: -5.000, -9.790- -0.021	Stronger association for males than females	Fair
Van den Berg et al., 2016, Spain, The Netherlands, Lithuania, UK [48]	Cross-Sectional Survey	18-75	3,748	Reported hours of greenspace visits in last month, Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Demographic, SES, Living Conditions, Childhood Nature Experience	Multilevel Linear Regression	Higher visits to greenspace: better mental health	C, CI: 0.030, 0.020-0.040	N/A	Good
Ward Thompson et al., 2014, Scotland [132]	Cross-Sectional Survey	NOT GIVEN	305	Patterns of greenspace use Urban areas only	SWEMWBS	Mental Wellbeing	Individual: Demographic, Income, Deprivation	Linear Regression	No association between greenspace use and mental wellbeing	No Statistical Results to Report	N/A	Fair
White et al., 2017, England [152]	Cross-Sectional Survey	NOT GIVEN	7,272	Did the individual visit greenspace yesterday. Amount of time spent outdoors Urban areas only	ONS4	Mental Wellbeing	Individual: Demographic, Marital, SES, Living Conditions, Health, Commuting. Local: IMD	Logistic Regression	Visiting a greenspace yesterday: higher happiness Spending time outdoors: more frequently associated with higher worth, decreasing with frequency	C, CI: Visited greenspace yesterday, happiness: 1.660, 1.320-2.080 Spending time outdoors everyday day, compared to never, worth: 1.960, 1.490-2.580	N/A	Good
Greenspace Accessibility												
Bjork et al., 2008, Sweden [46]	Cross-Sectional Survey	19-76	24,819	Number of 5 green qualities	SF-36 Vitality Component Survey	Vitality	Individual: Demographic,	Logistic Regression	More green qualities within 300m: better	Odds and CI, women with access to number of	Interaction s with gender	Good

				within 100 and 300m buffers: Serene, Wild, Lush, Spacious, Culture Rural areas only			SES, Financial Strain, Smoking		vitality, only for women More green qualities within 100m: no association Individual qualities: no association	qualities within 300m: 4-5: 1.070, 0.880-1.290 3: 1.220, 1.060-1.410 2: 1.060,0.940-1.190		
Bos et al., 2016, The Netherlands [126]	Cross-Sectional Survey	18-87	4,924	% greenspace within 1km and 3km buffers	Manchester Short Assessment of Quality of Life	Quality of Life	Individual: Demographic, Country of Origin, Marital, SES	Linear Regression	More greenspace within 3km: better quality of life, significant interactions for age and gender. For middle aged men, inverse association Greenspace within 1km: no association	C, SE: 1km: 5.200, 5.500. 3km: 6.300, 4.500	Interactions for life course and gender	Poor Limited Statistical reporting
Dadvand et al., 2016, Spain [153]	Cross-Sectional Survey	18-65+	3,461	% greenspace within 100m, 250m and 500m buffers, subjective presence of greenspace within 10 minute walk, objective presence of greenspace within 200m of minimum 5000m^2 Urban areas only	GHQ-12	Psychological Distress	Individual: Demographic, SES, Social Support, Physical Activity Local: Deprivation	Logistic Regression	More greenspace nearer to home: lower GHQ score. Effect sizes decreasing with distance. Greater subjective and objective proximity to greenspace: lower GHQ scores	Odds, CI: 100m : 1.320, 1.160-1.510 250m: 1.250, 1.100-1.400 500m: 1.170, 1.040-1.320 Subjective proximity: 1.300, 1.040-1.630 Objective proximity: 1.200, 0.970-1.480	N/A	Good

Dzhambov et al., 2018, Bulgaria [127]	Cross-Sectional Survey	15-25	399	Amount of green land within 500m of home, Euclidean distance to nearest greenspace, perceived neighbourhood greenness and quality, travel time to greenspace Urban areas only	GHQ-12	Psychological Distress	Individual: Demographic, SES, Living Conditions, Noise. Local: Population Density	Linear Mixed Models and Linear Mediation Models	Travel time to greenspace: lower GHQ scores. No statistically significant associations for objective greenspace measures.	C, CI: <5min to greenspace: -2.54, -3.96 - -1.12	Lower travel time to greenspace was associated with more physical activity and social cohesion, which was associated with lower GHQ scores..	Fair
Krekel et al., 2015, Germany [154]	Cross-sectional Survey	17-99	NOT GIVEN	Euclidean distance from home to green and abandoned areas Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Demographic, Country of Origin, Marital, SES, Living Conditions, Disabilities	Linear Regression	Access to urban greenspaces: better mental health Access to abandoned areas: poorer mental health	C: Greenspace: 0.007	N/A	Good
Maas et al., 2009, The Netherlands [93]	Cross-sectional Survey	12-65+	10,089	%greenspace within 1 and 3km buffers	GHQ-12	Psychological Distress	Individual: Demographic, Ethnicity, SES, Living Conditions, Health Insurance, Life Events in Last Year. Local: Level of Urbanity	Multilevel Linear Regression	More surrounding greenspace: lower GHQ score. Stronger association for 1km than 3km	C, SE: 1km: -0.005, 0.002 3km: -0.004, 0.002	N/A	Good

Sugiyama et al., 2008, Australia [137]	Cross-Sectional Survey	20-65	1,895	Neighbourhood Environment Walkability Scale, Urban areas only	SF-36 Mental Component Survey	Mental Health	Individual: Demographic, Marital, SES, Walking, Social Interaction	Logistic Regression	Higher reported greenness: better mental health	Odds, CI: High Perceived Greenness: 1.270, 0.990-1.620	N/A	Good
Triguero-Mas et al., 2015, Spain [129]	Cross-Sectional Survey	NOT GIVEN	8,793	Amount of greenspace within 100m, 300m, 500m and 1km buffers, presence of green and blue spaces within buffer Sensitivity analysis with other buffers	GHQ-12	Psychological Distress	Individual: Demographic, Birth Place, Marital, SES, Health Insurance. Local: SES	Logistic Regression	Higher amounts of greenspace: lower odds of higher GHQ score Consistent results for all buffers	Odds, CI: Males: 0.820, 0.700-0.980 Females: 0.770, 0.670-0.880	Stronger association for males than females	Fair
Subjective Connection to Nature												
Cervinka et al., 2012, Austria [155]	Cross-Sectional Survey	15-87	547	CN-SI*	SF-36 Component Surveys, SWLS, WHOQOL-BREF	Quality of Life, Life Satisfaction	Individual: Demographic	Linear Regression	Higher CN-SI Score: better meaningfulness, mental health, vitality and emotional-role function	C: Meaningfulness: 0.210 Mental Health: 0.180 Vitality: 0.230 Emotions: 0.190	N/A	Poor Limited sampling description
Howell et al., 2011, Canada [156]	Cross-Sectional Survey	University Students	452	CNS*	Keyes' Index of Well-Being and Mindful Attention Awareness Scale	Mental Wellbeing, Attention	NO	Linear Regression	Greater connection to nature: greater psychological wellbeing and social wellbeing. Not associated with	C: Psychological Wellbeing: 0.150 Social Wellbeing: 0.200	N/A	Poor No controls, minimal reporting

									emotional wellbeing or mindfulness			
Howell et al., 2013, Canada [157]	Cross-Sectional Survey	University Students	311	CNS, Nature Relatedness Scale*	Emotional Wellbeing, Steen Happiness Index, Meaning in Life Questionnaire, Meaningful Life Measure, General Life Purpose Scale	Mental Wellbeing, Happiness, Meaning in Life	NO	Linear Regression	Greater connection to nature: better reported wellbeing, meaning in life	C: Meaning: 0.310 Purpose: 0.250 Happiness: 0.220 Emotional Wellbeing: 0.200 Psychological Wellbeing: 0.250 Social Wellbeing: 0.260	N/A	Poor No controls, minimal reporting
Kamitsis and Francis, 2013, Australia [145]	Cross-Sectional Survey	18-69	190	Nature Exposure, CNS	WHOQOL-BREF	Quality of Life	Individual: Spirituality	Linear Regression	Higher nature exposure or connection to nature: better quality of life	C: Exposure: 0.280 CNS: 0.330	N/A	Poor Minimal controls
Nisbet et al., 2011, Canada [158]	Cross-Sectional Survey	Adults, student subgroup	184, 145,in two studies	Nature Relatedness Scale, New Ecological Consciousness Scale	Ryff's Psychological Well-Being Inventory, SWLS, PANAS	Mental Wellbeing, Life Satisfaction, Affect	NO	Linear Regression	Higher nature relatedness: better wellbeing, positive affect, purpose in life. No association for life satisfaction.	C: Study 1: Affect: 0.330 Purpose: 0.230 Study 2: Affect: 0.220 Purpose: 0.240	N/A	Fair
Zelenski et al., 2014, Canada [159]	Cross-Sectional Survey	NOT GIVEN	950	Nature Relatedness Scale, Inclusion of Nature in Self	Ryff's PWBI, SWLS, Subjective Happiness Scale (SHS), PANAS	Mental Wellbeing, Life Satisfaction, Happiness, Affect	NO	Linear Regression	Stronger connection to nature: improved wellbeing, happiness, life satisfaction and affect	C: Wellbeing: 0.250 Happiness: 0.360 Life Satisfaction: 0.310 Affect: 0.380	N/A	Poor No controls

Zhang et al., 2014, USA [160]	Cross-Sectional Survey	18-88	1,108	CNS, Engagement with Natural Beauty Scale	SWLS	Life Satisfaction	Individual: Demographic, Personality	Multilevel Linear Regression	Higher connectedness with nature: improved life satisfaction, only for those reporting being attuned to nature's beauty	C, CI: Connectedness: 0.1000, -0.990-0.109 Engagement: 0.155, 0.121-0.344 ConnectednessXENGAGEMENT: 0.080, 0.170-0.151	Positive interaction between connectedness to nature and being attuned to nature's beauty	Good

*LSOA, Lower-Layer Super Output Area, a census-based spatial unit. CD, Census District, a census-based spatial unit.
*CNS, Connectedness to Nature Scale, measure of individuals' trait levels of feeling emotionally connected to the natural world. CN-SI, single-item version of CNS. Nature Relatedness Scale, affective, cognitive, and experiential aspects of individual's connection to nature
**All associations described in this table are statistically significant, unless otherwise specified
Effect sizes: C, Coefficient. CI, Confidence Interval. SE, Standard Error. Odds, Odds Ratio

Table 3.4 Main characteristics of included studies

Study	*Greenspace Type*	*Measure Type*	*Metrics Used*	*Spatial Scale*
Amount of Local area Greenspace				
Alcock et al., 2015 [121]	Natural Land Cover	Land Cover Map	Proportion of area that is greenspace	LSOA
Alcock et al., 2014 [113]	Greenspace and Private Gardens	Generalised Land Use Database (GLUD)	Proportion of area that is greenspace	LSOA
Ambrey and Fleming, 2014 [122]	Public Greenspace (including public parks, community gardens cemeteries, sports fields, national parks and wilderness areas)	GIS	Proportion of area that is greenspace	Census District
Ambrey, 2016 [123]	Public Greenspace (including public parks, community gardens cemeteries, sports fields, national parks and wilderness areas)	GIS	Amount of greenspace per Capita	Census District
Ambrey, 2016 [124]	Public Greenspace (including public parks, community gardens cemeteries, sports fields, national parks and wilderness areas)	GIS	Amount of greenspace per Capita	Census District
Ambrey, 2016 [125]	Public Greenspace (including public parks, community gardens cemeteries, sports fields, national parks and wilderness areas)	GIS	Amount of greenspace per Capita	Census District
Astell-Burt et al., 2014 [45]	Green and Natural Environment (excluding water and private gardens)	Land Use Database	Proportion of area that is greenspace	Ward
Bos et al., 2016 [126]	Greenspace (urban green including vegetable gardens, sports areas >0.5ha, parks >1ha; and rural green including agricultural and natural green)	Dutch Land Use Database and GIS	Proportion of area that is greenspace	1km and 3km buffers of post code centroid
De Vries et al., 2003 [22]	Greenspace (urban green, agricultural green, forests and nature areas)	National Land Use Classification Database and GIS	Proportion of area that is greenspace	3km around centre of neighbourhood unit
De Vries et al., 2013 [87]	All types of visible vegetation, and quality based on variation, maintenance, orderly arrangement, absence of litter and general impression of greenspace	On-street Audit	Level of greenness (1- the street does not make a very green impression, to 5- the street makes a very green impression)	Average street greenness of neighbourhood unit
Dzhambov et al., 2018	Green land cover	NDVI	Proportion of area that is greenspace	500m Euclidean buffer of home

[127]	Greenspace (parks, gardens, street trees)	Self-reported	Perceived neighbourhood greenness and quality, travel time to and time spent in neighbourhood greenspace, green views from home	Self-reported neighbourhood
Houlden et al., 2017 [38]	Greenspace	Generalised Land Use Database (GLUD)	Proportion of area that is greenspace	LSOA
Maas et al., 2009 [93]	Greenspace (urban green, agricultural green, forests and nature areas)	National Land Use Classification Database and GIS	Proportion of area that is greenspace	1km and 3km buffer around individual's home
Taylor et al., 2018 [128]	Green land cover	NDVI	NDVI value	Post code
Triguero-Mas et al., 2015 [129]	Green land cover	NDVI	Amount of greenspace	300m Euclidean buffer of post codes
Triguero-Mas et al., 2017 [130]	Green land cover	NDVI	Amount of greenspace	300m Euclidean buffer of post codes
Vemuri and Costanza, 2006 [131]	Land Cover Types	Land Cover Map	Ecosystem Services Product (amount of each land cover, multiplied by ecosystem services per country)	Country
Ward Thompson et al., 2014 [132]	Greenspace (parks, woodlands, scrub and other publicly accessible natural environments)	GIS	Amount of Greenspace	Neighbourhood unit
White et al., 2013 [16]	Greenspace and Private Gardens	Generalised Land Use Database (GLUD)	Proportion of area that is greenspace	LSOA
White et al., 2013 [114]	Greenspace and Private Gardens	Generalised Land Use Database (GLUD)	Proportion of area that is greenspace	LSOA
Wood et al., 2017 [133]	Greenspace (parks and other areas of green public open spaces)	Land Cover Map	Amount and number of parks	1.6km road network buffer
Greenspace Types				
Alcock et al., 2015 [121]	Land Cover Types (broadleaf woodland, coniferous woodland, arable, improved grassland, semi-natural grassland, mountain, heath and bog, saltwater, freshwater, coastal, built-up areas including gardens)	Land Cover Map	Proportion of area of each type	LSOA

Annerstedt et al., 2012 [134]	5 qualities: Serene (place of peace, silence and care), Wild (place of fascination with wild nature), Lush (place rich in species), Spacious (place offering a restful feeling of entering another world), Culture (the essence of human culture)	CORINE Land Cover and GIS	Presence of each type	3km Euclidean buffer from home
Bjork et al., 2008 [46]	5 qualities: Serene, Wild, Lush, Spacious, Culture	CORINE Land Cover and GIS	Presence of each type	100 and 300m Euclidean buffers from home
Luck et al., 2011 [135]	Vegetation Cover (woody and non-woody vegetation)	Advanced Land Observation Satellite	Proportion of vegetation	Census District
	Vegetation Density (understory, mid-story and over-story cover)	Field Survey	Proportion of vegetation	Census District
MacKerron and Mourato, 2013 [136]	Land Cover Classes (marine and coastal, freshwater and wetlands, mountains and moors and heathland, semi-natural grasslands, farmland, coniferous woodland, broadleaf woodland, bare ground, suburban/rural development, continuous urban)	Land Cover Map	Type	Current GPS location
Sugiyama et al., 2008 [137]	Neighbourhood Greenness	Self-Reported	Level of greenness	Neighbourhood unit
Van den Bosch et al., 2015 [138]	5 qualities: Serene, Wild, Lush, Spacious, Culture	CORINE Land Cover and GIS	Amount and presence of each type	300m Euclidean buffer from home
Vemuri et al., 2011 [139]	Natural environment quality and satisfaction	Self-Reported	Perceptions of neighbourhood	Neighbourhood
Weimann et al., 2015 [140]	5 qualities: Serene, Wild, Lush, Spacious, Culture	CORINE Land Cover and GIS	Presence of each type	5-10 minute walk from homes
Wood et al., 2017 [133]	Sports, recreational, and natural greenspaces	Land Cover Map	Amount and presence of each type	1.6km network buffer of homes
Views of Greenspace				
Gilchrist et al., 2015 [141]	Workplace greenspace	Self–Reported	Perceptions of view of greenspace naturalness and extent	Workplace
Pretty et al., 2005 [47]	Rural pleasant and unpleasant scenes Urban pleasant and unpleasant scenes	Lab environment setting	Photographs	Photographs of views

Vemuri et al., 2011 [139]	Number of trees visible from home	Self-Reported	Perceptions of neighbourhood	Individual
Visits to Greenspace				
Duvall and Kaplan, 2014 [142]	Wilderness	Objective	Exposure through expedition	Individual
Dzhambov et al., 2018 [127]	Parks and gardens	Self-Reported	Time spent in greenspace	Self-reported Neighbourhood
Gilchrist et al., 2015 [141]	Workplace greenspace	Self–Reported	Frequency and duration of greenspace exposure	Workplace
Herzog and Stevey, 2008 [143]	Nature	Self-Reported	Typical contact	Individual
Jakubec et al., 2016 [144]	Wilderness	Objective	Exposure through expedition	Individual
Kamitsis and Francis, 2013 [145]	Nature	Self-Reported	Level of exposure	Individual
Marselle et al., 2013 [146]	Natural and semi-natural, green corridors, farmland, parks/gardens, urban, coastal, amenity greenspace, allotments, outdoor sports facilities, other	Land Use Database	Walking while exposed to different environments	Individual
Marselle et al., 2015 [147]	Natural and semi-natural, green corridors, farmland, parks/gardens, urban, coastal, amenity greenspace, allotments, outdoor sports facilities, other	Land Use Database,	Duration of walk and environment type	Individual
	Natural and semi-natural, green corridors, farmland, parks/gardens, urban, coastal, amenity greenspace, allotments, outdoor sports facilities, other	Self-Reported	Perceived naturalness, biodiversity, restorativeness, walk intensity	Individual
Mitchell, 2013 [28]	Woodland/forest, open space/park, country paths, beach/river, sports field/courts, swimming pool, gym/sports centre, pavements, home/garden, other, none	Self-Reported	Frequency of use of different greenspace types for physical activity	Individual
Molsher and Townsend, 2016 [148]	Rural nature	Objective	Engagement with 10-week Environmental Volunteering Project	Individual

Nisbet and Zekenski, 2011 [149]	Outdoors (in nature)	Objective	Walking indoors vs outdoors	Individual
Panno et al., 2017 [150]	Greenspace	Self-Reported	Greenspace visit frequency	Individual
Richardson et al., 2016 [151]	Nature	Self-Reported	Engagement with 100 days wild programme	Individual
Triguero-Mas et al., 2017 [130]	Natural outdoor environment	Urban Atlas, CORINE Land Cover and GIS	Duration of exposure to nature	Individual
Van den Berg et al., 2016 [48]	Greenspace (Public and private open spaces that contain 'green' and/or 'blue' natural elements such as street trees, forests, city parks and natural parks/reserves)	Self-Reported	Duration of visits to greenspace	Individual
Ward Thompson et al., 2014 [132]	Greenspace (parks, woodlands, scrub and other publicly accessible natural environments)	Self-Reported	Frequency of greenspace visits	Individual
White et al., 2017 [152]	Greenspace	Self-Reported	Having visited a greenspace yesterday	Individual
Greenspace Accessibility				
Bjork et al., 2008 [46]	5 qualities: Serene, Wild, Lush, Spacious, Culture	CORINE Land Cover and GIS	Presence of each type	100 and 300m Euclidean buffer of home
Bos et al., 2016 [126]	Greenspace (urban green including vegetable gardens, sports areas >0.5ha, parks >1ha; and rural green including agricultural and natural green)	Dutch Land Use Database and GIS	Proportion of area that is greenspace	1km and 3km Euclidean buffers of post code centroid
Dadvand et al., 2016 [153]	Green land cover	NDVI	Proportion of area that is greenspace Presence of 5000m^2 greenspace within 200m	100m, 250m and 500m Euclidean buffer of home
	Greenspace	Self-Reported	Proximity to greenspace	10 minute walk from home
Dzhambov et al., 2018 [127]	Greenspace (park, allotment, or recreational grounds)	OpenStreetMap and GIS	Proximity to greenspace	Euclidean distance from home

Krekel et al., 2015 [154]	Urban green areas (greens, forests, and waters), and abandoned urban areas	European Urban Atlas	Proximity to greenspace	Euclidean distance from home
Maas et al., 2009 [93]	Greenspace (urban green, agricultural green, forests and nature areas)	National Land Use Classification Database and GIS	Proportion of area that is greenspace	1km and 3km Euclidean buffer of home
Sugiyama et al., 2008 [137]	Neighbourhood Greenness	Self-Reported	Access to park or nature reserve	Neighbourhood
Triguero-Mas et al., 2015 [129]	Green land cover	NDVI	Amount of greenspace	100m, 300m, 500m, 1km Euclidean buffer of home
Subjective Connection to Nature				
Cervinka et al., 2012 [155]	Nature	Self-Reported	Connectedness to nature	Individual
Howell et al., 2011 [156]	Nature	Self-Reported	Connectedness to nature	Individual
Howell et al., 2013 [157]	Nature	Self-Reported	Connectedness to nature Nature relatedness	Individual
Kamitsis and Francis, 2013 [145]	Nature	Self-Reported	Connectedness to nature	Individual
Nisbet et al., 2011 [158]	Nature	Self-Reported	Nature relatedness Ecological consciousness	Individual
Zelenski et al., 2014 [159]	Nature	Self-Reported	Nature relatedness Inclusion of nature in self	Individual
Zhang et al., 2014 [160]	Nature	Self-Reported	Connectedness to nature Engagement with natural beauty	Individual

Table 3.5 Greenspace measures employed in included studies

3.3.1 Mental wellbeing measures

Only 14 studies were found to measure both hedonic and eudaimonic mental wellbeing, of which the most commonly used measure was the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS) [28, 38, 132, 133, 141, 146]. WEMWBS includes 14 positively worded questions, regarding individual feelings over the past 2 weeks, including 'feeling relaxed', 'interested in new things', and 'close to others' [59]; there is also a reduced 7-item version, known as SWEMWBS (Shortened-WEMWBS) [61]. The recent Personal Wellbeing ONS4 (Office for National Statistics 4), applied in one study [152], measures individuals' life satisfaction, happiness and anxiety (hedonic wellbeing) and sense of worth (eudaimonic wellbeing) [36].

The remaining 32 studies assessed outcomes considered to be aspects of mental wellbeing, such as quality of life, life satisfaction, and affect, but did not report both hedonic and eudaimonic wellbeing. The WHO-5 (World Health Organisation) Well-Being Index, used in 2 studies [128, 150], asks how frequently individuals have felt 'cheerful and in good spirits' and 'calm and relaxed', over the previous 2 weeks, but focusses on hedonic rather than eudaimonic wellbeing [161].

Quality of life was measured in 6 studies, two using the WHOQOL-BREF [145, 155], a 26-item questionnaire covering physical and psychological health, social relationships and personal environment [162]. The SF-36 instrument measures quality of life with 36 physical, emotional and psychological health questions [163], and was used in 4 studies [87, 124, 125, 155]. A brief 12-item version (SF-12) has three subscales: mental health, vitality [46], and emotional-role functioning. The mental component summary (MCS), derived from a subset of emotional problems, wellbeing and social functioning questions, was used in 6 papers [48, 123, 130, 137, 154, 155], asking how often the individual recently felt 'full of energy', 'nervous' and 'happy' [163].

Single-item Life Satisfaction was used in 6 studies [16, 60, 114, 123, 124, 131]. The Satisfaction With Life Scale (SWLS) was applied to 4 studies [155, 158-160], and includes a more thorough 5 life-evaluation questions, which ask how ideal and satisfying the individual's life is, and if they have 'gotten the important things… in life' [164].

Happiness was measured with one question in 4 studies [136, 147, 149, 151]. The Attentional Functioning Index (AFI), which assesses daily functioning, was used in one study [142, 165].

Eight studies reported affect scores [142, 143, 146-149, 158, 159], which include positive feelings (happiness, interest), and negative emotions (anger, sadness), using the 20-item Positive and Negative Affect Scale (PANAS) [166]. Similarly, The Profile of Mood States (POMS) asks about experiences of 65 different emotions, including some positive items, such as 'lively' and 'relaxed' [167], and was used in one study [47]. The General Health Questionnaire (GHQ) was used in 14 studies [16, 22, 28, 45, 93, 113, 114, 121, 127, 129, 134, 138, 140, 153]. It contains some positively worded items ('In the last 2 weeks I have… been able to concentrate', 'felt I have been playing a useful part' and 'feeling reasonably happy') but was designed and validated as a screening tool for psychiatric disorders, with higher scores indicative of greater distress [168]. Other studies which measured only poor mental health were excluded from this review.

Full details of the included studies are presented in Table 3.4, which is ordered by greenspace characteristic. Where articles cover multiple characteristics, the study appears under different headings.

3.3.2 Greenspace characteristics

3.3.2.1 Amount of local area greenspace

21 studies examined associations between quantities of local area greenspace and mental wellbeing, 2 of which were longitudinal. Most calculated the proportion of greenspace for each Lower-Layer Super Output Area (LSOA, a geographic area generated for being as consistent in population size as possible, with a minimum population of 1000 and the mean of 1500), Census District (CD, an Australian spatial unit similar to LSOAs, designed to be homogeneous, each containing about 225 dwellings), or within a defined radius of residents. Two articles measured greenspace area per capita. Of 15 studies, one was restricted to public greenspace [122], and 14 included only urban areas.

Only four (cross-sectional) studies measured hedonic and eudaimonic mental wellbeing (Shortened Warwick-Edinburgh Mental Well-Being Scale and ONS4). No statistically significant association was reported between greenspace and mental wellbeing in three studies [38, 132, 152], although urban residents who reported 'sufficient local greenspace' showed significantly higher SWEMWBS scores [132]. However, Wood et al.'s study found that a 1ha increase in park area within a 1.6km walk of an individual's home showed a 0.070-point increases in SWEMWBS score [133]; this suggests that examining greenspace around individuals, rather than aggregating to local area, may better detect associations.

Five studies, 4 of which were Good quality and based in urban areas, found that life satisfaction was significantly higher in areas with more greenspace [16, 122, 124, 131], albeit with small linear effect sizes of 0.002-0.003 [16, 122]. The study by White et al. included a large sample, over 10,000 individuals, demonstrating a slight but significant association between LSOA greenspace proportions and life satisfaction. Another large study by the same authors found no significant association between mental wellbeing and the amount of rural local area greenspace [114], suggesting that associations may differ between urban and rural environments.

An ecological analysis of over 172 countries measured the amount of green land cover per km^2, adjusted for the nation's size, finding a significant association with better life satisfaction. Despite the large sample size and strong odds ratios (2.450), the study was of poor methodological quality, due to its ecological design and hence inability to adjust for individual-level confounding factors [131]. Four studies also found the quantity of urban greenspace was associated with quality of life or mental health, characterised by the SF-36 scale and its sub-components [124-126, 154]; however, three others, which included only public urban greenspace, found no association [87, 122, 130]. Taylor et al. observed mixed results: the amount of urban greenspace was positively and significantly associated with hedonic wellbeing for two cities in Australia, but not two others in New Zealand [128].

Based on these Good quality studies, it is concluded that there is adequate evidence for an association between local area urban greenspace and life satisfaction, but not rural greenspace. Mixed results provide inadequate evidence for associations with quality of life, mental health, and multidimensional mental wellbeing.

GHQ (General Health Questionnaire) was the outcome in 8 studies, of which 6 were Good quality and 3 were confined to urban areas. All but one [127] found an inverse association between the amount of greenspace and GHQ score [16, 22, 45, 93, 113, 114, 129, 130], implying reduced mental distress; again, linear regression coefficients varied considerably, from 0.003 to 0.431. The Fair quality study by Dzhambov et al., however, found no statistically significant association for objective greenspace quantities, but observed significantly lower GHQ scores for those with higher perceived greenness in their neighbourhood [127]. In a longitudinal study, Alcock et al. found that people moving to areas with higher greenspace proportions had significantly lower GHQ score after relocating, averaging 0.430 points lower 3 years post-move [113]. Therefore, there was adequate evidence for the inverse association between the amount of local area greenspace and (lower) GHQ score.

3.3.2.2 Greenspace types

A total of 8 Good and 2 Fair quality studies classified greenspace according to greenspace types, using bespoke classification systems; no consensus was observed regarding greenspace typology. Four of these were longitudinal studies.

Only one Fair study measured hedonic and eudaimonic wellbeing, with the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS), comparing linear associations between the amount of sport, recreational and 'natural' spaces within a 1.6km buffer of the individual [133]. The strongest associations were observed for sports (0.430 increase in WEMWBS for each additional space), followed by recreational and natural spaces (0.110 each).

One research group conducted four studies (3 longitudinal) using the longitudinal Swedish Health Survey (SHS), based in suburban and rural areas. They classified public greenspace within 300m of each residents' home into 5 aspects: Serene (quiet, audible 'nature'), Wild (undeveloped, no visible human impact), Lush (biodiversity), Spacious (large cohesive area) and Cultural (cultural heritage, old trees) [46, 134, 138]. Two studies measured GHQ: the first found associations between Serene or Spacious greenspace and slightly, but significantly, lower GHQ scores for physically active individuals; however, associations with Spacious greenspace held only for women [134]. In the second, only women moving to areas with Serene greenspace had significantly lowered GHQ scores, but with much higher odds than in Annerstedt et al.'s work [138]. In a cross-sectional analysis, these authors found that the total number of green aspects (Serene, Wild, Lush, Spacious, Cultural) was associated with slightly better SF-36 Vitality scores for women [46]. The third longitudinal study found marginally but significantly lower GHQ scores for greater numbers of different green aspects, including those moving between areas [140].

In a cross-sectional study, based on 12,697 observations from 2,020 residents of rural England, no association was found between LSOA land cover classes and General Health Questionnaire scores. However, individuals who relocated to areas with more arable, grass, 'natural', mountainous and heath land had significantly lower GHQ scores post-move [121].

Among 3 cross-sectional studies, urban residents with higher amounts of local vegetative or 'natural' greenspaces reported better mental wellbeing: vegetation density and cover, from field surveys and satellite imagery in Australia, were strongly and significantly associated with life satisfaction [135]. The number of trees, or an indicator of how 'green' the neighbourhood is, were significantly associated with better mental health (SF-36 Mental Component) and life satisfaction [137, 139]. Residents' ratings of the 'quality of their local natural environment', on a scale of 0-10 (very dissatisfied to very satisfied), was associated with higher SF-36 Mental Component Summary scores [139].

A large cross-sectional study in the UK used app data on users' self-reported feelings, while their phones' GPS linked their location to a land-cover database; this novel study therefore benefits from measuring happiness in situ. Being in mountainous, woodland or 'semi-natural grassland' areas, as opposed to urban, was associated with approximately 2-points higher happiness, on a scale of 0-10, although no additional factors were controlled for [136].

While most of these studies were Good quality, interpretation is difficult due to lack of consensus in greenspace classification; in addition, four reports were based on data from the same survey. All but one were restricted to either urban or rural areas, so comparisons between these environments is not possible; however, larger effect sizes were observed in rural studies. Two of the Swedish studies concluded that green aspects were associated with lower GHQ scores for women, while 6 others highlighted that Serene (quiet, 'natural') and 'natural' rural greenspaces were associated with improved life satisfaction, SF-36 and lower GHQ scores, although none defined the term 'natural'. Additionally, two studies reported an association between subjective perceptions of local greenspace and mental wellbeing. Evidence is therefore limited.

3.3.2.3 Visits to greenspace

Seventeen papers reported studies of visits, either comparing mental wellbeing scores before and after an intervention (*n* = 7), or testing cross-sectional associations with greenspace visiting patterns (*n* = 10).

Fair quality studies compared happiness and positive affect for those walking in 'natural' versus indoor environments [149], and walks in urban versus green areas [146]. The former reported a statistically significant difference in favour of greenspace walking, the latter did not. In a further Fair quality cross-sectional study, Marselle et al. reported a positive association between perceived restorativeness of the walking environment and positive affect and happiness [147].

Duvall and Kaplan observed 73 individuals on a wilderness expedition; attention and affect were improved post-expedition, persisting for 3-4 weeks [142]. Although effects were quite large (score changes of 0.270 to 0.340), participants were not blind to the intervention. A Fair quality uncontrolled study encouraged individuals to engage with 'nature' for 30 days by noticing/protecting wildlife, sharing experiences, or connecting with 'nature'. Participants reported greater happiness following the programme [151]. Similarly, Molsher and Townsend noted mental wellbeing improvements following engagement with environmental volunteering projects [148], although their study displayed high risk of bias. Jakubec, however, reported no association between visiting greenspaces and Quality of Life Inventory score, in a Poor quality study [144].

A further 10 cross-sectional studies of varying quality examined self-reported greenspace visit frequency. Three studies measured both hedonic and eudaimonic wellbeing, with mixed findings [141, 143, 152]. In the first Fair study, university students who claimed greater typical contact with nature reported better mental wellbeing using Ryff's Scale of Psychological Wellbeing [143, 169]. These findings were not replicated in a Good study by Glichrist et al., who examined associations between mental wellbeing (Shortened Warwick-Edinburgh Mental Well-Being Scale) and greenspaces surrounding workplaces in Scotland [141]. White et al.'s Good study, measuring Office for National Statistics 4, found that those spending time outdoors and in nature every day, compared to never, had strong odds (OR 1.960) of a high sense of worth, the effect size decreasing with visit frequency. No associations were detected for visit frequency and hedonic wellbeing, although those reporting visiting greenspace the previous day had higher happiness scores, with no associations for life satisfaction, anxiety or worth [152].

A further 5 studies, one of which was Poor, showed that quality of life and mental health were improved, and distress (General Health Questionnaire) scores reduced, with the number of greenspace visits [28, 48, 130, 132, 145]; Triguero-Mas et al. also noted that associations with mental health were stronger for males than females [130]. In a Good study, Mitchell found that those who more regularly visited a local park had lower GHQ scores [28]. However, although Panno et al. observed that greater frequency of greenspace visits was associated with higher hedonic wellbeing, these results were not statistically significant [150], and Dzhambov et al. found no association between time spent in greenspace and GHQ [127].

Due to the mixed quality and inconsistent results, evidence for an association between greenspace visit frequency and mental wellbeing is considered limited.

3.3.2.4 Views of greenspace

Association between views of greenspace and mental wellbeing was reported in 3 papers. Gilchrist et al.'s Good quality study found that workers' satisfaction with their office views, particularly of trees, lawns and flowering plants, was associated with improved mental wellbeing (SWEMWBS) scores [141]. Similarly, urban residents reporting greater visibility of trees from their home had slightly better life satisfaction [139]. Pretty et al. observed increases in self-esteem for those viewing rural pleasant scenes, while both unpleasant urban and rural scenes could be detrimental; however, they did not control for potentially confounding factors [47]. The mixed quality and small study sample leads the evidence here to be classified as inadequate.

3.3.2.5 Greenspace accessibility

There were 8 cross-sectional studies identified, mostly Good quality, which tested associations between greenspace accessibility and mental wellbeing. Two studies measured mental health using the SF-12 Mental Component, with significant positive findings [137, 154]. In the first, a weak association was found with Euclidean (direct) distance from homes to the nearest public greenspace [154]. In the second, Sugiyama et al. used the Neighbourhood Environment Walkability Scale, which measures self-reported greenspace access. Access to the highest of levels of greenspace (perceived neighbourhood greenness, terciles) was associated with strong odds (OR 1.270) of better mental health [137].

Only one, Fair study compared public greenspace within different Euclidean buffers around individuals' post codes [129]. Triguero-Mas et al. found greater amounts of greenspace within 300m were significantly associated with reduced risk of high GHQ scores (dichotomised around 3), with consistent results for control buffers of 100m, 500m, and 1km [129]. Bos et al. found that greenspace within 3km, but not 1km, of homes was significantly associated with greater quality of life [126], although this study was rated as Poor study because of limited statistical reporting. In a larger study, scores on the SF-36 Vitality scale were associated with rural greenspace, but this was only significant for women and within 300m (but not 100m), of their home [46]. Maas et al.'s large cross-sectional study showed that those with more greenspace within 1km, but not 3km, had slightly lower GHQ scores, contrary to findings by Bos et al. [93, 126]. Dadvand et al. also used the General Health Questionnaire (dichotomised around 3), finding strong odds of low GHQ scores for the amount of greenspace within 100m of homes (OR 1.320), effect sizes reducing with distance (OR 1.250 for 250m, 1.170 for 500m); stronger associations were also noted for subjective, than objective, proximity to greenspace, measured as self-report and calculated presence of a greenspace within a 10-minute walk [153]. Dzhambov et al. also found a significant association between subjective accessibility (time to walk to nearest greenspace) and lower GHQ, although associations for objectively measured Euclidean distance were not statistically significant [127].

Although several of these studies reported an association between greenspace accessibility and aspects of mental wellbeing, different measures of both were used and findings were inconsistent, providing limited evidence of an association.

3.3.2.6 Subjective connectedness to nature

Seven cross-sectional studies were identified examining associations between subjective connection to nature and mental wellbeing. The Connectedness to Nature Scale measures the extent to which individuals 'feel nature is part of their identity', with particular emphasis on sense of care for nature; this has been linked to the theory of biophilia: that humans possess an innate desire to affiliate with other forms of life [21, 149]. Of these studies, 5 were of Poor quality, with no controls for potential confounding. Four studies demonstrated that self-reported ‘connection to nature’ was positively associated with mental wellbeing [156-159]. Effect sizes were moderate and consistent across the studies, although lower methodological quality means their results have limited generalisability; only one was of Good quality, and adjusted for potentially confounding factors. Similarly, meaning in life, quality of life, happiness and affect were higher for those who reported greater connection to nature [145, 155, 156, 159]. Life satisfaction was also positively related to nature connectedness in two studies [159, 160], with moderate effect sizes, although Zhang et al. revealed that the association only held for those who actively engaged with nature [160]. While consistent in their findings, poor study quality means that the evidence is inadequate.

3.4 Discussion

3.4.1 Summary of findings

While both the World Health Organisation and United Nations agree that greenspace is vital for healthy, liveable environments [10, 170], it remains unclear which amounts, types and uses of greenspace are most beneficial to mental wellbeing. Previous reviews have focussed on associations between greenspace (or nature) and general health or mental distress [10, 19, 24, 101], but no previous systematic reviews have been found of published evidence specifically for associations between greenspace and validated, positive measures of mental wellbeing in adults. Even after stratifying this review according to the six main ways in which greenspace was conceptualised and measured, methodological heterogeneity precluded meta-analysis. A narrative synthesis was therefore undertaken.

The largest number of studies were concerned with the amount of local area greenspace, although few used detailed hedonic and eudaimonic wellbeing measures. Consistent results revealed adequate evidence for an association between urban local area greenspace and life satisfaction. This result did not hold for rural greenspace, however. There was also adequate evidence for an association between local area greenspace and lower General Health Questionnaire (GHQ) scores.

Inconsistencies in the categorisation of greenspace types, and dearth of definitions, made it difficult to synthesise results; limited evidence was therefore found for associations between mental wellbeing and variety and ‘nature’ in land cover. Evidence was similarly limited for greenspace accessibility, with results generally concluding that nearer greenspace has the strongest associations, but with results differing according to the mental wellbeing measure;

limited evidence was also found for associations between greenspace visits and mental wellbeing.

However, while there was some evidence for an association between mental wellbeing and views of greenery and connectedness to nature, this was considered inadequate, due to the mixed quality and small sample sizes of studies. Table 3.6 provides full details of the evidence summary and implications for research and policy.

3.4.2 Mental wellbeing measures

Only 14 of the 52 studies used a measure of mental wellbeing that captured both hedonic and eudaimonic dimensions, while others measured aspects such as life satisfaction, happiness and quality of life. GHQ, which was designed as a psychiatric screening tool, was included as a prevalent surrogate in the literature, which includes some positive items. Papers using other psychiatric screening tools were excluded if they covered only symptoms, ie mental distress.

3.4.3 Greenspace definitions and indicators

Greenspace was found to be assessed in six different ways: amount of local area greenspace, greenspace types, visits to greenspace, views of greenspace, greenspace accessibility and self-reported connection to nature.

The amount of local area greenspace was most commonly measured as the proportion of greenspace in a resident's local area, or more specifically within a set radius of participants' homes. Most of these studies were restricted to urban areas. Most researchers quantified greenspace objectively, while a small number of studies reported associations with perceptions of the adequacy of the amount of local greenspace provision. All studies used either linear or logistic regression, which may overestimate associations in spatial data. Although a number of studies examined different types of greenspace, no consensus was observed for a typology, and as such conflicting results were observed.

One of the UN's Sustainable Development Goals is to 'provide universal access to…green and public spaces' [170]; most studies assessed accessibility by distance to greenspace. While the EU and UK recommend that individuals should have access to a greenspace within 300m of their home [42, 50], only one study conducted sensitivity analysis to test this guideline [129];

no difference in associations was observed for buffers of 100m, 300m, 500m and 1km. One study used buffer radii of 100m and 300m, reporting a significant association between the latter and mental wellbeing, while a second found that associations with GHQ decreased with distance, at 100m, 250m and 500m buffers. Others found contradictory results using radii of 1 and 3km. Another drawback was the use of Euclidean distance, which doesn't account for access routes. Application of network distance and consideration of pedestrian routes may give a greater indication of accessibility on foot.

Greenspace visiting patterns were measured inconsistently, in small or cross-sectional studies. Individuals who visited greenspace more often reported greater mental wellbeing, though a second study found this held only for eudaimonic wellbeing; no associations were found in an analysis of greenspace adjacent to workplaces. This study did however report a positive association with views of greenspace from the workplace. This is in keeping with previous research showing that green views reduce the effects of stress [19, 25, 26, 77]. While two studies highlighted that the perceptions of greenspace quality were more strongly associated with mental wellbeing than quantity [132, 139], the size of this difference was not estimated.

Individual connection to nature, assessed in seven studies, relied on self-report for both the greenspace and wellbeing measures, thereby carrying a high risk of reporting bias, especially since few controlled for potentially confounding factors.

Greenspace Characteristic	*Summary of Evidence*	*Strength of Evidence*	*Implications*
Amount of local area greenspace	Positive association between urban greenspace and life satisfaction	Adequate	Research: Studies are required to measure both hedonic and eudaimonic wellbeing Associations may differ between urban and rural environments National studies should stratify for urban/rural setting Local area statistics may be less effective at detecting associations than measures which consider greenspace relative to the individual. Greenspace within set distances of individuals should be further investigated. Methods should consider the potential spatial nature of the data More longitudinal analyses are required to establish causality Greenspace measures should consider where people spend their time (ie while commuting, at work), not just relative to homes Policy: Increasing provision of local area greenspace in urban environments is recommended for potential benefits to life satisfaction
	Inverse association between urban greenspace with GHQ	Adequate	Research: Studies are required to measure positive mental wellbeing (both hedonic and eudaimonic dimensions) Policy: Increasing provision of urban local area greenspace is recommended for potentially reducing symptoms of psychiatric distress
Greenspace types	Some association between 'nature'/variety in land cover and aspects of mental wellbeing	Limited	Research: Studies are required to measure both hedonic and eudaimonic wellbeing More consistency is needed in establishing a greenspace typology Specific features of greenspace should be investigated More consistency is needed in defining terms, particularly 'nature', which is often undefined Measures of greenspace quality should also be included Policy: Variety and nature in greenspace types may be important, but currently more evidence is required to recommend this for mental wellbeing benefit

Visits to greenspace	Frequency of visits to greenspace may be associated with aspects of mental wellbeing	Limited	Research: Studies are required to measure both hedonic and eudaimonic wellbeing More objective assessments of greenspace visiting patterns are required Social context and individual experiences of greenspace patterns should be considered Participants must be blind to interventions to ensure a fair sample More controlled case studies, and longitudinal analyses may help in understanding the direction of associations Policy: Promoting visits to greenspace may improve aspects of mental wellbeing, though more evidence is required
Views of greenspace	Views of greenspace/green features may be associated with some aspects of mental wellbeing	Inadequate	Research: Studies are required to measure both hedonic and eudaimonic wellbeing Much more research should examine associations between views of greenspace and mental wellbeing With potential differences between views from homes and workplaces, greenspace measures should consider where people spend their time
Subjective connection to nature	Personal connection to nature may be associated with mental wellbeing	Inadequate	Research: Studies must control for potentially confounding factors More objective assessments of connection to nature and mental wellbeing are required More consistency is needed in defining terms, particularly 'nature', which is often undefined

Table 3.6 Summary of findings and implication

3.4.4 Strengths and limitations

This review comprised comprehensive database search, thorough screening of articles, risk of bias assessment, and detailed narrative synthesis of the 52 studies which met the inclusion criteria. Six different ways in which greenspace was conceptualised and measured were identified, and by which the review was stratified. It is believed this is the first review to systematically appraise the evidence for associations between greenspace and adult mental wellbeing, using only validated measures of positive mental health.

Selection criteria were designed to ensure results of sufficient quality and relevance, and an information specialist was consulted to maximise search efficiency. Screening was undertaken by two independent reviewers, to minimise potential bias. While these criteria were designed to be inclusive, an element of subjectivity means there was a possible risk of excluding potentially interesting studies; attempts were made to minimise this by appraising each study with assessments recommended by the Cochrane Handbook, which provides guidance for internationally recognised highest-standard research [115, 117-120].

All greenspaces were considered, not restricting the criteria to studies specifically in urban areas, although some studies were confined to urban or rural locations. Nationwide studies were likely to have included both, without stratifying for setting. It was difficult, therefore, to draw clear conclusions about interactions between urban and rural location and associations with mental wellbeing. Although there is interest in understanding how urban greenspaces should best be designed and constructed, it was not possible to draw conclusions specifically for those living in cities.

Only one-quarter of included studies measured both hedonic and eudaimonic mental wellbeing; the majority focused only on aspects such as life satisfaction, affect and vitality, while others used measures (such as the General Health Questionnaire) which combined positive and negative (distress) items.

While several studies implied that 'nature' was associated with aspects of mental wellbeing, none provided a definition of this term. To further complicate matters 'nature' and 'greenspace' were sometimes used synonymously [28, 45, 46, 48, 152]. Vegetative or 'natural' greenspaces, such as those described as 'serene' (quiet, 'natural'), or with more trees, were most strongly associated with aspects of mental wellbeing, although one study found a stronger association for sports facilities. However, there were few direct comparisons between greenspace types. While Government Guidance provides a standardised greenspace typology for urban planning in the UK [51], no studies used this classification.

Studies that considered greenspace accessibility were limited to estimates of Euclidean distances from home rather than access routes [88]. These studies did not take account of participants' routines, or where they spent their time. None of the included studies assessed greenspace quality (such as captured by the Green Flag Award [171]), or the social contexts in which greenspaces are situated [24, 108].

Only 6 of the 52 papers reported longitudinal studies. Cross-sectional analyses cannot distinguish between reverse causality and associations which may be causal in nature, and, like all observational studies, are prone to confounding (especially by indication) and bias. Although 27 studies were deemed to be of Good quality, 13 were Fair, and the remaining 12 were Poor; this was mostly due to lack of control for potentially confounding, minimal statistical reporting, and, in 3 cases, lack of participant blinding to an intervention.

3.5 Conclusions

This study sought to synthesise and appraise the evidence for associations between greenspace and mental wellbeing, but found few studies measuring both hedonic and eudaimonic wellbeing. Results suggest associations between greenspace and mental wellbeing, particularly hedonic wellbeing. Adequate evidence was discovered for associations between urban greenspace and life satisfaction; however, the evidence for the remainder of the greenspace characteristics, including greenspace (land use) type, accessibility, viewing and visiting patterns, was limited or inadequate. Although not a true measure of mental wellbeing, studies using the General Health Questionnaire were prevalent in the literature. This measure includes some positive items, and it is further concluded that there was adequate evidence for associations between greenspace and lower GHQ scores. While this review was limited by the lack of available data to conduct a meta-analysis, it was possible to highlight key areas for future research through the narrative synthesis.

Government guidelines for greenspace provision require robust evidence, but evidence is currently not sufficient for informed, specific planning recommendations. Further methodological work in this field is needed, including the development of operational definitions of 'nature' and 'natural', and agreement on a land use typology. Measures of greenspace quality are also needed. More studies are required to measure both hedonic and eudaimonic mental wellbeing. Greenspace accessibility should also be measured more specifically, using individual travel distances, using spatial methods of analysis, to better understand how greenspaces should be designed and incorporated into environments. Further research is needed that considers differences in associations between greenspace and mental wellbeing in urban versus rural settings.

4.0 Local area greenspace and mental wellbeing in England

"Landscape without nature is like a city without people"

- Andrew Grant

4.1 Introduction

Evidence suggests that exposure to nature is associated with positive emotions such as relaxation, satisfaction and general happiness [2, 16, 22, 77, 172-177]; in urban environments, this is provided through greenspace. While these may be important aspects of mental wellbeing, there is currently inadequate evidence for the relationship with a multidimensional view of wellbeing, covering both hedonic and eudaimonic domains, which remains relatively unexplored [16, 27-30].

Characterisation of greenspace in the literature varies widely, although the most commonly used measure is the amount available within a locality. In the UK, local areas can be defined in different ways, according to the data and subject under consideration. Lower Layer Super Output Areas (LSOAs) are a data collection unit commonly used for analysing neighbourhood variables, as they are designed to be homogeneous in terms of population and demographic. In particular, this measure has been used often in research to examine the association between local area proportion of greenspace and symptoms of psychiatric distress (GHQ score) [16, 29] and life satisfaction [16]. For example, a UK population study found that life satisfaction was significantly higher for those with more greenspace in the LSOA where they lived, while another showed that mental distress decreased for those moving to an LSOA with a higher prevalence of greenspace, an association which persisted for several years for following their relocation [29].

As a multidimensional view of mental wellbeing includes aspects of satisfaction and positive emotions, it follows that this may also be associated with local area greenspace. There is only one other known study which begins to investigate such a relationship. This was undertaken with a small selective sample in deprived areas of Scotland, and examined the association between greenspace proportions and mental wellbeing, of which the results were mixed and inconclusive [178]. It therefore remains to be seen whether an association can be detected in a national, representative sample.

While generally abundant in rural areas, greenspaces are designed into the urban landscape, typically at the expense of buildings. While access to greenspace can therefore vary widely across the population, it has also been suggested that mental health may differ between urban and rural areas, with studies contrasting in the direction of their conclusions [6, 179, 180]. Previous studies have tended to consider either urban greenspace or the wider benefits of contact with nature; very few studies have been found which stratify by urbanity. Urban-rural differences in health have been studied, but is not yet known whether the association between greenspace and mental wellbeing in particular differs in urban and rural areas [22, 23, 72, 77, 181]. Living in an urban area may reduce opportunities for people to interact with natural environments, which could contribute to these health inequalities, although it remains unclear whether or how this might affect the mental wellbeing of those who live in cities [19, 182].

With a growing urban population and increasing health divides, planners and policy makes are becoming more aware that places can influence individual health. There is therefore a need to identify whether nearby greenspace may be important for mental health and wellbeing.

This study was therefore designed to answer the second research question:

Research Question 2 - Is the quantity of greenspace in a local (census) area associated with multidimensional mental wellbeing?

The primary aim of this research was to test two hypotheses:

(1) that neighbourhood areas of England with greater proportions of local area greenspace are associated with higher levels of mental wellbeing; and
(2) that the association between the proportion of local area greenspace and mental wellbeing may be confounded and/or modified by urban versus rural location.

4.2 Methods

4.2.1 Sample and Setting

Data were drawn from the first wave of the UK Longitudinal Household Panel Study (UKHLS), known as *Understanding Society*, which ran from 2009-2010 [183]. The sample was then restricted only to residents of England, because of the availability of both land use and deprivation data. The UKHLS is a biennial survey of people aged 16 and over in a sample of private households across England, Scotland, Wales and Northern Ireland. Households were selected via random sampling of individual addresses within specific post code sectors, to optimise sampling efficiency [184]. These post codes, known as the Primary Sampling Units (PSUs), are also designed to be representative of the UK population, in both socio-economic and ethnic terms. In the data collection process, individual households are selected from each of these PSUs, so that results may be generalised to the wider UK society. As such, the individuals are not randomly distributed across England, but are spatially grouped within their PSU, where residents share similar industrial, physical and social environments [35].

The wave 1 sample contained 50,994 individuals, from 30,169 households. Each household is also given a local area identifier, by special licence access, which can be used to link UKHLS to the geographical greenspace data, which is also provided at LSOA level. These Lower-Layer Super Output Areas (LSOAs) are standardised UK Census units ideal for examining spatial data. England is divided up into 32,844 LSOAs, each of which contains 400-1200 residences and, within this data set, covers an average area of 4.2km^2 (sd 12.8km^2).

4.2.2 Study Variables

4.2.2.2 Mental wellbeing

Mental wellbeing was measured using the Short Warwick-Edinburgh Mental Well-Being Scale (SWEMWBS), which is comprised of 7 positively-worded questions relating to both hedonic and eudaimonic aspects of positive mental health [59, 183].

The Short Warwick-Edinburgh
Mental Well-being Scale
(SWEMWBS)

Below are some statements about feelings and thoughts.

Please tick the box that best describes your experience of each over the last 2 weeks

STATEMENTS	None of the time	Rarely	Some of the time	Often	All of the time
I've been feeling optimistic about the future	1	2	3	4	5
I've been feeling useful	1	2	3	4	5
I've been feeling relaxed	1	2	3	4	5
I've been dealing with problems well	1	2	3	4	5
I've been thinking clearly	1	2	3	4	5
I've been feeling close to other people	1	2	3	4	5
I've been able to make up my own mind about things	1	2	3	4	5

Figure 4.1 Full SWEMWBS questionnaire, from Tennant et al.[44]

A full 14 item scale was developed in 2007, as a short and psychometrically robust scale, to measures positive mental health at a population level [59]; it has been extensively tested to ensure internal construct validity and no ceiling effects. The shortened, 7 item version is designed for efficiency and robustness in large surveys, where question lengths may be an issue.

The questionnaire, issued through the *Understanding Society* survey, asked respondents to rate how they have been feeling 'over the last 2 weeks' on 7 domains: optimistic about the future, useful, relaxed, close to other people, dealing with problems well, thinking clearly, and able to make up one's mind. Using a 5-point Likert scale, options are 'none of the time' (score 1), 'rarely', 'some of the time', 'often' and 'all of the time' (score 5). This results in a final rating between 7 and 35, with a higher number indicating better mental wellbeing [59]; the full questionnaire is shown in Figure 4.1.

4.2.2.3 Individual and household-level confounders

Potential confounders of the association between greenspace and mental wellbeing were identified from the literature, as well as examination of the individual data available within *Understanding Society* [16, 28, 29, 140, 178, 185, 186]. These included ten-year age group, gender, marital status (single/unmarried, married/civil partnership, and separated/divorced/widowed), ethnicity (white British, white other, black, South Asian, other), and total number of serious on-going physical health conditions (continuous, including clinical diagnoses of, for example, epilepsy, heart disease, cancer). Socioeconomic status was assessed by means of employment status (unemployed, employed and economically inactive), household income (quintiles adjusted for household composition [187]), household space (bedrooms per person, categorised into <1, 1-3, > 3), living alone, living with children, and housing tenure (whether or not the resident owns their current home). Data on commuting time to work was also included, in line with previous work [16, 29, 122]. Local area deprivation, measured at the LSOA level, was controlled for using the 2010 English Index of Multiple Deprivation (IMD), which provides a score based on several domains, and provides a relative deprivation score for each locality in England. Every LSOA is ranked according to its deprivation, comparative to that of all other areas; these rankings of relative deprivation were used in this analysis. The Indices are based on 38 separate indicators, which are grouped to cover seven distinct aspects: income deprivation, employment deprivation, health deprivation and disability, barriers to housing and services, crime, and finally living environment deprivation [188]. These statistics are based on data from 2008, as well as some information from the earlier 2001 census. According to the UK Government documentation, in 2010, 98% of the most deprived LSOAs were in urban areas, although there were pockets of deprivation across rural areas, as well [188].

4.2.2.4 Greenspace

Greenspace data were obtained from the 2005 General Land Use Database (GLUD) [105], which provides land cover information for each LSOA in England, but not the rest of the UK, hence limiting the useable sample size from *Understanding Society*. Each LSOA is given a total land cover and then divided into 9 usage categories, derived from Ordnance Survey's MasterMap using visual inspection and information from the land registry; these groupings are domestic buildings, non-domestic buildings, domestic gardens, greenspace, water, path, road, rail, and 'other' [105]. For the purposes of this research, domestic gardens were not included as greenspace, as the category provided in the dataset included all domestic outdoor space, and so it could not be guaranteed that this was green. The relative amount of greenspace for each locality was calculated by dividing the area of greenspace by the total area for each LSOA, giving a proportion between 0 and 1, in line with other studies [16, 29].

4.2.2.5 Rural-urban classification

Also included within the *Understanding Society* data [183], the Rural-Urban Classification divides England's LSOAs into categories according to their level of urbanicity, based on population [189]. At the broadest level, urban centres are defined as settlements with a residential population greater than 10,000; as such, any local area is classified as urban if over 74% if its resident population lives in such an urban settlement. Within this dataset, the number of residents in urban areas, *n*, total 25,547 (82.7%); the remaining 17.3% are considered rural (*n* = 5,353). Further breakdown is available, classifying areas according to the sparsity, although direct differences in associations within urban and rural areas was the focus of this research, and so this widest classification was selected for broad comparison and to ensure adequate amounts of data within each group.

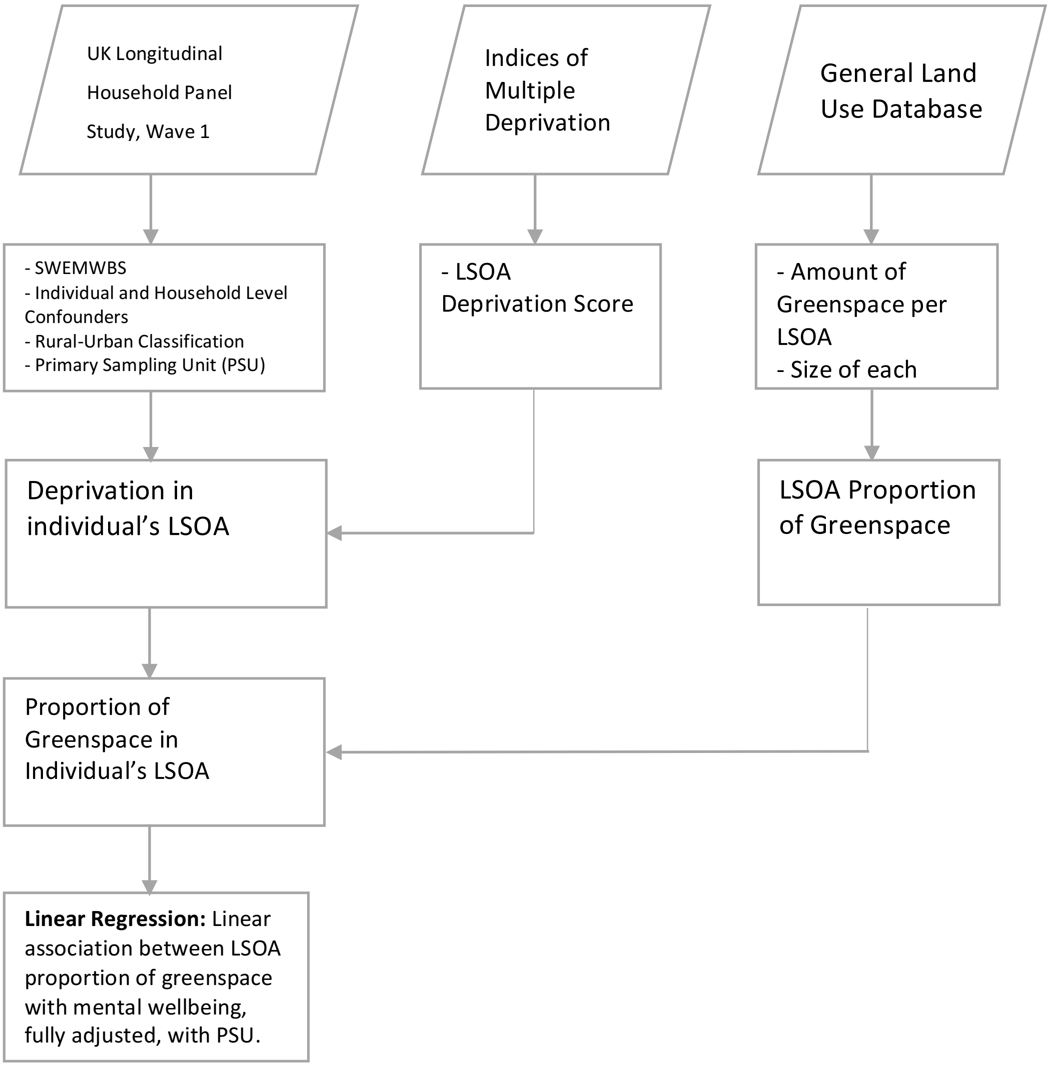


Figure 4.2 Data flow to final sample and analysis

4.2.3 Analysis

Analysis began by describing the distributions of mental wellbeing and greenspace, along with the characteristics of the study sample, both statistically and graphically. Using Geographical Information Systems (GIS), the proportion of greenspace in each LSOA was plotted on a map of England, in order to visually inspect the spatial distribution. The location of urban and rural LSOAs was also visualised, to represent the geographic positioning of the individuals in the sample, variation in size of localities across the study space, and between urban and rural environments.

To test for potential confounding, and to avoid collinearity, associations were estimated between each individual variable and the proportion of local area greenspace and mental wellbeing, in turn. Those that were associated with both variables to a statistically significant degree (at the 95% level) hence met the selection criteria and were therefore considered to be potentially confounding factors. Included in the final dataset were: sex, age group, marital status, ethnicity, health conditions, employment, household adjusted income quintile, household space, living alone, living with children, housing tenure and commuting time to work; the Index of Multiple Deprivation (IMD) score was also found to be appropriate to include at the LSOA level.

As exploratory analyses revealed the distribution of SWEMWBS to be moderately skewed (skewness -0.45), the variance of this output was investigated, in order to determine the most appropriate modelling technique. Linear regression modelling was revealed to be the most suitable, and thus was used to estimate the association between mental wellbeing (SWEMWBS score) and the proportion of greenspace in each LSOA. As an established methodology for predicting a dependent variable based on a mixture of continuous (greenspace, health conditions, IMD Score) and categorical (all other individual- level factors) data, it is ideal for examining the effect of each independent item and the significance of the input, as well as predictive strength.

Survey commands in the R 'Survey' package were also added to control for the clustered sampling of participants within the primary sampling units (PSUs). The Survey command itself receives the list of individual PSUs, provided with the *Understanding Society* data, which are then adjusted for within the linear regression model. Linear regression models assume spatial independence, and so adjusting for this geographical clustering allowed for the generation of robust estimates of variance in the association between individual exposure to greenspace and mental wellbeing, by taking account of spatial autocorrelation (and therefore higher-level variances) in the dataset. Spatial autocorrelation exists where individual data points (in this case, individuals) are more similar to each other than would statistically be expected by chance, and is common in survey datasets where individuals are sampled within households, within local areas.

The fixed-effects linear regression model can be expressed as shown in Equation (4.1).

$$SWEMWBS_i = \alpha + \beta_1 Greenspace_i + \cdots + \beta_n I_{ni} + e_i \qquad (4.1)$$

Where *SWEMWBS*$_i$ is the measure of an individual *i*'s SWEMWBS score, α is the calculated constant, which standardises the result, β is the greenspace coefficient, which describes the contribution of the variable, *Greenspace*$_i$ is the proportion of greenspace in individual *i*'s LSOA. The potentially confounding factors, included in the multivariate models, are described by coefficients β_n and values I_{ni} for variable *n* and individual *i*, with e_i being the error term for individual *i*.

In the unadjusted model, the SWEMWBS score is the dependent variable, the regression coefficient (*B*) for greenspace represents an estimate of the amount by which the wellbeing score increases for a standard deviation increase in greenspace. This relative increase was selected in order to make realistic comparisons between the prevalence of greenspace in different localities, and consider the coefficient as a feasible amount of change.

To adjust for potential confounders, multivariate models were then built, which included all potentially confounding factors (age group, sex, marital status, ethnicity, number of health conditions, employment, household adjusted income, household space, living alone, living with children, housing tenure, commuting time, and local area deprivation).

This adjusted regression model was then run using a binary urban/rural location indicator as an additional variable, to observe how location affected the outcome. To further investigate associations separately in urban and rural environments, the data was then stratified, and univariate models run for each. Results for these models could therefore be directly compared, and differences considered.

As a sensitivity analysis, the multivariate regression models were also calculated using quasi-poisson regression, to account for the skewed distribution of the SWEMWBS variable. This modelling technique assumes that the variance of the outcome variable is dependent upon the SWEMWBS score, based on the predictors (specifically that the variance is a linear function of the mean), rather than the variance being assumed constant in the linear regression models. This model therefore is suited to more skewed distributions and over dispersed data [190]. However, application of this technique did not significantly change the model findings, and so it was determined that linear regression was an appropriate model, while also being a simpler and more intuitive method of presenting such associations, which is most prevalent in the literature.

All analyses were completed with R 3.1.2 [191] using the Survey package [192], with some further statistical investigations implemented using Stata [193].

4.3 Results

In total, 50,994 individuals were included in wave 1 of the UK Longitudinal Household Panel Study, from 30,169 different households, which equates to a 57.6% participation response from the initially selected households, followed by an 81.8% individual-level response rate to the questionnaires issued to these agreeing households [194]. Little direct information was available regarding the characteristics of non-responding individuals, although they may be compared in terms of local area socioeconomic statistics. The data collectors (*Understanding Society*) observed slightly lower response rates in areas with higher proportions of single-person households (59.0% response in 1st quartile of single-person households, compared to 55.5% in the highest quartile) and people in full-time employment (59.7% response in 1st quartile, 56.6% in 4th). Similarly, at the individual level, response rates were somewhat higher in areas of lower deprivation, in terms of Council Tax band (86.2% response in the lowest band A, 79.5% response in the highest bands E-H), suggesting a modest association between socio-economic status and survey participation [194].

Of the responding individuals, 42,972 were residents of England. After removing those who had missing SWEMWBS (mental wellbeing) scores, the final sample contained 30,900 individuals, from 19,684 different households, which is 61.0% of the original sample from the UKHLS. This sample covers 11,096 LSOAs across England, which vary considerably in size between urban (mean 0.9km^2, sd 2.3km^2) and rural areas (mean 19.6km^2, sd 25.1km^2). Of those not completing the mental wellbeing questions, the mean local area greenspace proportion was 0.36 (sd 0.28), which was slightly lower than the final sample (mean 0.42, sd 0.30) (Significance of t-test, $p < 0.001$).

From a socioeconomic perspective, local area deprivation was significantly greater among SWEMWBS non-completers (mean score 27.1, sd 17.2 versus, 22.2, sd 15.6) (p <0.001), although average equivalised income was consistent (£5,515/month, sd £5,438 for responders versus £5,511/month, sd £5,970 for non-responders) (p = 0.831).

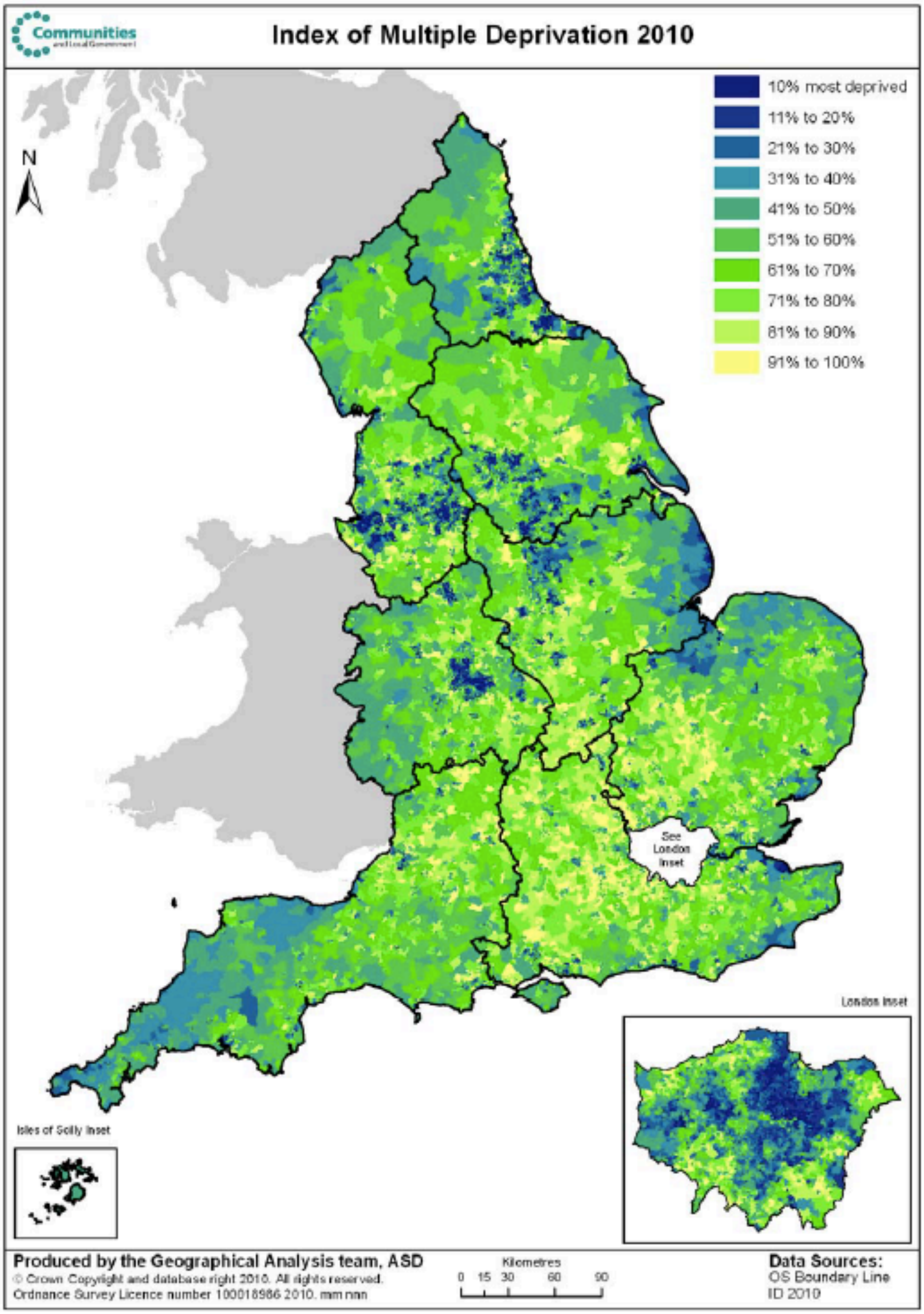


Figure 4.3 Distribution of index of multiple deprivation scores across England

Figure 4.3 displays the geographical distribution of local area deprivation in England, provided by the UK Government [188]. It is evident that many of the top 10% most deprived areas are situated towards the North of the country, and within the North-East of London. Clusters of highly deprived regions can be seen in particular around urban centres which can be inferred as Birmingham, Leeds, Manchester and Newcastle. The least deprived areas, indicated by lighter greens and yellows, tend to become more prevalent towards the South of England, although moderate amounts of deprivation can also be seen in the most South-Westerly region in Cornwall.

In the final sample, prevalence of local area greenspace, given as a proportion of each LSOA, had a mean value of 0.42 (sd 0.30), with values of 0.33 (sd 0.24) and 0.82 (sd 0.19) in urban and rural areas, respectively. The spatial distribution of these LSOA proportions of greenspace across England is presented in Figure 4.4, according to quintile.

Similarly to patterns observed for local area deprivation, there are obvious clusters of lower proportions of greenspace in London and within larger cities towards the North of England. It is evident that, although most (82.7%) of the final sample of survey participants reside in urban areas, and the mean local area proportion of greenspace was 0.42, the majority of England's area has much higher prevalence of greenspace, as demonstrated clearly in Figure 4.3. This may be due, in part, to the fact that LSOAs are defined according to population, so those in rural areas will naturally be spatially much larger than those in urban areas. Despite this overwhelming majority of the country's population being urban residents, towns and cities account for less than 10% of the country's land, by area. According to the Generalised Land Use Database, almost 90% of land cover in England is greenspace. This further emphasises the necessity of informed urban design, and the importance of providing access to greenspaces in an increasingly urban-dwelling country.

Figure 4.5 presents the graphical distribution of individuals' local area proportions of greenspace, and in Figure 4.6 stratified by urban and rural area. It is clear that there exists a marked divide in the amount of local area greenspace, with Figure 4.3 demonstrating 2 peaks in the distribution, which evidently relate to the separation of urban and rural areas, which appear to display almost opposite distributions. Relatively few people appear to have greenspace availability between proportions of 0.3 and 0.8, with local maxima observed either side of this range.

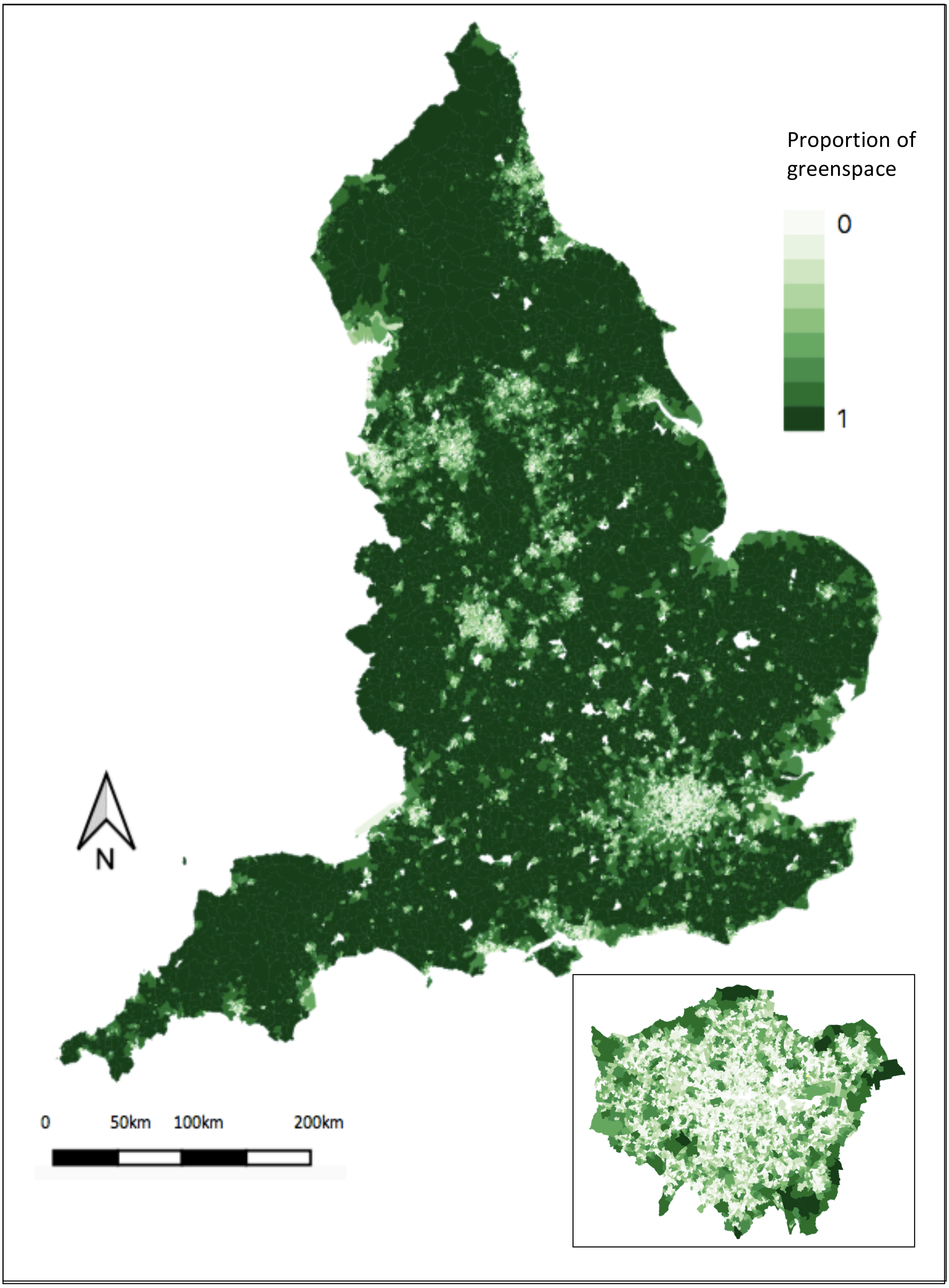


Figure 4.4 Distribution of proportions of greenspace in the data. Inset: London.

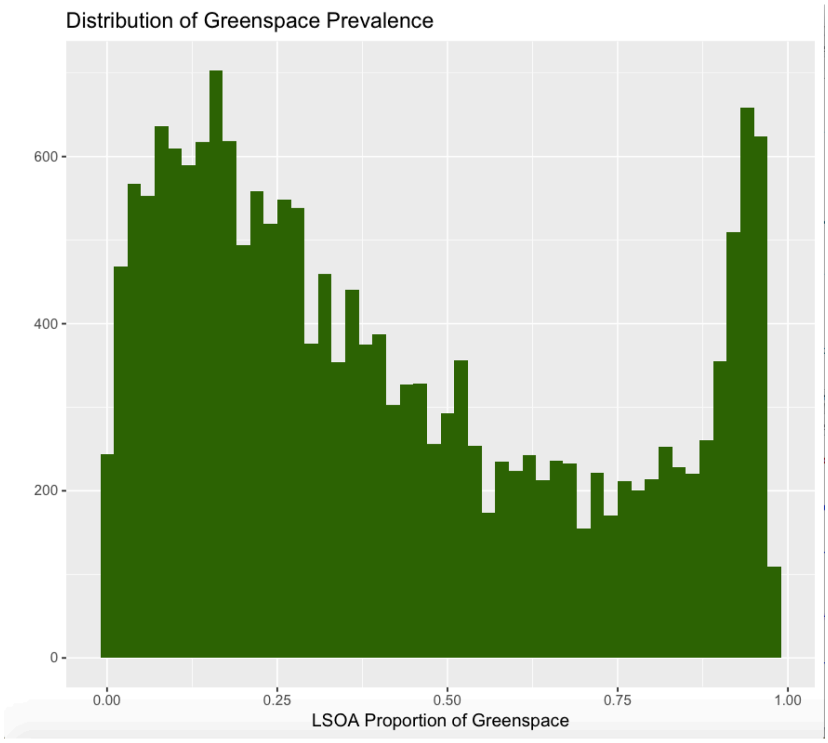


Figure 4.5 Distribution of individuals' LSOA proportion of greenspace, across the sample

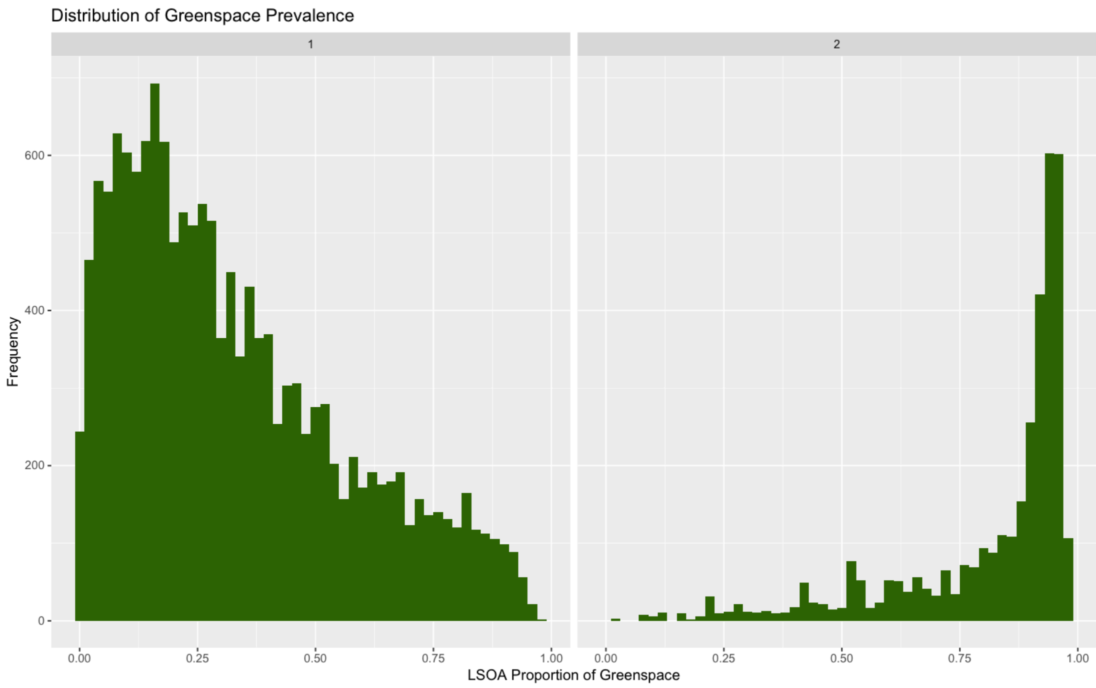


Figure 4.6 Distribution of individuals' LSOA proportion of greenspace, across (1) urban areas, and (2) rural areas

In the final sample of individuals, SWEMWBS scores were slightly negatively skewed; the mean score for the sample as a whole was 25.2 (sd 4.5), with a modal value of 28.0, and was slightly but significantly lower in urban than rural areas (mean score 25.1 (sd 4.6) versus 25.6

(sd 4.3)) (p< 0.001), although the distributions are visually similar. The distribution of SWEMWBS scores across the sample as a whole is presented in Figure 4.7, then stratified according to urban and rural location and given as a proportion of the total in Figure 4.8.

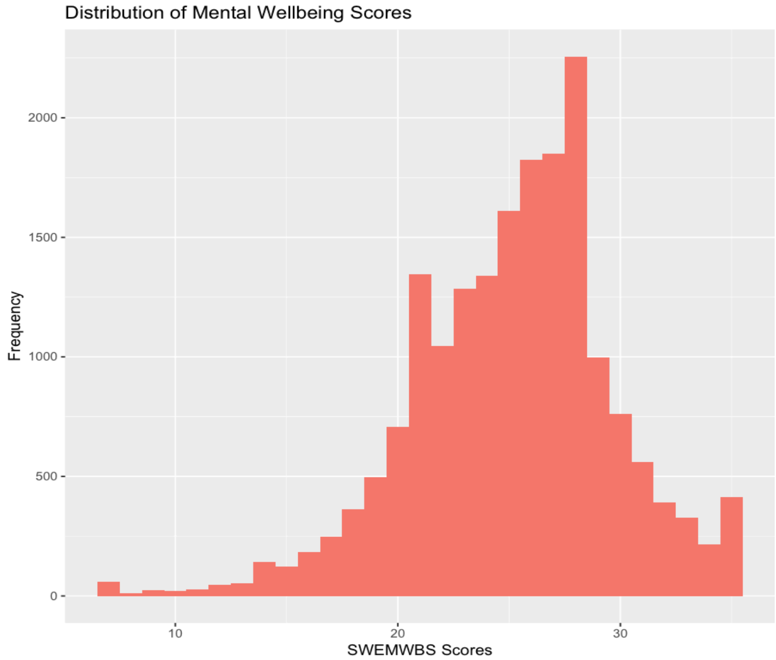


Figure 4.7 Frequency distribution of individual SWEMWBS scores

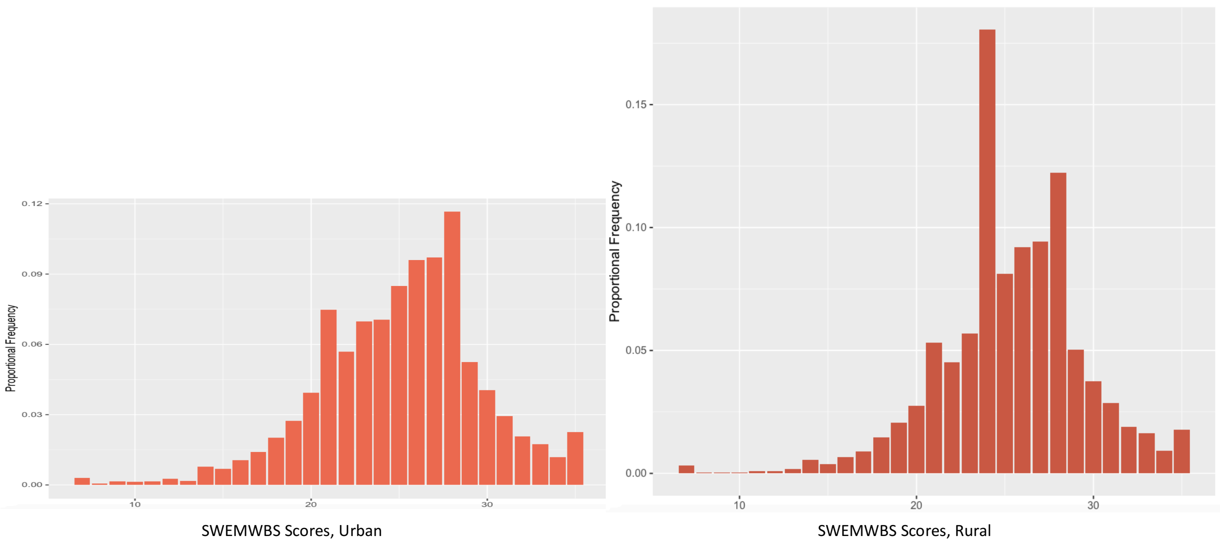


Figure 4.8 Distribution of SWEMWBS scores across (a, left) urban areas, and (b, right) rural areas

		All UKHLS Observations		Urban Only	Rural Only	
Variable	*Value*	*n*	*mean (sd)/%*	*mean (sd)/%*	*mean (sd)/%*	*p urban rural dif.*
Individuals		30900		25547	5353	
Greenspace proportion		30900	0.42 (0.30)	0.33 (0.24)	0.82(0.19)	<0.001
SWEMWBS		30900	25.2(4.5)	25.1(4.6)	25.6(4.3)	<0.001
Sex	Female	17221	55.7	54.2	56.0	0.701
Age	16-24	4421	14.3	15.2	10.0	<0.001
	25-34	5199	16.8	18.2	10.2	<0.001
	35-44	6145	17.5	20.4	17.3	<0.001
	45-54	5395	17.5	17.2	18.6	0.140
	55-64	4597	14.9	13.8	20.1	<0.001
	65+	5143	16.6	15.2	23.7	<0.001
Marital Status	Single	9800	31.7	33.8	21.8	<0.001
	Married	15810	51.2	49.4	59.5	<0.001
	Post Marriage	5278	17.1	16.7	18.7	0.001
Ethnicity	White, British	23997	77.7	73.8	96.1	<0.001
	White, Other	1151	3.7	4.0	2.5	<0.001
	Black	1863	6.0	7.2	0.2	<0.001
	South Asian	2670	8.6	10.4	0.4	<0.001
	Other	1193	3.9	4.5	0.7	<0.001
Health Conditions	Number of conditions	30900	0.5(0.9)	0.5(0.9)	0.6(0.9)	<0.001
Employment	Unemployed	1960	6.3	7.0	3.4	<0.001
	Employed	16993	55.0	55.0	54.9	0.866
	Economically Inactive	11947	38.7	38.0	41.6	<0.001
Income, Quintiles (mean)	1^{st}	6180	£6385	18.6	13.5	<0.001
	2^{nd}	6180	£11241	19.8	17.6	<0.001
	3^{rd}	6180	£15085	20.4	20.2	0.693
	4^{th}	6180	£20059	20.9	22.0	0.550
	5^{th}	6180	£36127	20.3	26.6	<0.001
Household Space	<1 rooms per person	9622	31.1	33.2	21.3	<0.001
	1-3 rooms per person	20917	67.7	65.8	76.6	<0.001
	>3 rooms per person	1749	5.7	5.4	7.1	<0.001
Living Alone		4504	14.6	14.8	13.7	0.032
Living with Children		10822	35.0	36.4	28.5	<0.001
Housing Tenure	Own Home	20849	67.5	65.6	76.4	<0.001
Commuting	<15mins	6392	20.7	20.9	19.8	0.064
	15-30mins	4760	15.4	15.7	14.2	0.004
	30-50mins	2107	6.8	6.9	6.3	0.065
	>50mins	1757	5.7	6.0	4.1	<0.001
IMD rank	Continuous	30900	22.2(15.6)	24.1(16.2)	13.5(7.6)	<0.001

Table 4.1 Full descriptive statistics of the sample from Understanding Society, for the sample as a whole and stratified by urban/rural area

The characteristics of people living in urban (*n* = 25, 547*)* and rural (n = 5,353*)* areas also differed. The mean age of respondents was higher in rural areas, which also had greater proportions of married individuals. Income was also higher in rural areas, where area-level deprivation was considerably lower, household space was greater and more people owned their own home. These findings are presented in Table 4.1; t-tests were used to estimate the significance of the difference between urban and rural variables.

Figure 4.9 presents geographically the locations of the LSOAs of individuals present in the study sample. The LSOAs are distributed evenly throughout most of England, with slightly fewer towards the North, East and South West. It can be seen that rural residents are spread fairly uniformly across England, with most of the urban LSOAs clusters within and around London, and towards the North-West. The rural areas are also clearly much larger spatially than their urban counterparts, despite being home to just 17.3% of the residents. Comparing this to Figure 4.2, it is clear that the urban areas seem visually to coincide with regions of low greenspace prevalence, as would be expected, as well as some areas of relatively higher deprivation scores.

Results of the initial univariate Ordinary Least Squares linear regression model, using the whole sample, revealed a positive, statistically significant (at the 95% level) association between greenspace and mental wellbeing. The unadjusted regression coefficient, *B*, was 0.17 points (*95% CI* 0.11, 0.23) in the SWEMWBS score, per standard deviation increase in greenspace. This therefore implies that individual mental wellbeing scores are generally higher in areas with greater proportions of greenspace.

However, after controlling for all individual and household-level potentially confounding factors, this coefficient was reduced to just 0.01 points (-0.05, 0.07) and was no longer statistically significant (p = 0.774) (Table 4.2).

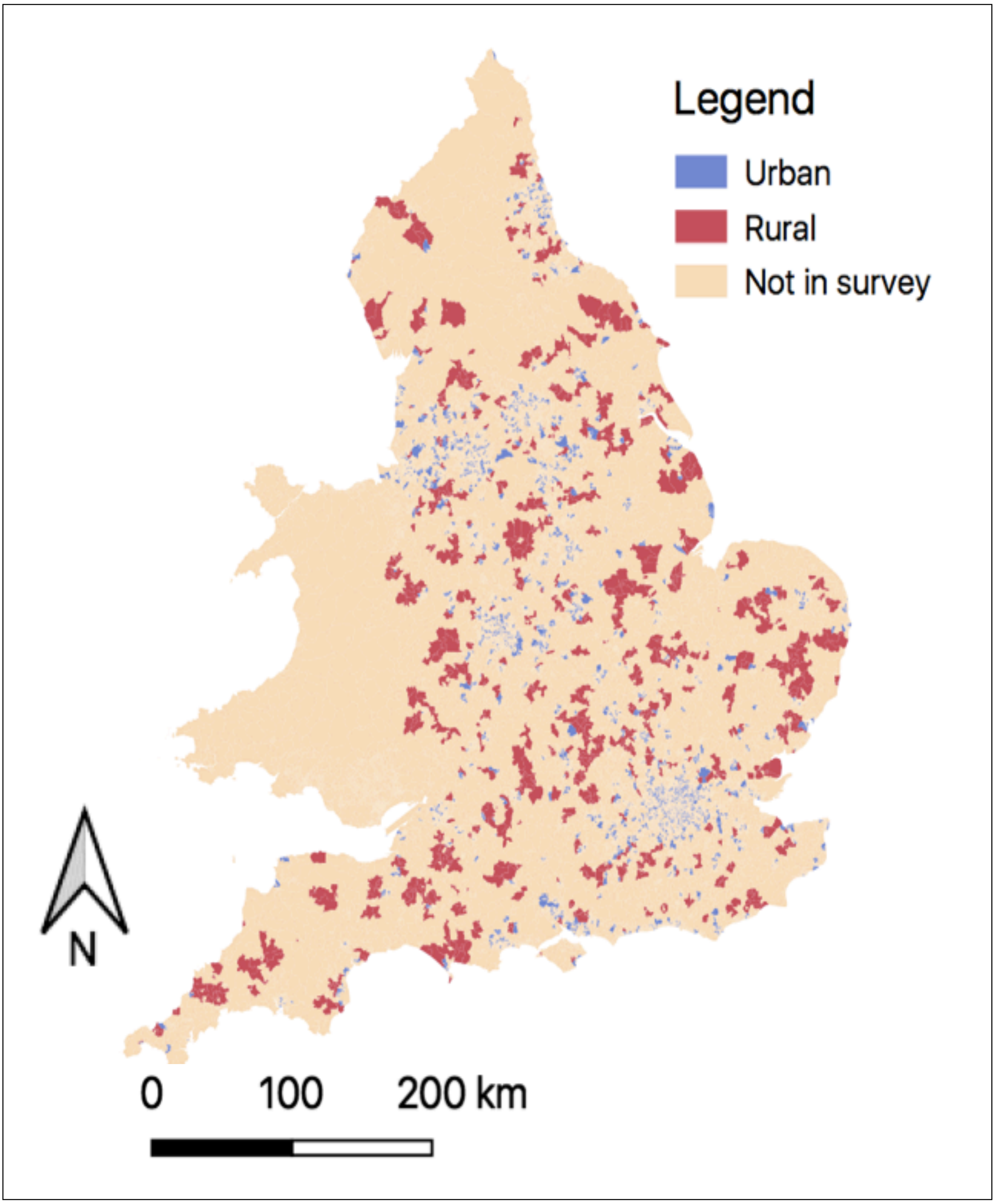


Figure 4.9 Distribution of urban and rural areas in the sample from Understanding Society

Variable	*Value*	*B (95% CI)*	*p*
Proportion of Greenspace	(sd increase)	-0.01 (-0.08, 0.05)	0.712
Sex	Male as reference		
	Female	-0.07 (-0.16, 0.18)	0.164
Age	16-24 as reference		
	25-34	-0.34 (-0.56, -0.12)	0.002
	35-44	-0.86 (-1.09, -0.63)	<0.001
	45-54	-0.90 (-1.14, -0.66)	<0.001
	55-64	0.28 (0.02, 0.54)	0.032
	65+	1.24 (0.96, 1.52)	<0.001
Marital Status	Married as reference		
	Single/Unmarried	-0.69 (-0.86, -0.53)	<0.001
	Separated/Divorced/Widowed	-0.69 (-0.86, -0.52)	<0.001
Ethnicity	White, British as reference		
White, Other		0.42 (0.14, 0.69)	0.003
Black		1.01 (0.76, 1.26)	<0.001
South Asian		0.28 (0.05, 0.52)	0.019
Other		0.18 (-0.11, 0.47)	0.224
Health Conditions		-0.63 (-0.69, -0.57)	<0.001
Employment	Employed as reference		
	Unemployed	-1.10 (-1.35, -0.035)	<0.001
	Economically Inactive	-0.38 (-0.53, -0.23)	<0.001
Income, Quintiles	1st as reference		
	2nd	0.24 (0.06, 0.43)	0.010
	3rd	0.29 (0.10, 0.47)	0.002
	4th	0.67 (0.48, 0.86)	<0.001
	5th	0.94 (0.75, 1.13)	<0.001
Household Space	1-3 rooms per person as reference		
	<1 room per person	-0.08 (-0.22, 0.06)	0.258
	>3 rooms per person	0.19 (-0.09, 0.46)	0.18
Living Alone	No as reference		
	Yes	-0.06 (-0.27, 0.15)	0.576
Living with Children	No as reference		
	Yes	-0.18 (-0.32, -0.03)	0.018
Housing Tenure	Does not own home as reference		
	Own Home	0.32 (0.19, 0.46)	<0.001
Commuting Time	<15 mins as reference		
	15-30 mins	0.03 (-0.11, 0.18)	0.664
	30-50 mins	0.06 (-0.14, 0.26)	0.561
	>50 mins	0.27 (0.06, 0.49)	0.012
Deprivation		-0.02 (-0.02, -0.01)	<0.001
Urban/Rural Setting	Rural as reference		
	Urban	-0.10 (-0.27, 0.08)	0.283

Table 4.2 Fully adjusted linear regression model

Finally, adjusting further for urban/rural location in the association between a standard deviation increase in greenspace and SWEMWBS score, the resultant *B* value was -0.01 points (-0.08, 0.50), and again highly non-significant (*p* = 0.712). While greenspace and urbanity were significantly linearly associated (*B* = -0.23, *p* <0.001), there was evidence of only slight, but statistically insignificant effect modification (*B* = -0.11, *95% CI* -0.29, 0.11, *p* = 0.382) between these variables. The results of the fully-adjusted model are presented in Table 4.2.

Variable	*Value*	*B (95% CI)*	*p*
Proportion of greenspace, urban areas		0.282 (0.033, 0.532)	0.027
Proportion of greenspace, rural areas		0.651 (-0.030, 1.332)	0.062

Table 4.3 Results of linear regression models, stratified by urban and rural areas

The preliminary linear regression was also calculated separately for urban and rural residents. These stratified univariate models showed that the positive association between local area greenspace was slightly stronger in rural (*B* = 0.12 points, *p* = 0.062) than urban areas (*B* = 0.07 points, *p* = 0.027), for a standard deviation increase in greenspace; only the urban result was statistically significant at the 95% level, with the rural model still significant at a conservative 90% level. However, both of these regression coefficients were weaker than that calculated for the sample as a whole, which suggests that the former model was perhaps strengthened by including the differences between urban and rural areas within its training sample. The results of the urban-rural stratified models are presented in Table 4.3. To demonstrate the consideration of a quasi-poisson model, to fit the distribution of the SWEMWBS scores, results of this model are presented in Table 4.4, for information only.

Variable	*Value*	*B (95% CI)*	*p*
Proportion of Greenspace		-0.002 (-0.011, 0.007)	0.693
Sex	Female	-0.003 (-0.006, 0.001)	0.171
Age	16-24 as reference		
	25-34	-0.014 (-0.026, -0.005)	0.002
	35-44	-0.003 (-0.044, -0.025)	<0.001
	45-54	-0.037 (-0.046, -0.027)	<0.001
	55-64	0.010 (0.000, 0.021)	0.050
	65+	0.048 (0.037, 0.059)	<0.001
Marital Status	Married as reference		
	Single/Unmarried	-0.028 (-0.034, -0.021)	<0.001
	Separated/Divorced/Widowed	-0.028 (-0.034, -0.021)	<0.001
Ethnicity	White, British as reference		
	White, Other	0.017 (0.006, 0.028)	0.002
	Black	0.041 (0.031, 0.051)	<0.001
	South Asian	0.011 (0.002, 0.021)	0.018
	Other	0.007 (-0.004, 0.019)	0.211
Health Conditions		-0.025 (-0.028, -0.023)	<0.001
Employment	Employed as reference		
	Unemployed	-0.046 (-0.056, -0.035)	<0.001
	Economically Inactive	-0.015 (-0.021, -0.009)	<0.001
Income, Quintiles	1st as reference		
	2nd	0.010 (0.002, 0.018)	0.011
	3rd	0.012 (0.004, 0.019)	0.002
	4th	0.027 (0.019, 0.034)	<0.001
	5th	0.037 (0.029, 0.044)	<0.001
Household Space	1-3 rooms per person as reference		
	<1 room per person	-0.003 (-0.009, 0.002)	0.271
	>3 rooms per person	0.007 (-0.003, 0.018)	0.179
Living Alone	No as reference		
	Yes	-0.002 (-0.011, 0.007)	0.644
Living with Children	No as reference		
	Yes	-0.007 (-0.013, -0.001)	0.018
Housing Tenure	Does not own home as reference		
	Own Home	0.013 (0.008, 0.018)	<0.001
Commuting Time	<15 mins as reference		
	15-30 mins	0.001 (-0.0054, 0.007)	0.644
	30-50 mins	0.002 (-0.005, 0.010)	0.542
	>50 mins	0.011 (0.003, 0.019)	0.011
Deprivation		-0.001 (-0.001, 0.000)	*<0.001*
Setting	Urban	0.004(-0.011, 0.003)	0.279

Table 4.4 Results of the fully adjusted quasi-poisson regression model

4.4 Discussion

4.4.1 Main findings

Previous research has demonstrated local area prevalence of greenspace to be positively related to life satisfaction, happiness and reduced risk of psychiatric morbidity [16, 29, 140, 195]. In particular, studies applying data from the British Household Panel Survey (the predecessor to *Understanding Society*, which collected similar individual data), have shown a significant association between proportion of local area greenspace and lower GHQ scores, which held across longitudinal analyses [16, 29, 195]. Although preliminary results of this study revealed a positive association between local area prevalence of greenspace and a measure of multidimensional mental wellbeing, this study did not replicate the associations found in other research, after adjusting for a wide range of potentially confounding factors.

These differences may be methodological, as this study controlled for local area deprivation and urban/rural location, as well as modelling greenspace as a continuous proportion, while comparable research by Astell-Burt et al. did not [196]. However, White et al. found significant associations between greenspace and GHQ in their urban area studies, while controlling for similar potential confounders, which, considered in conjunction with the current study's results, may provide further evidence that mental wellbeing itself reflects more than simply an absence of mental distress [16].

Although, in adjusted models, no association between proportion of local area greenspace and individual mental wellbeing was found, several of the potentially confounding factors were significantly associated with the SWEMWBS score. In particular, individuals who were aged over 65, married, employed, earning a higher (household-adjusted) income, owning their own home, or living in a relatively less deprived LSOA, were generally more likely to have higher mental wellbeing scores. In addition, factors of living with children, being in a middle age group (between 35 and 54), being of an ethnicity that was not white-British, and having a greater number of ongoing physical health conditions, were all negatively and significantly associated with mental wellbeing, as indicated by lower SWEMWBS scores.

Whilst, at the outset, it was hypothesised that urban/rural location may modify associations between greenspace and mental wellbeing, this study was not able to provide statistically significant evidence supporting such an effect modification. However, results of stratified univariate analyses suggested that the association between local area greenspace and mental wellbeing was considerably stronger in rural areas, but was only significant in urban LSOAs.

It may be useful to speculate on the processes underlying these unexpected results. For example, it has been suggested that levels of community and social support may be lower in rural areas, where people may be more isolated (perhaps because of difficulties accessing transport, lack of local facilities, or through fewer opportunities to socialise in remoter rural areas) [6]. Similarly, services (health and otherwise) may be less accessible in rural regions. However, it should also be noted that the estimates of this study may have been limited by the much smaller sample of those living in rural areas, where LSOAs are spatially much greater, and variance in the proportion of greenspace was also lesser than that observed in urban areas.

These findings may also reflect methodological limitations, such as only including LSOA level greenspace prevalence, or conceal more nuanced associations between greenspace and mental wellbeing. In reality, LSOAs are a data collection unit which may not represent the true living neighbourhood of the resident, so studying greenspace at this level may obscure individual-level associations from detection [15]. This is the Modifiable Area Unit Problem, which states that the results of aggregating data will be influenced by the size and shape of the unit [197], which for LSOAs may vary considerably across the study space.

Greenspace was measured according to local area proportion, in line with other research into neighbourhood greenspace and mental health, although this does not allow absolute quantities to be considered. Attention Restoration Theory proposes that, in order to be restorative, environments must have sufficient *extent*; it may be that the absolute size of each greenspace is more beneficial to individual mental wellbeing than the relative proportion of each locality. Such environments must also provide *compatibility* with individual needs, and so consideration of the facilities (types of greenery, footpaths for walking, benches, toilets and other amenities) may influence whether an individual is able to effectively utilise and hence benefit from their local greenspace. Proximity to the individual may also be relevant, in particular as government recommendations advise minimum distance between residences and nearby greenspaces, and views of trees from the home have been associated with improved mental wellbeing [198, 199].

Greenspace itself may also take many forms, and it may be that the association with mental wellbeing depends on the type rather amount of greenspace [200, 201]. For example, many studies into the health effects of greenspace focus on nature itself, and theories such as Biophilia suggest that humans have an innate desire to connect with other forms of life and may experience positive emotions when exposed to natural environments [20]. As the vast majority of individuals within this study lived in urban areas, it is likely that most of their local greenspace would be in the form of parks, public gardens and sports facilities, where evidence of human intervention and artificially constricted landscaping is prevalent. While these spaces may still be beneficial to health, by providing opportunities for social interaction, physical activity, and an escape from the city, it may be that more natural greenspaces could be the most important for mental wellbeing in particular. Alternatively, it may be that different types of greenspace are important to different people, or in different areas.

Further, previous studies have shown that the quality of greenspace, and its biodiversity, were positively associated with mental health, where quantity was found to be less significant [202]. Context is also likely to matter [23, 181] and studies show that places that look untended, unsupervised, or are poorly lit may be perceived as unsafe, which therefore discourages use [93, 203, 204]. Some urban greenspaces in particular may also have access restrictions, such as London square gardens, which are visible to passersby but available only to neighbouring residents. Access to parks may also be limited by their opening hours, which restrict when individuals are able to visit, and therefore benefit from them.

4.4.2 Strengths and limitations

This is believed to be the first study to test the association between greenspace and a validated multidimensional mental wellbeing measure that includes both eudaimonic and hedonic mental wellbeing items, in all parts of England. The UK Longitudinal Household Panel Study was the largest ongoing survey at this level in the UK at the time of writing [16, 29], and contains extremely detailed socio-economic data as well as spatial identifiers. The latter allowed for linking the survey data to land use data, and to compare the effects of urban/rural location on mental wellbeing and on the association between greenspace and mental wellbeing.

Despite the strengths of this work, the quantification of greenspace is relatively simplistic, and it is possible that associations with mental wellbeing were not detected as a result of grouping all types of greenspace into one variable. Further research is required to examine the associations between different types of greenspaces (for example natural spaces, parks, sports facilities, etc) and mental wellbeing, to understand whether these are important individually. The Generalised Land Use Database also measures only designated greenspaces in its categorisation, and therefore is likely to exclude much streetscape greenery, such as trees, living walls, and balcony planting, which may themselves create a greener environment and benefit wellbeing [87], particularly in urban areas where space is at a premium.

It is also possible that the attribution of greenspace scores according to the value for LSOAs introduced an element of misclassification, since it takes no account of accessibility or interaction with this space. As the LSOAs are derived according to population size and density, neighbourhoods in urban areas will naturally be much smaller geographically than those in sparser settings, thereby making adjacent areas in built-up environments more accessible to these residents. Future research which includes data on distances to the nearest greenspace (which may extend to that in adjacent LSOAs), or greenspace within a set radius of individuals' homes, might demonstrate larger associations with mental wellbeing. Consideration of the absolute size of each greenspace, and the travel distance for the individual, may also reveal different relationships.

These data were also limited to the greenspace in the LSOA of residence, and did not take account of where respondents worked or spent time, or areas traversed when commuting. Greenspace close to home may be most important for the very young, the elderly, less able, the unemployed, or others who spend more time in their residential neighbourhood, whereas greenspace close to the workplace may be most valuable to an individual in full-time employment during the working week. Within the survey itself, at the individual level there was evidence of greater response rates in less deprived areas, which may be a potential source of selection bias. Finally, as a cross-sectional study, by design, this provides limited capacity to establish any causality.

4.5 Conclusions

The proportion of greenspace in an individual's local area was significantly and positively associated with mental wellbeing in univariate models, but became weaker and statistically non-significant after adjusting for socio-demographic variables, and further for urban/rural location. Although the associations differed slightly between urban and rural environments, this difference was not statistically significant. While the greenspace in an individual's local area has been shown to be related to aspects of mental health such as happiness, life satisfaction, and reduced symptoms of psychiatric distress, the association to multidimensional mental wellbeing is much less clear from this study. Further research is therefore needed to explore the relationship of other aspects of greenspaces with mental wellbeing, aside from relative prevalence. These factors should include absolute size, accessibility and type of greenspace.

5.0 A spatial analysis of proximate greenspace and mental wellbeing in London

"I felt my lungs inflate with the onrush of scenery—air, mountains, trees, people. I thought, this is what it is to be happy"
- Sylvia Plath

5.1 Introduction

As urbanisation increases, policy makers and planners are being challenged to accommodate new residents in sustainable ways [3, 205], including through the provision of greenspace. Although the required amount and proximity of greenspace are not known, both the UK government and European Union recommend that greenspace should available within 300m of homes [50, 51].

Studies of proximity to greenspace have revealed a weak association between lower Euclidean (straight-line) distances to the nearest greenspace and improved mental health [154], typically assessed using measures that are concerned predominantly with symptoms of mental distress rather than multidimensional mental wellbeing (i.e. positive mental health, covering hedonic and eudaimonic domains). Positive associations have been observed between the amount of greenspace within a 300m, but not 100m radius of individuals' homes and vitality, which is associated with improved mental health [46]. However, sensitivity analyses that tested buffers of 100m, 300m, 500m and 1000m, found consistent associations between the amount of local greenspace and (fewer) symptoms of mental distress over all four distances [129]. Another study, based in Barcelona, reported a dose-response effect in which larger effect sizes were observed for the amount of greenspace within 100m of participants' homes compared with 250m and 500m, respectively [153]. Other research has considered associations over larger distances (1km and 3km) with mixed results [78, 93, 126, 206]. The contrasting findings within these results may be due, in part, to the inconsistencies in measurement of mental health outcome [37]. No studies have been found which examine associations between the amount of greenspace within a set distance and measures of hedonic and eudaimonic wellbeing, to understand how this might be patterned spatially, or whether this varies between people and places [37].

As discovered in Chapter 3, most research concerning greenspace and mental health has tested associations between the amount of local area greenspace within administrative boundaries [16, 40, 113, 123] and symptoms of either mental distress, happiness or life satisfaction (hedonic wellbeing). Studies which examined associations between hedonic and eudaimonic mental wellbeing and the amount of greenspace within data-collection boundaries, such as that in Chapter 4, found no statistically significant associations [16, 38, 132, 133]. Studying greenspace in this way may misclassify exposure, because greenspace may be present in adjacent areas and because this ignores access, use and type of greenspace. Studies using areas centred on each participant's place of residence go some way towards addressing this [46, 78, 93, 126, 129, 153, 206], though no studies have yet tested associations between the amount of greenspace estimated in this way and hedonic and eudaimonic wellbeing.

There are other challenges to the study of greenspace and mental wellbeing. Both vary spatially; moreover, those who live in greener areas may spend more time in greenspace [19, 88, 207, 208], feel a stronger connection with nature [145, 209, 210] or value local greenspace more highly than those who live in less green areas [40, 209, 210]. Those who value greenspace more highly may also be more likely to move to greener areas [106, 208]. For this reason, it is also possible that the association between greenspace and mental wellbeing varies between people and between areas [22, 128, 207, 211]. Techniques such as Geographically Weighted Regression (GWR) adjust for this non-stationarity and permit model parameters to vary over space, thereby allowing variations in the associations between people and places to be estimated and modelled [212-216].

The aim of this study was therefore to investigate associations between individual-level greenspace and hedonic and eudaimonic wellbeing using spatial methods, by addressing the third research question:

Research Question 3- Measuring the amount of greenspace within a radius of individuals' homes, do associations with mental wellbeing differ to what is detected at an aggregated, local area, level?

This project tested the hypotheses that:

(1) surrounding greenspace is positively and significantly associated with mental wellbeing; and

(2) that the association between nearby greenspace and mental wellbeing varies spatially.

5.2 Methods

5.2.1 Sample and setting

Data were drawn from the Annual Population Survey (APS) pooled dataset April 2012-March 2015 [217]. The APS, undertaken by the UK's Office for National Statistics, is a quarterly survey of households in Great Britain and Northern Ireland, in which areas are first stratified by post code, then systematically sampled from a random start. The quarterly samples add approximately 15,000 individuals from 8,700 UK households to the set, using initial face-to-face and follow-up telephone interviews for each participating individual in the household. The original UK sample for the 2012-2015 APS dataset was 567,481 individuals, a response rate of approximately 55% for the pooled data, which is combined at the end of the survey period. As greenspace data availability restricted analyses to Greater London, the final dataset comprised 25,518 individuals. Variables in the dataset cover aspects of wellbeing, demography, socio-economic status, and living conditions. The dataset also includes spatial identifiers (full post code) and LSOA (Lower Layer Super Output Areas, an administrative district). There are 4,844 LSOAs in London, with an average area of 0.33km^2 and population of 1,700 [218]. These identifiers were used to link other datasets at the level of individual respondents (see Figure 5.3).

5.2.2 Study variables

5.2.2.1 Mental wellbeing

Mental wellbeing variables were based on three (of 4) questions developed by the Office of National Statistics (ONS) [219] for monitoring mental wellbeing in the UK [217]. They ask: 'Overall, how satisfied with your life are you nowadays?', 'To what extent do you feel the things you do in your life are worthwhile?' and 'How happy did you feel yesterday?'; responses are rated on a scale of 0 (not at all) to 10 (completely). These questions are designed to cover hedonic (life satisfaction, happiness) and eudaimonic (worth) mental wellbeing. Data based on the fourth ONS wellbeing question, 'how anxious did you feel yesterday?', were not used as these were considered to reflect mental distress rather than mental wellbeing.

5.2.2.2 Individual and household-level covariates

Potential confounding factors were identified from the published literature and survey questions available [38, 46, 129]. Variables included at individual level comprised age (in 10-year grouped classes), sex, marital status (married/cohabiting or not), ethnicity (using Census categories), and education (having obtained a degree or diploma). Health was ascertained using self-reported general health (on a likert-type scale from very good to very poor). Socio-economic status was assessed by income (in quintiles based on gross pay), economic activity (whether employed, unemployed, or inactive) and housing tenure. Living circumstances were characterised by whether or not the individual lived with children, as well as their housing type (detached house, semi-detached house, terraced house, flat/maisonette, other) [217].

5.2.2.3 Local area characteristics

Local area data were retrieved from the London Data Store, providing population statistics and Indices of Multiple Deprivation (IMD) for each London LSOA, applied here as local area-level covariates [188, 218]. IMD scores were calculated across a number of domains including local education, crime and access to services, with a higher score indicative of a more deprived LSOA. Population density was calculated by dividing the number of residents in each LSOA by its area.

5.2.2.4 London maps

The Code Point map was obtained from Ordnance Survey and provides a centroid location for each post code in London [220]. This was used to determine the spatial coordinates for each individual post code.

5.2.2.5 Greenspace

Greenspace data were obtained from the Greenspace Information for Greater London group (GiGL), who collate data from London Borough councils. The dataset comprises GIS (Geographic Information System) files with greenspace polygons describing the shape, size and location of 20,000 public greenspaces in London [104]. The geographic location of each greenspace allow them to be spatially linked to the other data files.

To calculate the quantity of local greenspace in the vicinity of the home of each participant, GIS tools were implemented using ArcGIS [221] and R [191]. Firstly, Euclidean (straight-line) distance buffers were generated, by drawing a circle around the centroid of each individual's post code, at a radius of 300m, chosen to test the Natural England guideline [50]. This buffer was then spatially intersected with the GiGL data, which was used to calculate the total amount (m^2) of greenspace within 300m of each individual's homes; this process is demonstrated in Figures 5.1 and 5.2. Buffers of 500m and 1km were also calculated in order to perform sensitivity analysis. Figure 5.3 demonstrates the processes performed to merge and analyse the data throughout this project. The background map is obtained from OpenStreetMap [222].

Figure 5.1 Greenspace data in London

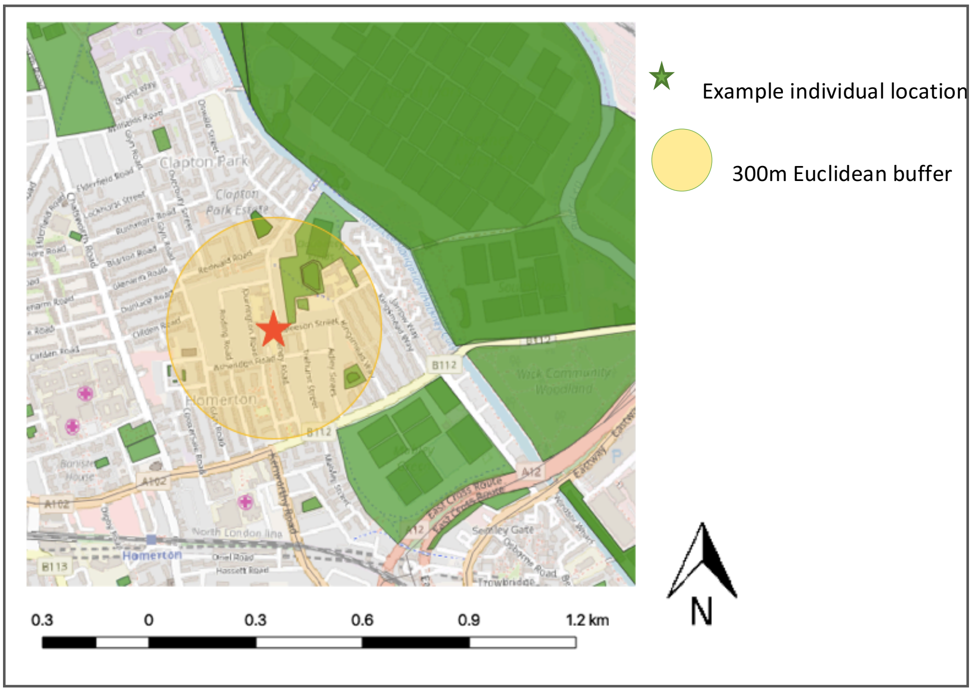


Figure 5.2 Calculating a 300m Euclidean buffer around an (example) individual

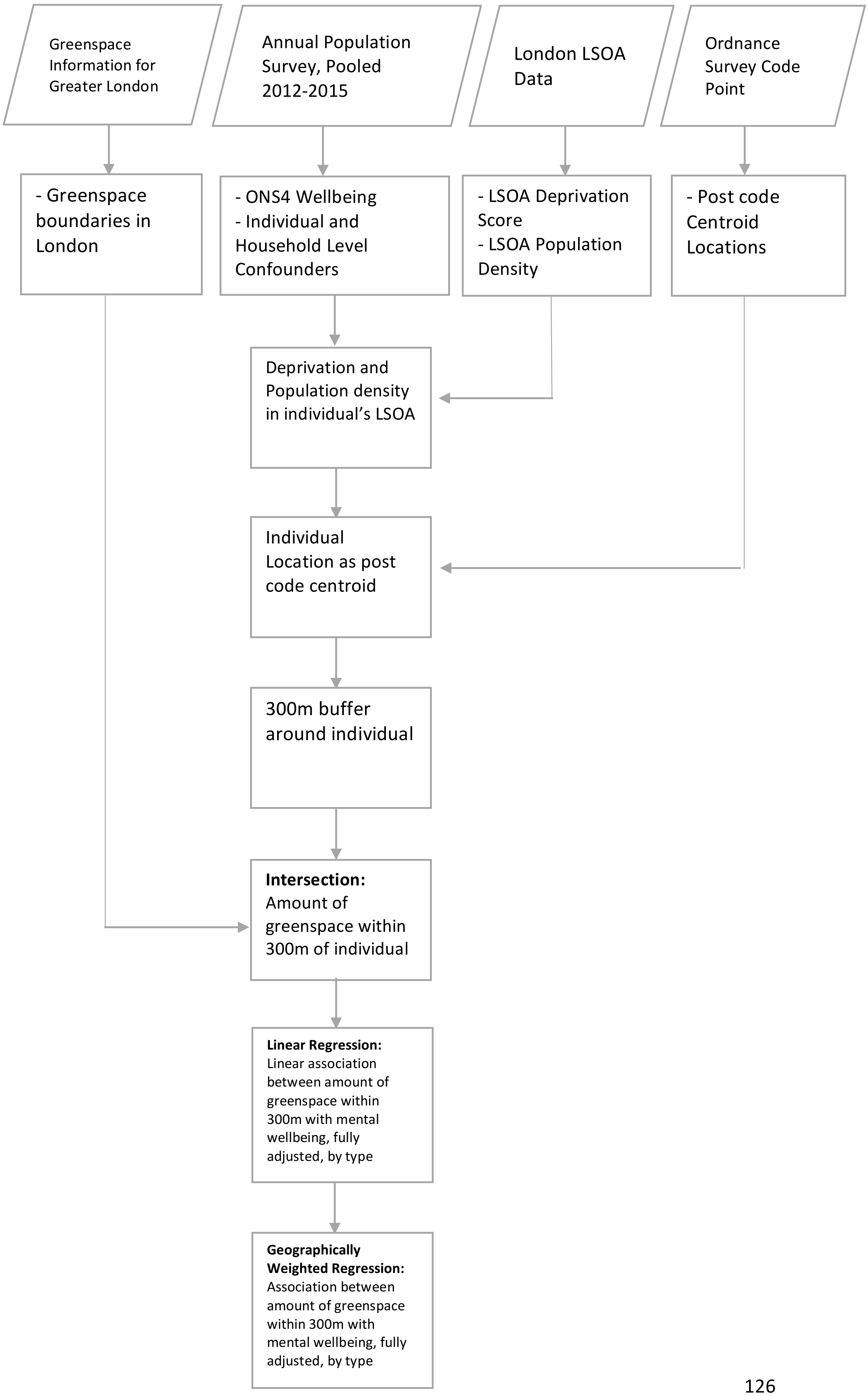


Figure 5.3 Data flow to final sample and analysis

5.2.3 Analysis

Analyses were undertaken using both ArcGIS and R software [191, 221]. Distributions of the greenspace and mental wellbeing variables, as well as the characteristics of the study sample, were examined.

To first investigate the linear association between the amount of surrounding greenspace and mental wellbeing, univariate Ordinary Least Squares (OLS) linear regression models were created for the association between the amount of greenspace within 300m and each of the wellbeing questions in turn (life satisfaction, worth, happiness).

After testing for bivariate associations between each of the individual variables and mental wellbeing and the amount of greenspace within 300m in turn, the following were significantly associated with both, and thus included in the models as potential confounders: age, sex, marital status, ethnicity, general health, education, employment status, income, living with children, housing tenure, housing type, LSOA population density, and LSOA deprivation. Multicollinearity tests (using Variance Inflation Factors) revealed all of the potentially confounding factors to be sufficiently independent. OLS multivariate models were then built, which include all socioeconomic and local area variables identified as potential confounders. Baseline models, including only these factors, were calculated, so the contribution of adding greenspace indicators could be observed; including greenspace significantly improved fit.

Tests of spatial autocorrelations were then undertaken. Spatial autocorrelation refers to the degree to which attributes of objects are significantly clustered spatially, and leads to a risk of underestimating errors and overestimating the statistical significance of regression coefficients in a model [223]. A *K* nearest neighbours (*KNN*) approach was implemented, using Euclidean (straight-line) distance between individuals' post code centroid, to identify the closest *N* points (taken as the locations of other study participants) for each individual, in turn. Taking the standard approach, the rounded square root of the number of instances (25,518) as *K*, 160 nearest neighbours were selected.

The Global Moran's *I* statistics was then used to measure spatial autocorrelation between each of the mental wellbeing measures in turn; this method compares the actual wellbeing value for each individual to a distance-weighted matrix of neighbours, and returns a value for the overall spatial clustering of the data [224, 225]. Local Moran's *I* was then investigated, which provides a clustering value for each individual in the dataset, by comparing the value of each wellbeing measure to that of its 160 nearest neighbours [224, 225]. Both measures output a value between -1 (perfect dispersion, where differing values cluster) and 1 (perfect clustering, where higher or lower values cluster), with a value of 0 indicating no autocorrelation. These are plotted on a Local Indicators of Spatial Association (LISA) cluster map.

The residual errors of the OLS models were also investigated, revealing significant spatial clustering, and highlighting how the model systematically over- and under-estimates the associations, implying geographic variation across the study space.

As with previous studies of the environment and health, Geographically Weighted Regression (GWR) was therefore selected as an appropriate method to adjust for these evident underlying spatial processes, and investigate the geographic variation in the association between local greenspace and mental wellbeing [214-216]. The GWR method calculates a localised regression using distance-based weighting for each point; this method is essentially therefore a regression model in which the coefficients are allowed to vary over space [212, 213].

$$MWB_i = \beta_0 + \beta_1 GS_{1i} + \cdots \beta_m x_{mi} + \varepsilon_i \qquad \text{for} \qquad i = 1, \ldots, n \tag{5.1}$$

$$\beta_m = (X^T X)^{-1} X^T Y \tag{5.2}$$

Equation (5.1) represents an OLS regression, where MWB_i is the predicted value of individual *i*'s mental wellbeing score (life satisfaction, worth, happiness, or anxiety), β_0 is the calculated constant, β_1 is the greenspace coefficient, GS_{1i} is the amount of greenspace within a specific buffer of the individual *i*'s post code centroid, and $\beta_m x_{mi}$ and ε_0 represent the contribution of the potentially confounding factors and an error term, respectively. The regression coefficients are calculated as shown in Equation (5.2), assumed to be constant over space, where *X* and *Y* are matrices of *x* and *y* values.

$$MWB_i = \beta_{0i} + \beta_{1i} GS_{1i} + \cdots + \beta_{mi} x_{mi} + \varepsilon_{mi} \qquad \text{for} \qquad i = 1, \ldots, n \tag{5.3}$$

$$\beta_m = (X^T W_i X)^{-1} X^T W_i Y \tag{5.4}$$

Geographically Weighted Regression, however, allows these correlation coefficients β_{ni} to vary spatially, generating a separate model for each event location *i* in the data set, as demonstrated in Equation (5.3). Therefore, MWB_i is the predicted value of individual *i*'s mental wellbeing score, β_{0i} is the calculated constant and β_{1i} is the greenspace coefficient. Using the standardised approach, a Gaussian distribution was assumed for a kernel, which is used to calculate the weights (W_i, Equation 5.4) assigned to the data points surrounding the individual *i*, such that observations closer to *i* are given a greater weight than observations further away, to calculate the coefficients for the GWR model. Therefore, while the regression coefficients of the linear regression model are calculated using all the data (*X*, Equation (5.2)), those for GWR are calculated using the weighted matrix of neighbours for individual *i* (W_i). The bandwidth (*h*) of the Gaussian weighting kernel is selected using leave-one-out cross-validation, to minimise errors in the model. The process of weighting the data with a moving kernel is demonstrated in Figure 5.4.

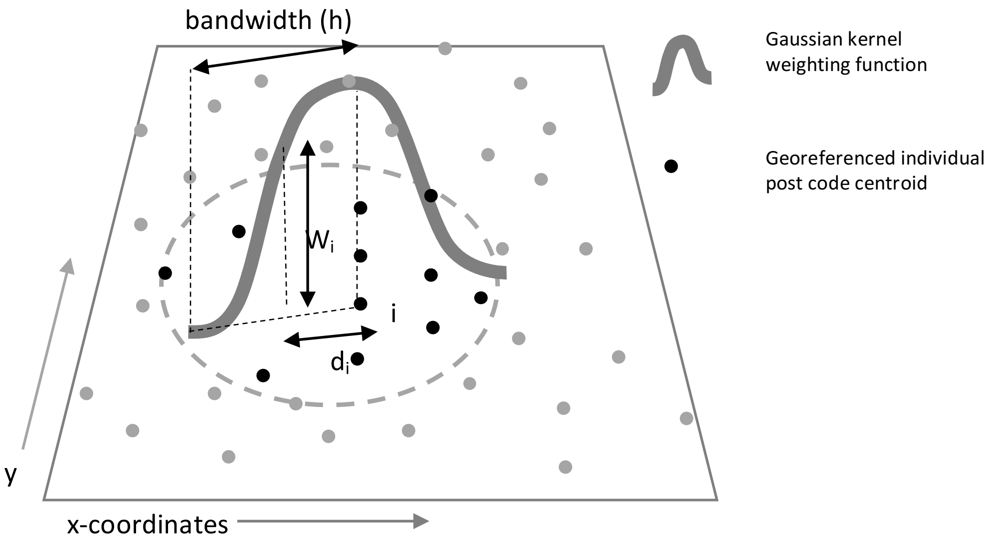


Figure 5.4 Demonstration of GWR calculations

The kernel bandwidths for Geographically Weighted Regression define the radius within which the model searches for neighbours to include in each regression; larger bandwidths therefore include a wider area. These values are calculated to maximise the fit, and minimise errors in each model, and were calculated for the association with the amount of greenspace within the 300m buffer, and were determined as follows: 1,596m for life satisfaction, 2,639m for worth, and 3,149m for happiness.

Univariate GWR models were calculated for each of the greenspace buffers and mental wellbeing measures in turn, and then adjusted for the full set of potentially confounding factors, as with the OLS models, using the s*pgwr* package in R. As this technique runs a localised regression around each data point (individual), the output provides the distribution of the coefficients; the global value is taken as the general *B* coefficient. One-sample t-tests were used to estimate the statistical significance of the global coefficient for each predictor variable. Autocorrelations of the residual errors were then examined, to investigate improved fit from the OLS to GWR models, and to demonstrate the contribution of the addition of greenspace to the model.

5.3 Results

There were 25,518 residents of greater London in the final sample. Mean wellbeing scores were fairly consistent across the three positive questions, with the greatest standard deviation observed for happiness (2.1). The amount of greenspace within a 300m buffer had a mean of 0.045km^2, with 0.152km^2 and 0.727km^2 in the 500m and 1000m buffers, respectively. The percentage of females in the final dataset was higher than males, at 55.7%, which is slightly above the UK average [226]; the majority were also cohabiting (53.5%), white (60.7%) and employed (59.1%). Full characteristics of participants are shown in Table 5.1.

Frequency distributions of the three wellbeing questions, shown in Figure 5.5a-c, were comparable across the three variables (life satisfaction, worth, happiness), displaying a negatively skewed distribution, and mean values of 7.4, 7.7 and 7.3, respectively, each with smaller local maxima around 5.

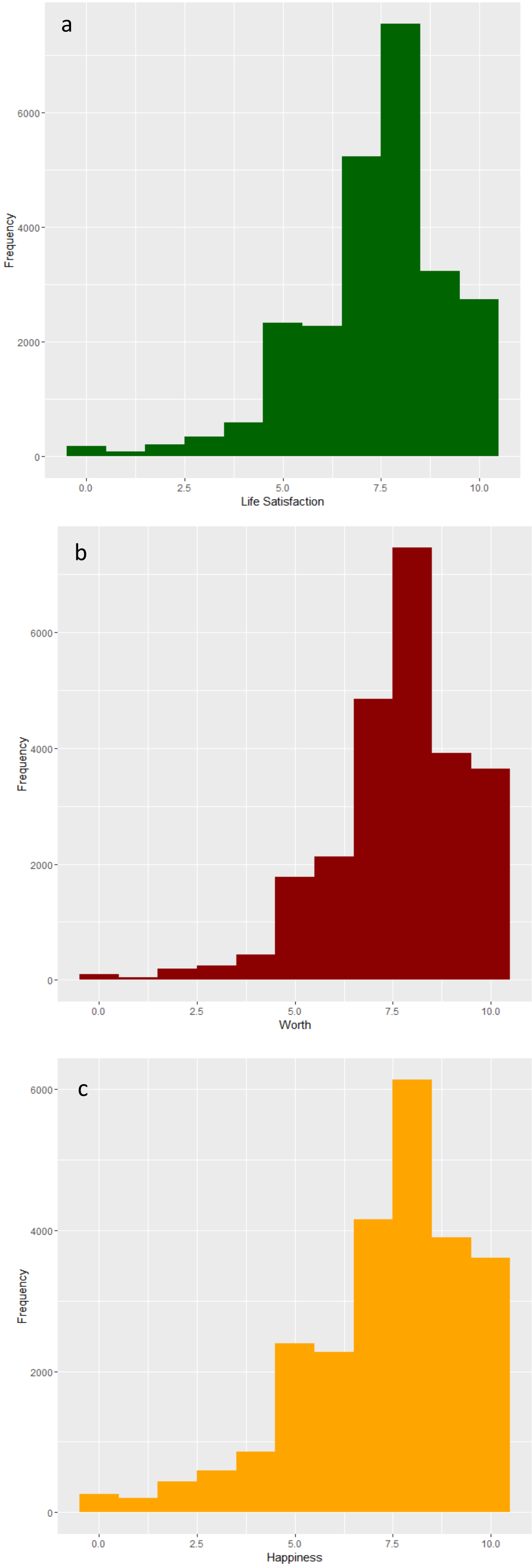


Figure 5.5a-c Frequency distributions of the wellbeing variables

Variable	*Value*	*n*	*Mean(sd) / %*
Wellbeing	Life Satisfaction	25,518	7.4 (1.8)
	Worth	25,518	7.7 (1.7)
	Happiness	25,518	7.3 (2.1)
Age Group	16-24	1734	6.8
	25-34	5014	19.6
	35-44	5321	20.8
	45-54	4590	18.0
	55-64	3670	14.4
	65-74	3010	11.8
	75+	2179	8.5
Sex	Female	14,201	55.7
Married/Cohabiting	Yes	13,655	53.5
Ethnicity	White	17,099	67.0
	Black	2,737	10.7
	South Asian	2,721	10.7
	Other Asian	1,050	4.1
	Mixed	484	1.9
	Other	1,427	5.6
Diploma/Degree	Yes	10,348	40.6
General Health	Very Good	8,703	34.1
	Good	10,512	41.2
	Fair	4,722	18.5
	Poor	1,229	4.8
	Very Poor	352	1.4
Work Limiting Health	Yes	2,730	10.7
Economic Activity	Employed	15,077	59.1
	Unemployed	1,284	5.0
	Inactive	9,157	35.9
Full Time Employment	Yes	11,098	43.5
Income Quintiles	1	2,018	7.9
	2	2,020	7.9
	3	2,103	8.2
	4	1,946	7.6
	5	1,978	7.8
Living With Children	Yes	8,758	34.3
Housing Tenure	Owns Home	6,469	23.4
Housing Type	Detached	774	3.0
	Semi-Detached	2,566	10.1
	Terraced	5,454	21.4
	Flat	7,508	29.4
	Other	9,216	36.1
LSOA Variables	IMD	25,518	23.3 (12.5)
	Population	25,518	97.9 (63.7)
Greenspace Area, m^2	300m buffer	25,518	45,232.6
	500m buffer	25,518	151,444.6
	1km buffer	25,518	727,158.0

Table 5.1 Descriptive statistics of the final sample

Results of the OLS models, shown in Table 5.2, revealed positive and statistically significant associations between the amount of greenspace within 300m and all three wellbeing measures. However, after adjusting for all individual and local level potentially confounding factors, only the models predicting life satisfaction and worth were statistically significant. The regression coefficient, *B*, for the association between the amount of greenspace within 300m and life satisfaction was 0.783 (p = 0.006), which represents an expected rise in the life satisfaction score, for a 1km^2 increase in greenspace. Similar *B* values were observed for associations with worth, with coefficients of 0.731 (p = 0.009), and slightly weaker for happiness (*B* = 0.513, p = 0.140), although the latter was not statistically significant.

Greenspace within Buffer	*Life Satisfaction* *B*	*p*	R^2	*Worth* *B*	*p*	R^2	*Happiness* *B*	*p*	R^2
300m	0.601	0.037	0.013	0.874	0.002	0.020	0.299	0.003	0.005
300m, adjusted	***0.783***	***0.006***	***0.388***	***0.731***	***0.009***	***0.307***	0.513	0.140	0.288

Table 5.2 Results and greenspace coefficients for unadjusted and fully adjusted OLS associations between greenspace and mental wellbeing. Adjusted models include controls for: age, sex, marital status, ethnicity, general health, qualifications, economic activity, full time employment, income, housing tenure, living with children, housing type, LSOA population density and LSOA deprivation. (Statistically significant fully adjusted results are highlighted in bold italics)

Figure 5.6a-c present these associations graphically, with the lines of best fit signifying the fully-adjusted model parameters. Frequency density heat maps are plotted to demonstrate associations between individuals' greenspace prevalence and their wellbeing outcome scores; this representation ensures adequate privacy of individual-level data.

Global Moran's *I* tests detected very small, but statistically significant (at the 95% level) global autocorrelation of the residuals for each of these models (values of 0.005, 0.003 and 0.001 for life satisfaction, worth, and happiness models, respectively). Local Moran's *I* results also revealed statistically significant spatial clustering of the OLS results, as demonstrated by LISA cluster maps in Figure 5.7a-c, which demonstrate the locations and directions of this clustering. The legend defines whether the clusters are of low (the model over predicts) or high residuals (the model underestimated), and whether these indicate positive (clustering of similar values) or negative (dispersion) autocorrelation.

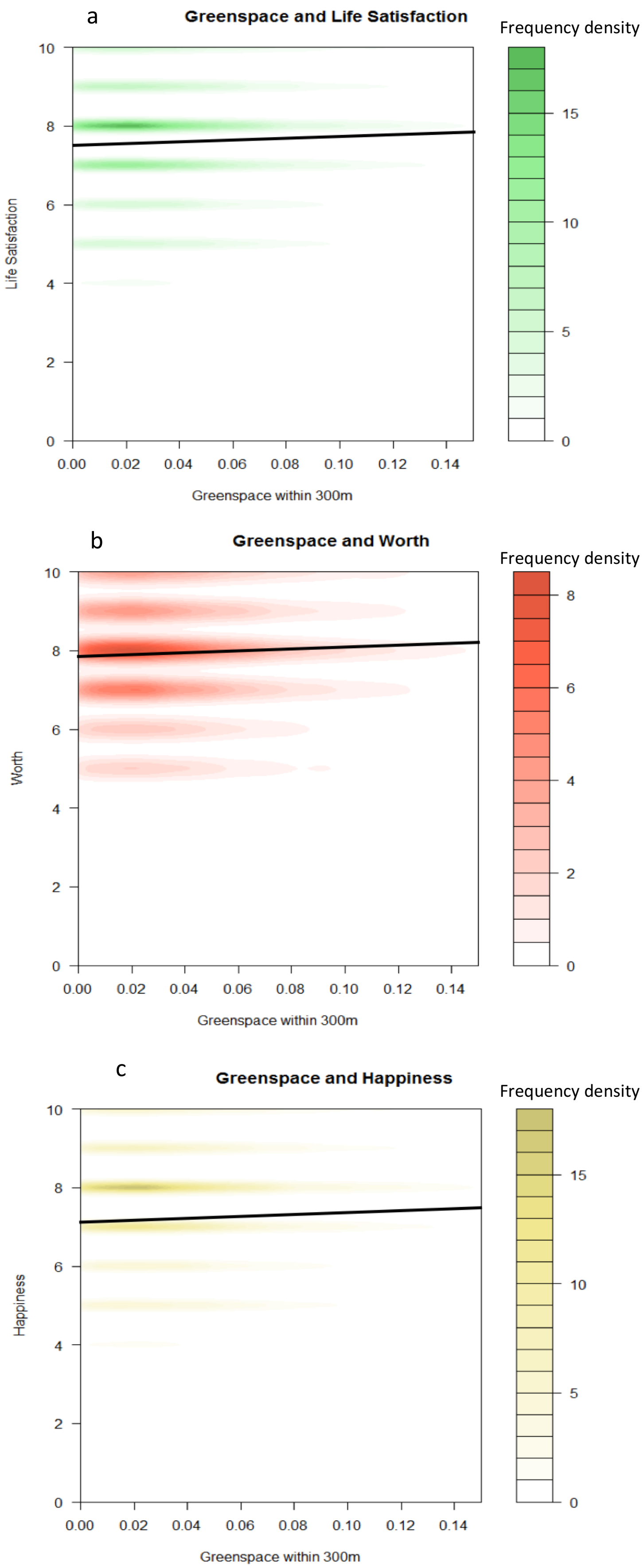


Figure 5.6a-c Heat-density plots of adjusted linear associations between the amount of greenspace (hectares) and mental wellbeing

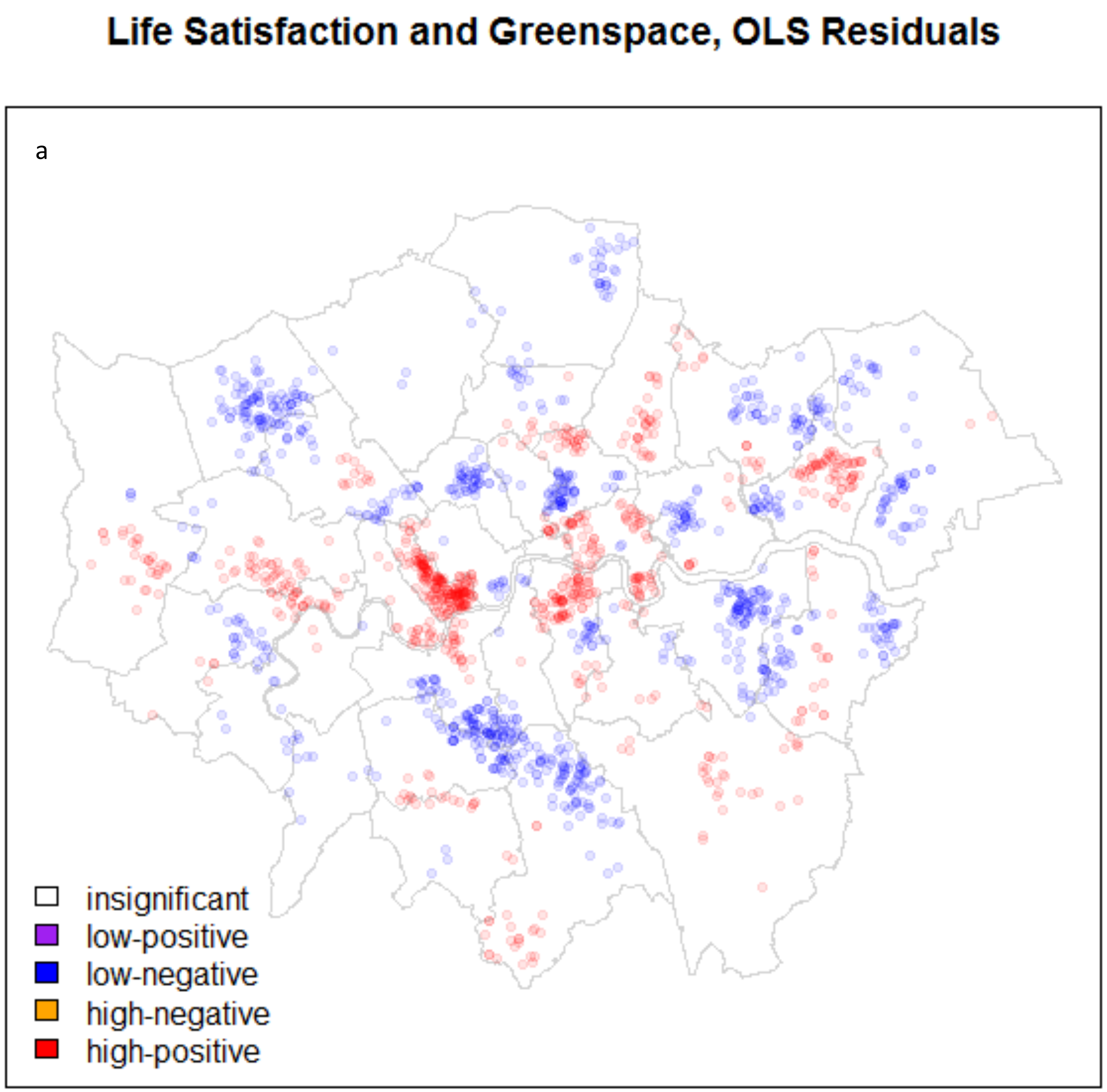


Figure 5.7 LISA cluster map of the residuals of the OLS regression models

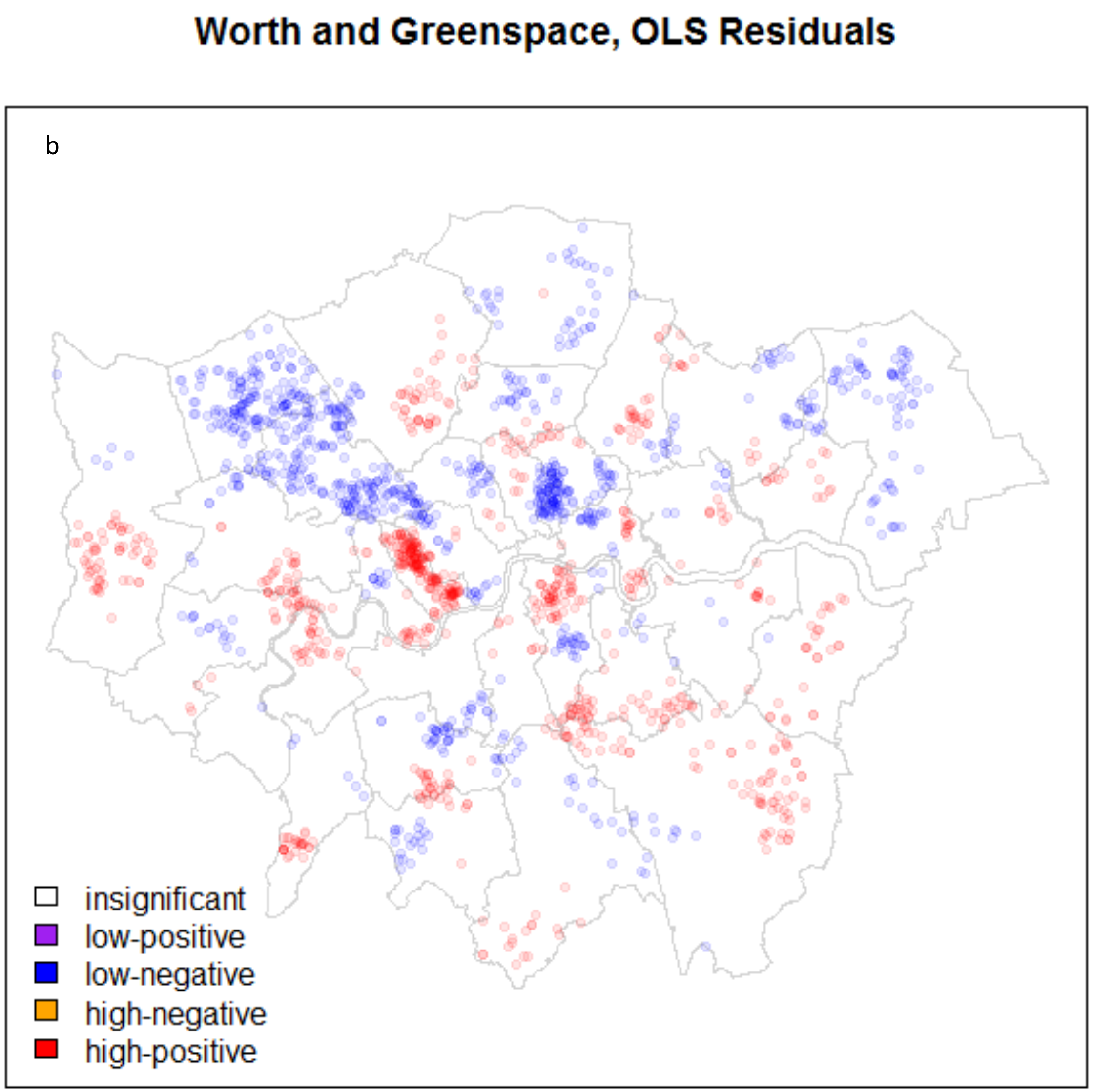


Figure 5.7LISA cluster map of the residuals of the OLS regression models

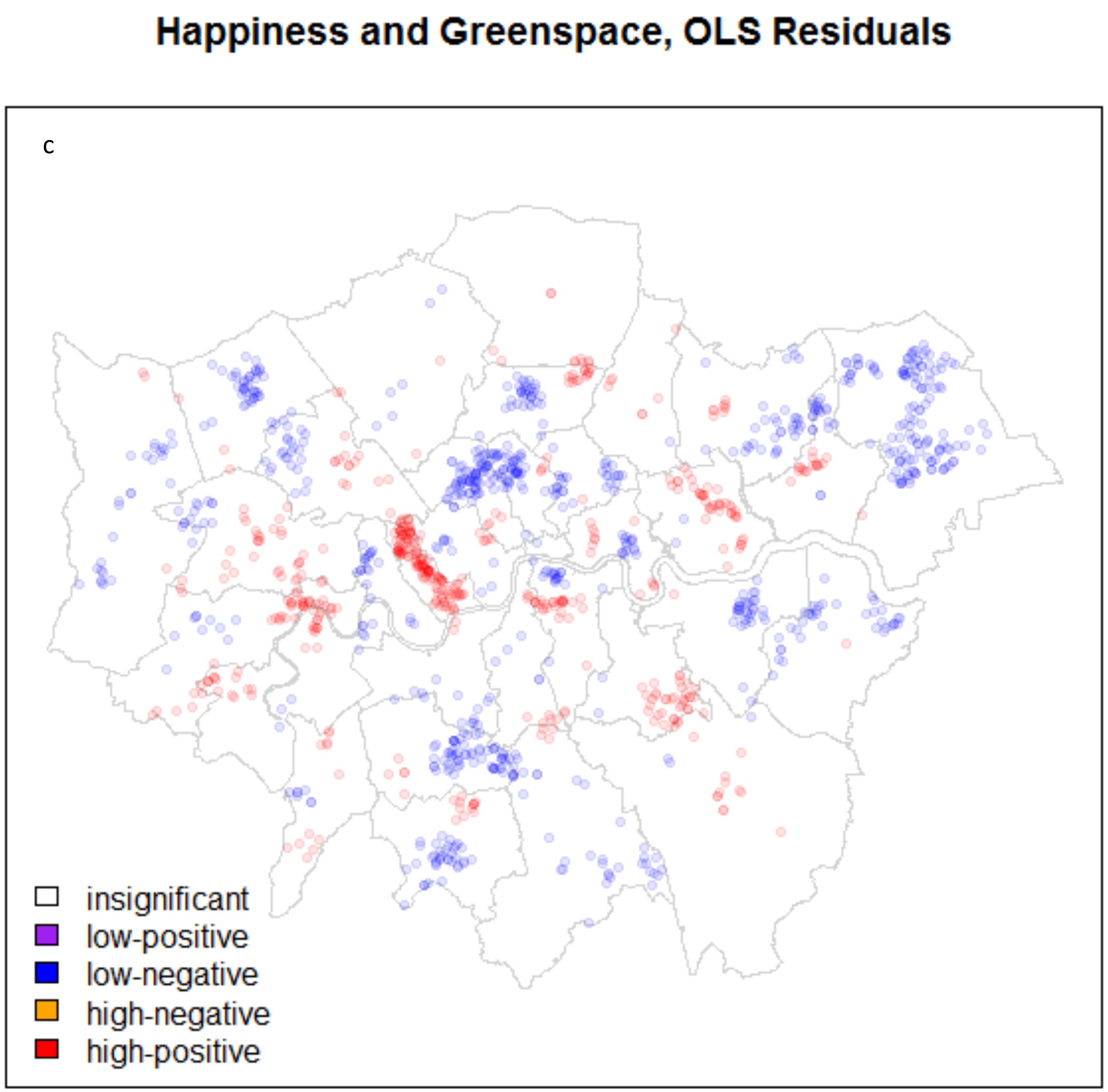


Figure 5.7 LISA cluster map of the residuals of the OLS regression models

The clusters of low and high residual values highlight areas where the OLS models systematically over- and under-estimate the associations between greenspace and wellbeing, across the study space. In the life satisfaction model, for example, high residuals towards the centre of London indicate the model over-estimating mental wellbeing, with predictions falling short towards the North and East of the city.

To further explore the spatial nature of the data, geographically weighted statistics were calculated for each wellbeing outcome; this method uses the selected kernels to predict mean scores from the matrix of neighbours within the bandwidth, weighted according to the Gaussian distribution. As plotted in Figure 5.8a-c, the geographically weighted means highlight how localised average scores vary across London. Life satisfaction and worth outcomes display similar patterns, with lower average scores clustering in the North of London, and darker areas of higher scores more prevalent towards in South. The map of happiness values again suggests higher scores further South, but also towards to West and North, with clusters of lower scores scattered around the edges of the map. The variation of the scores is also of note, with geographically weighted mean life satisfaction scores varying from 3-10, and a narrower 6-9 for worth. Happiness is similar to worth, ranging from a slightly lower 5-8.5.

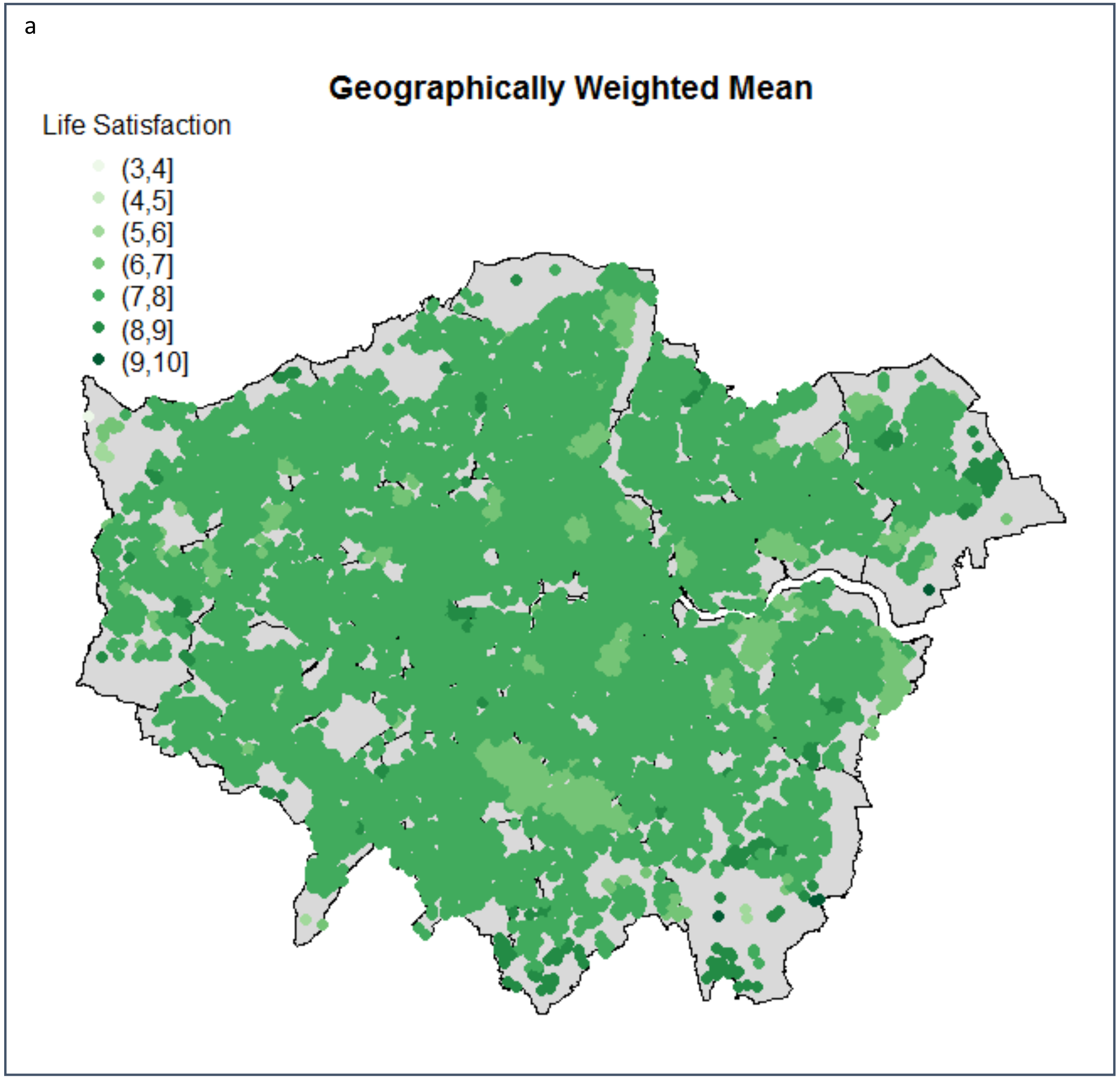


Figure 5.8a Geographically weighted means of wellbeing variables

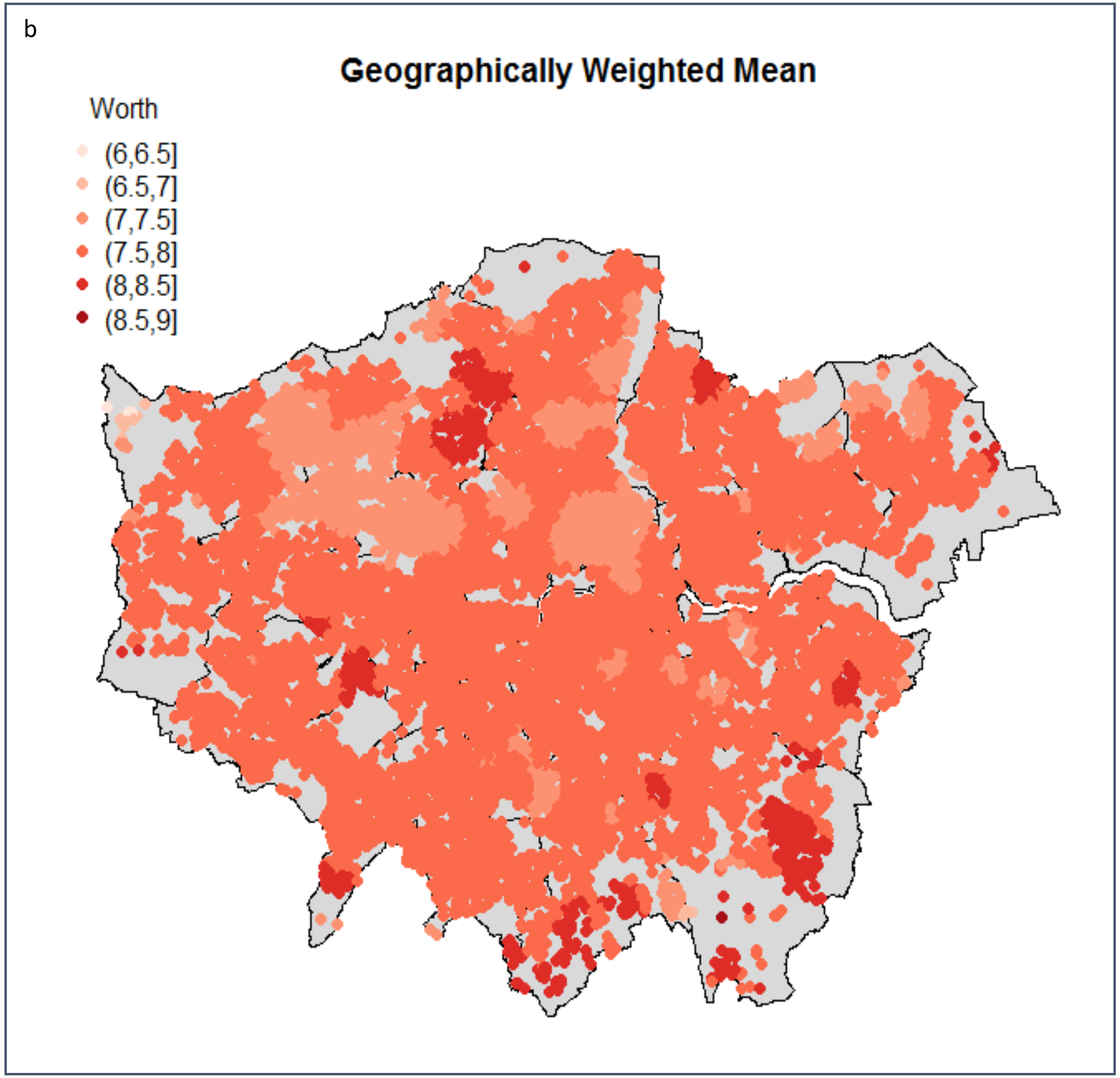


Figure 5.8b Geographically weighted means of wellbeing variables

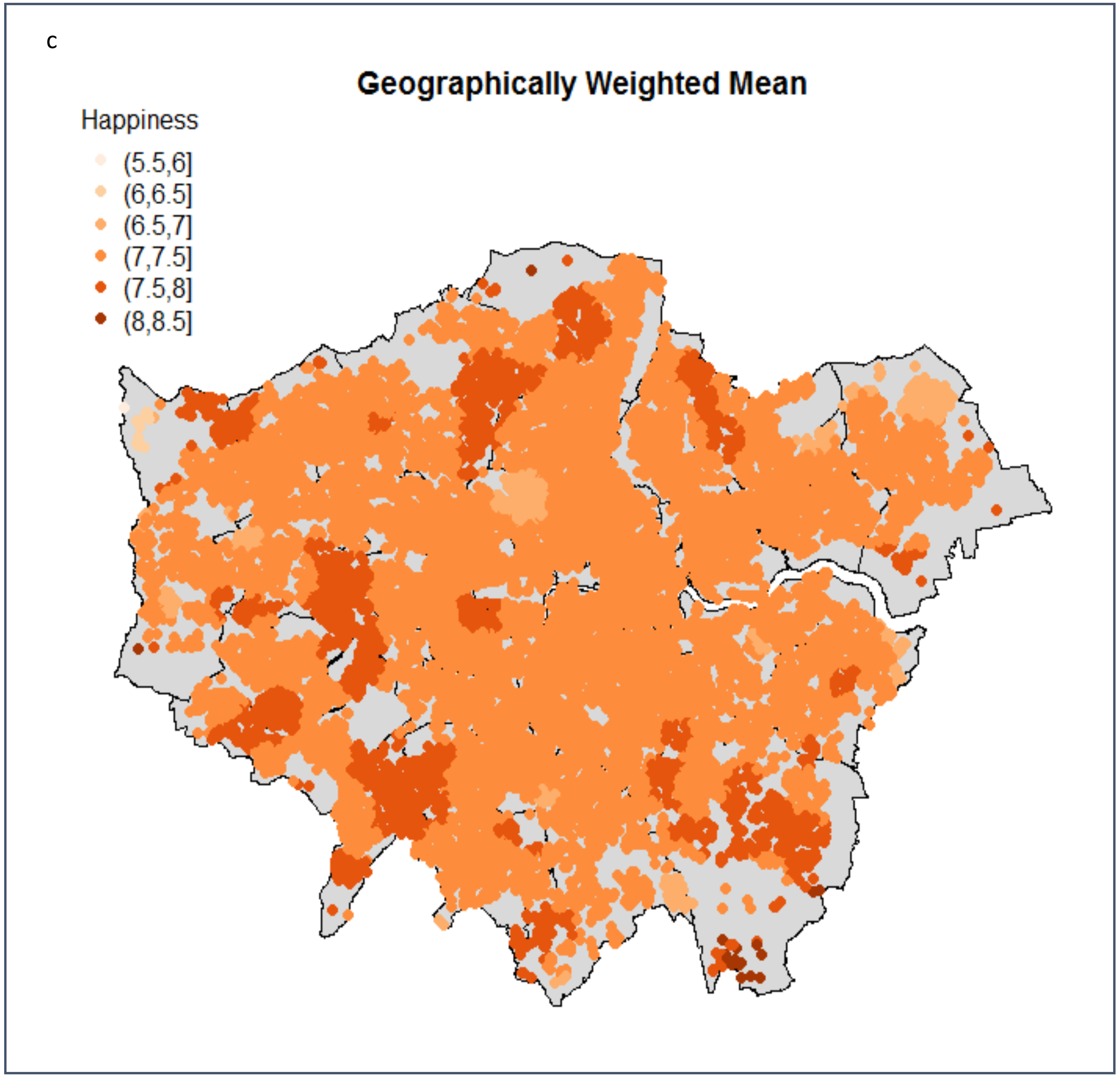


Figure 5.8c Geographically weighted means of wellbeing variables

Univariate geographically weighted regression models revealed statistically significant associations between larger amounts of greenspace within 300m and higher mental wellbeing scores for life satisfaction, worth and happiness. Worth showed the strongest association with a global *B* value of 0.821.

Coefficients for greenspace variables calculated with GWR models are presented in Table 5.3, for both univariate and fully adjusted models. The *B* value represents the mean value of the regression coefficient, β, indicating the expected increase in wellbeing score for a 1km^2 increase in greenspace provision within each buffer.

Greenspace	*Life Satisfaction*			*Worth*			*Happiness*		
within Buffer	*B*	*p*	R^2	*B*	*p*	R^2	*B*	*p*	R^2
300m	0.4840	<0.001	0.012	0.8212	<0.001	0.010	0.2985	<0.001	0.010
300m, adjusted	***0.8034***	***<0.001***	***0.305***	***0.7398***	***<0.001***	***0.170***	***0.5208***	***<0.001***	***0.136***

Table 5.3 Results and greenspace coefficients for unadjusted and fully adjusted GWR associations between greenspace and mental wellbeing. Adjusted models include controls for: age, sex, marital status, ethnicity, general health, qualifications, economic activity, full time employment, income, housing tenure, living with children, housing type, LSOA population density and LSOA deprivation. (Statistically significant fully adjusted results are highlighted in bold italics)

Positive and statistically significant associations were observed for fully-adjusted models with the amount of greenspace within 300m and life satisfaction, worth, and happiness, with *B* values of 0.8034, 0.7398 and 0.5208, respectively. Models predicting life satisfaction showed much higher goodness of fit, as indicated by the R^2 value (0.305), than the other wellbeing indicators (0.170 for worth, 0.136 for happiness). Interestingly, the *B* value for worth decreased slightly from unadjusted to adjusted models, whereas coefficients for life satisfaction and happiness both increased considerably when potentially confounding factors were adjusted for. Full results are shown in Tables 5.4-5.6.

Life Satisfaction, 300m

Variable	*Value*	*Global B*	*p*
Greenspace	300m	0.8034	<0.001
Age	16-24, as ref		
	25-34	-0.3296	<0.001
	35-44	-0.5181	<0.001
	45-54	-0.6633	<0.001
	55-64	-0.2554	<0.001
	65-75	0.1841	<0.001
	over 75	0.3064	<0.001
Sex	Male, as ref		
	Female	0.0918	<0.001
Married/Cohabiting	No, as ref		
	Yes	0.4826	<0.001
Ethnicity	White, as ref		
	Other Asian	0.0592	<0.001
	Black	-0.1983	<0.001
	Mixed	-0.109	<0.001
	Other	0.0535	<0.001
	South Asian	0.1707	<0.001
General Health	Very Poor, as ref		
	Poor	1.083	<0.001
	Fair	1.9515	<0.001
	Good	2.5822	<0.001
	Very Good	2.9968	
Qualifications	No degree, as ref		
	Degree/Diploma	-0.0736	<0.001
Economic Activity	Employed, as ref		
	Economically Inactive	-0.0915	<0.001
	Employed	-0.7221	<0.001
Full Time Employment	No, as ref		
	Yes	0.0098	<0.001
Income, Quintiles	1st	-0.127	<0.001
	2nd	-0.1125	<0.001
	3rd	-0.0367	<0.001
	4th	0.0984	<0.001
	5th	0.2218	<0.001
Living with Children	No, as ref		
	Yes	0.0429	<0.001
Housing Tenure	Does not own current home, as ref		
	Owns current home	0.1653	<0.001
Housing Type	Detached, as ref		
	Flat	-0.0694	<0.001
	Other	-0.0852	<0.001
	Semi Detached	-0.0263	0.1168
	Terraced	-0.0136	<0.001
Population Density		0.0006	<0.001
Deprivation		-0.0019	<0.001

Table 5.4 Results of fully adjusted geographically weighted regression model for life satisfaction and greenspace within 300m

Worth, 300m

Variable	*Value*	*Global B*	*p*
Greenspace	300m	0.7398	<0.001
Age	16-24, as ref		
	25-34	-0.1887	<0.001
	35-44	-0.247	<0.001
	45-54	-0.3152	<0.001
	55-64	0.1402	<0.001
	65-75	0.3874	<0.001
	over 75	0.3665	<0.001
Sex	Male, as ref		
	Female	0.2298	<0.001
Married/Cohabiting	No, as ref		
	Yes	0.2845	<0.001
Ethnicity	White, as ref		
	Other Asian	-0.0651	0.0037
	Black	0.044	<0.001
	Mixed	0.1705	<0.001
	Other	-0.0401	<0.001
	South Asian	0.0922	<0.001
General Health	Very Poor, as ref		
	Poor	0.8593	<0.001
	Fair	1.5886	<0.001
	Good	2.0186	<0.001
	Very Good	2.3915	<0.001
Qualifications	No degree, as ref		
	Degree/Diploma	-0.0162	<0.001
Economic Activity	Employed, as ref		
	Economically Inactive	-0.122	<0.001
	Employed	-0.5079	<0.001
Full Time Employment	No, as ref		
	Yes	-0.0051	<0.001
Income, Quintiles	1st	-0.0238	<0.001
	2nd	-0.064	<0.001
	3rd	0.0179	<0.001
	4th	0.0608	<0.001
	5th	0.0414	<0.001
Living with Children	No, as ref		
	Yes	0.2537	<0.001
Housing Tenure	Does not own current home, as ref		
	Owns current home	0.1082	<0.001
Housing Type	Detached, as ref		
	Flat	-0.1264	<0.001
	Other	-0.0892	<0.001
	Semi Detached	-0.061	<0.001
	Terraced	-0.0447	<0.001
Population Density		0.0002	<0.001
Deprivation		-0.0012	<0.001

Table 5.5 Results of fully adjusted geographically weighted regression model for worth and greenspace within 300m

Happiness, 300m

Variable	*Value*	*Global B*	*p*
Greenspace	300m	0.5208	<0.001
Age	16-24, as ref		
	25-34	-0.1307	<0.001
	35-44	-0.1818	<0.001
	45-54	-0.2317	<0.001
	55-64	0.0930	<0.001
	65-75	0.4727	<0.001
	over 75	0.5093	<0.001
Sex	Male, as ref		
	Female	0.0274	<0.001
Married/Cohabiting	No, as ref		
	Yes	0.3699	<0.001
Ethnicity	White, as ref		
	Other Asian	0.1110	0.0554
	Black	0.0967	<0.001
	Mixed	-0.1035	<0.001
	Other	0.0382	<0.001
	South Asian	0.2375	<0.001
General Health	Very Poor, as ref		
	Poor	0.9836	<0.001
	Fair	1.8975	<0.001
	Good	2.4760	<0.001
	Very Good	2.9740	<0.001
Qualifications	No degree, as ref		
	Degree/Diploma	-0.0579	<0.001
Economic Activity	Employed, as ref		
	Economically Inactive	0.0403	<0.001
	Employed	-0.3320	<0.001
Full Time Employment	No, as ref		
	Yes	0.0289	<0.001
Income, Quintiles	1st	0.0848	<0.001
	2nd	-0.0461	<0.001
	3rd	-0.0090	<0.001
	4th	-0.0870	<0.001
	5th	0.0036	0.1407
Living with Children	No, as ref		
	Yes	0.0570	<0.001
Housing Tenure	Does not own current home, as ref		
	Owns current home	0.0696	<0.001
Housing Type	Detached, as ref		
	Flat	-0.0116	0.0012
	Other	0.0287	<0.001
	Semi Detached	0.0304	<0.001
	Terraced	0.0464	<0.001
Population Density		0.0006	<0.001
Deprivation		-0.0027	<0.001

Table 5.6 Results of fully adjusted geographically weighted regression model for happiness and greenspace within 300m

Sensitivity analyses revealed greenspace coefficients which became weaker with distance. For life satisfaction, for example, the greenspace coefficient was reduced to 0.3300 at 500m, approaching 0 at a radius of 1km (0.0421). Similar patterns were observed for both worth and happiness. Full results tables for each of these models is presented in Appendix A.

Figure 5.9 represents graphically how the fully-adjusted mean coefficients for the amount of greenspace in predicting wellbeing outcomes decrease with the distance considered, above 300m. Associations are strongest for life satisfaction, with slightly lower regression coefficients for worth, followed by happiness; associations are weakest for the anxiety outcome, remaining negligible, very close to 0. Represented this way, it is evident that greenspace within 300m shows the greatest association with positive wellbeing measures, and although still positive, is reduced to almost null after 500m.

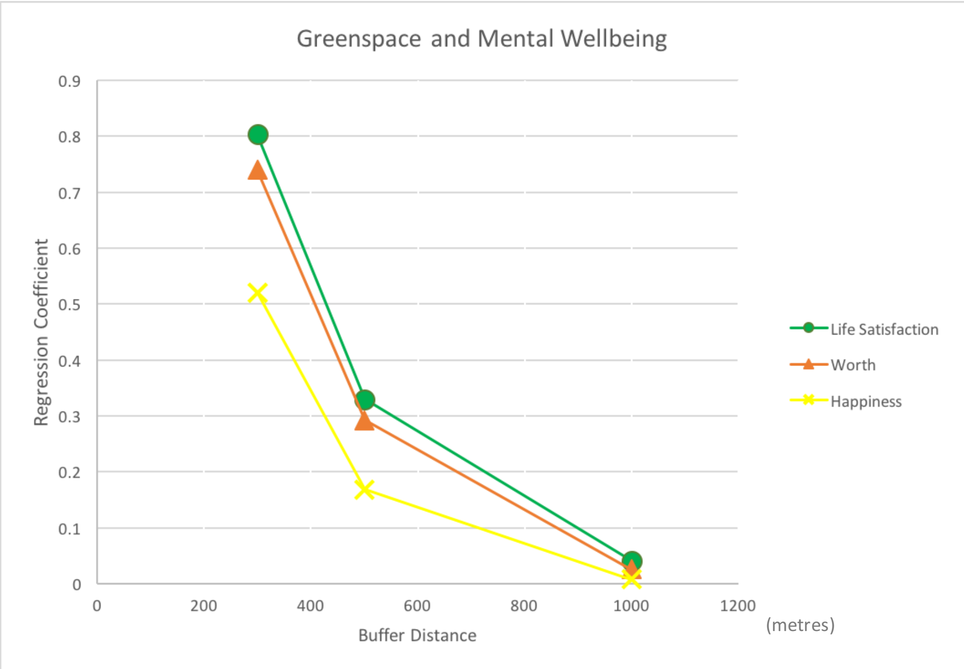


Figure 5.9 Regression coefficients for the association between greenspace and wellbeing, over increasing buffers

To visually investigate the spatial variation in these associations, the coefficients for each model were mapped (Figure 5.10a-c); the plots demonstrate expected variation in line with acceptable wellbeing outcome scores; coefficients vary from -10 to 10 for life satisfaction, and -6 to 6 for worth and happiness. Similar patterns of spatial variation can also be seen, particularly for associations between greenspace and worth and happiness, with lower β values generally observed towards the East of London.

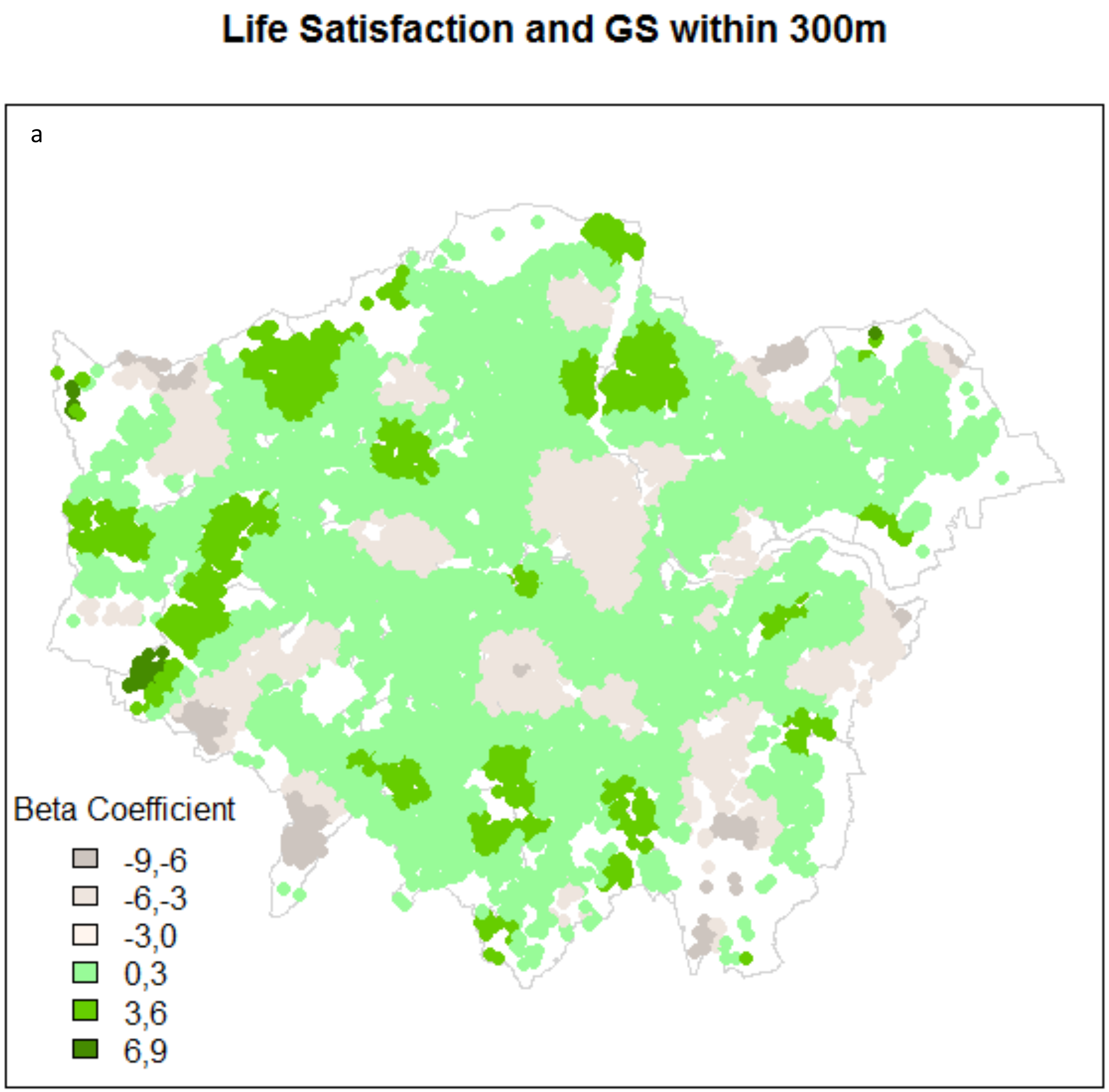


Figure 5.10a Beta coefficients of geographically weighted regression models

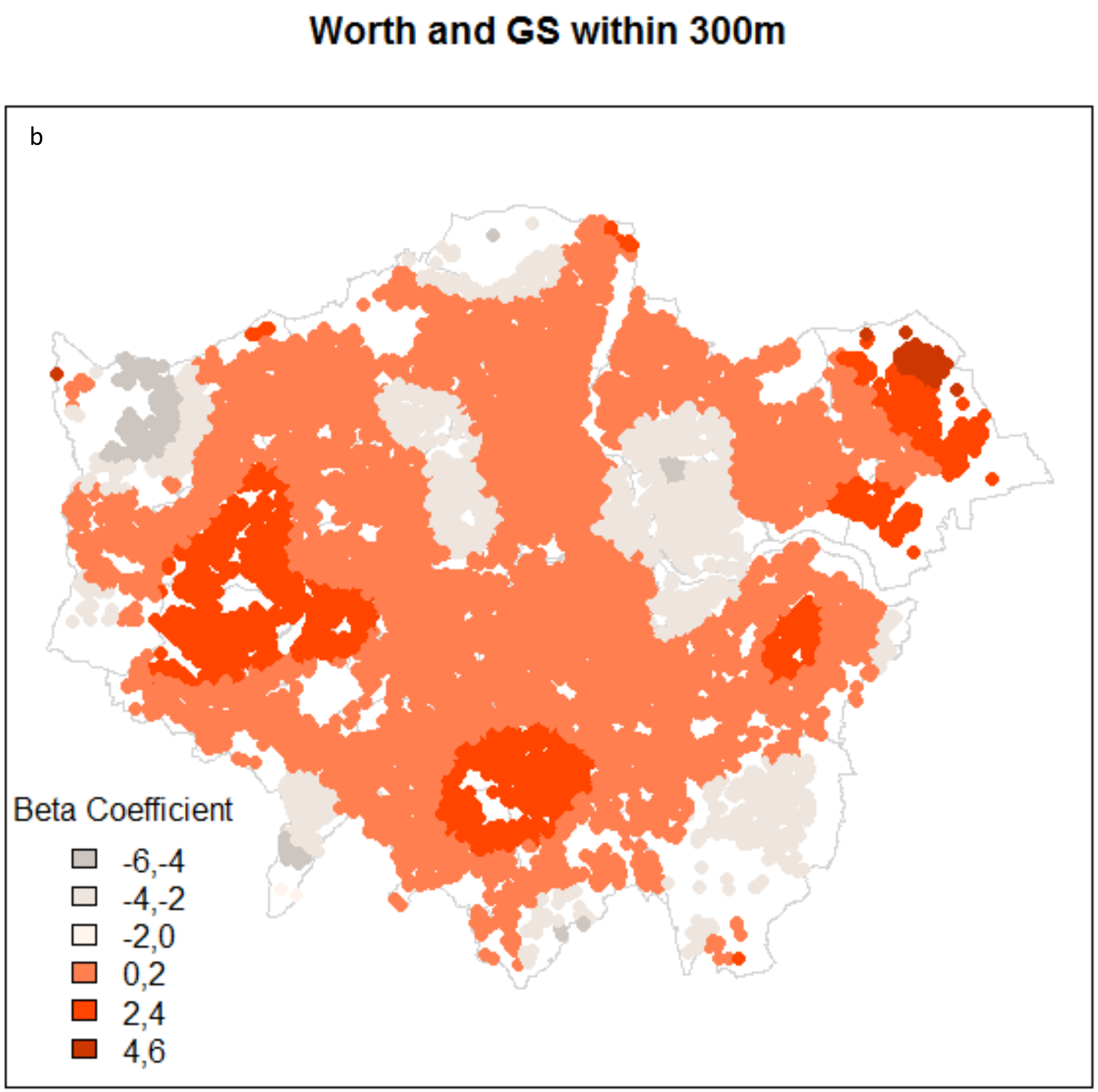


Figure 5.10b Beta coefficients of geographically weighted regression models

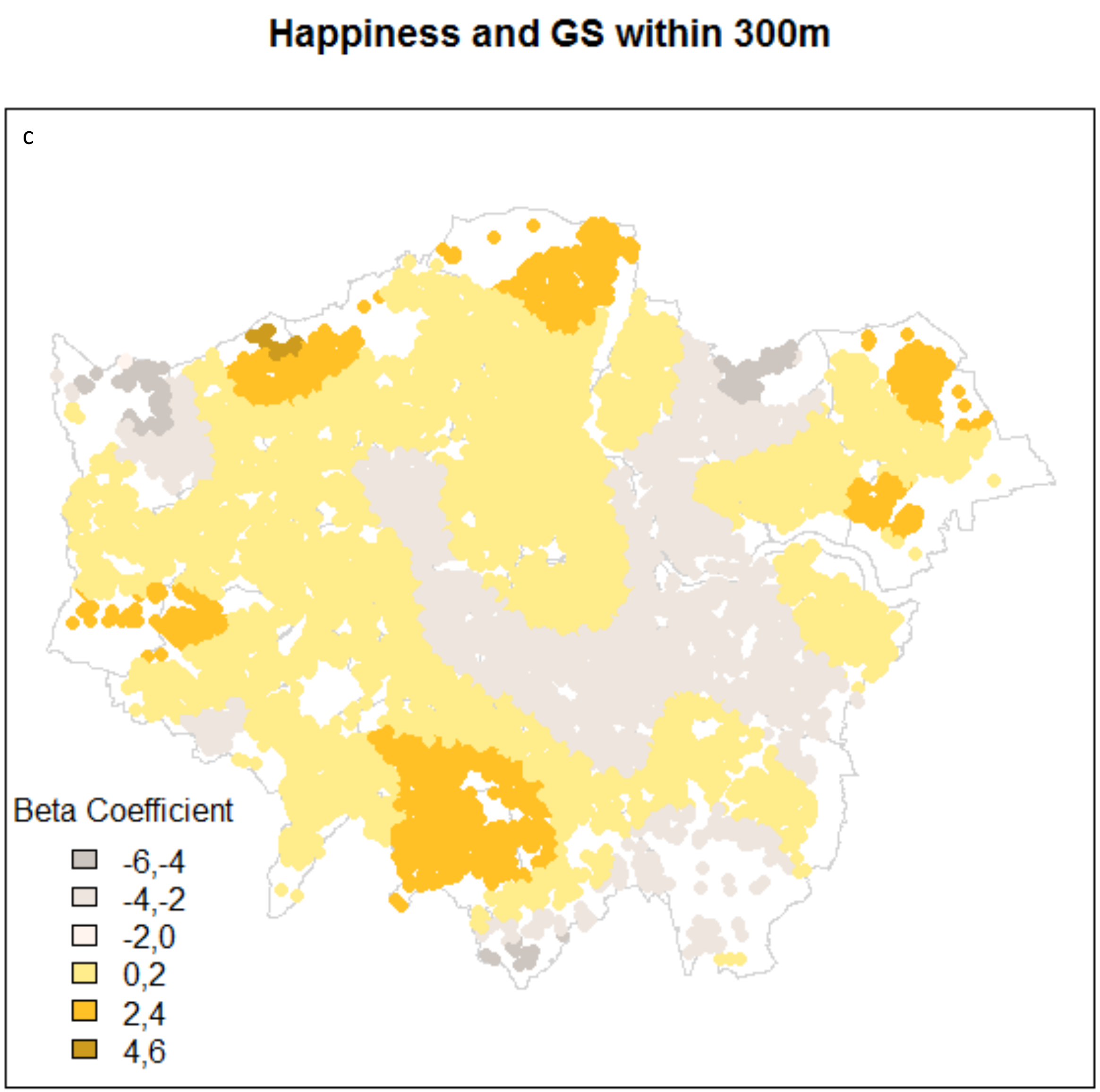


Figure 5.10c Beta coefficients of geographically weighted regression models

These visualisations therefore demonstrate the extent of the deviation in β values, and how geographically weighted regression models capture the spatial variation in associations between greenspace and mental wellbeing. For example, the greenspace and life satisfaction model (Figure 5.10a), while overall significantly positive, show stronger positive regression coefficients in the North, West and South of London, with some areas displaying negative associations towards the centre and East; this indicates how the importance of greenspace appears to be different in different regions.

Reductions in autocorrelations of residual errors highlighted that the GWR method effectively accounted for much of the spatial clustering in the data, and therefore considerably improved the fit of the model, for each wellbeing measure. The Global Moran's *I* value from the residual errors of a model predicting life satisfaction from just the potentially confounding factors was reduced from 0.005 to <0.001 when adding the variable for the amount of greenspace within 300m to a GWR model; similar patterns were observed for models both with worth and happiness as the outcomes. Plots indicating the statistical significance and direction of Local Moran's *I* for each of these associations are presented in Figure 5.11a-c. There was clear reduction in the residual error local autocorrelations when compared to the linear model equivalents shown in Figure 5.2a-c, which demonstrates that the addition of greenspace as a variable improves the capacity of the model to capture the spatial variation of the wellbeing scores.

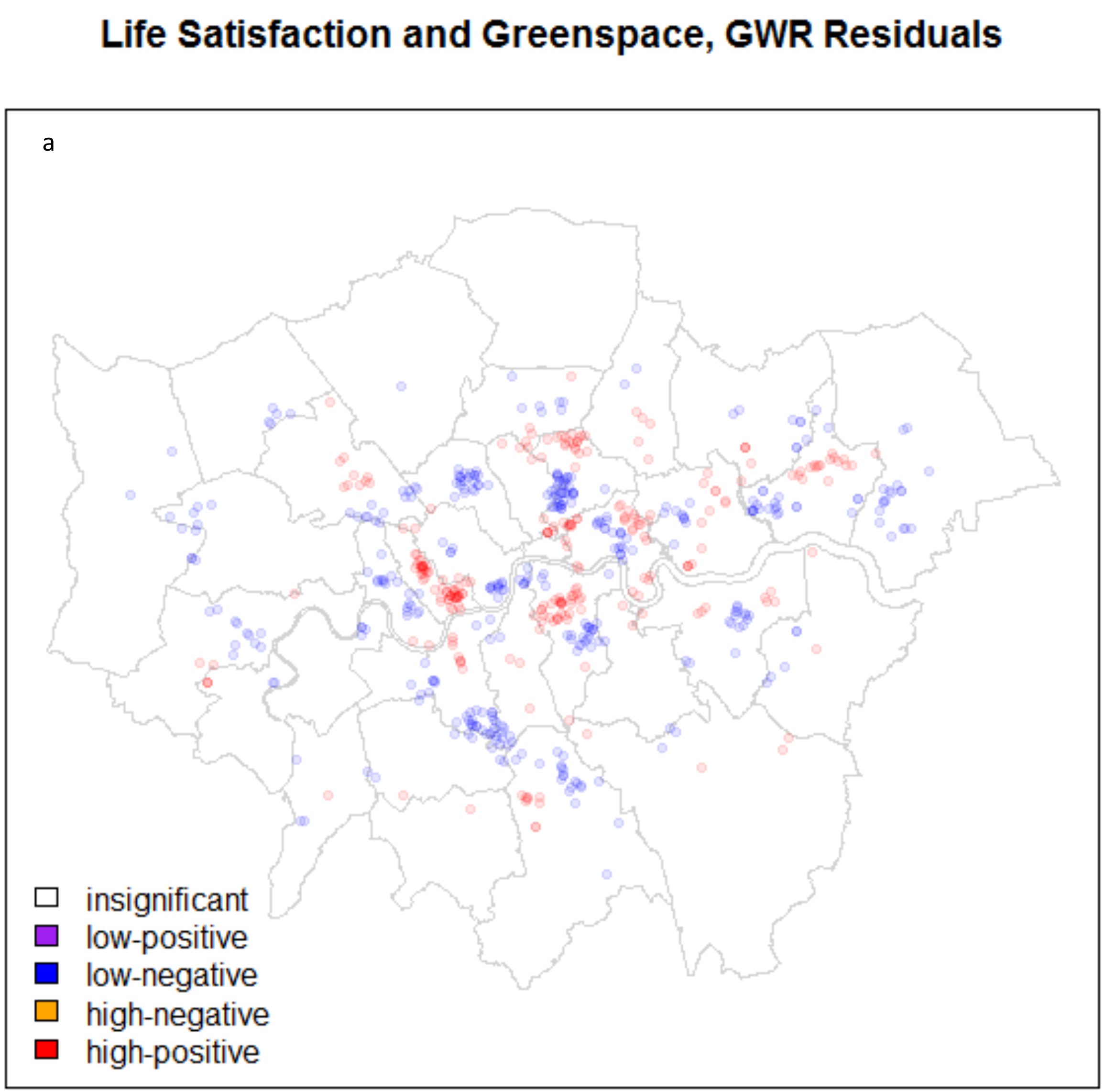


Figure 5.11a LISA cluster map of residuals of GWR models

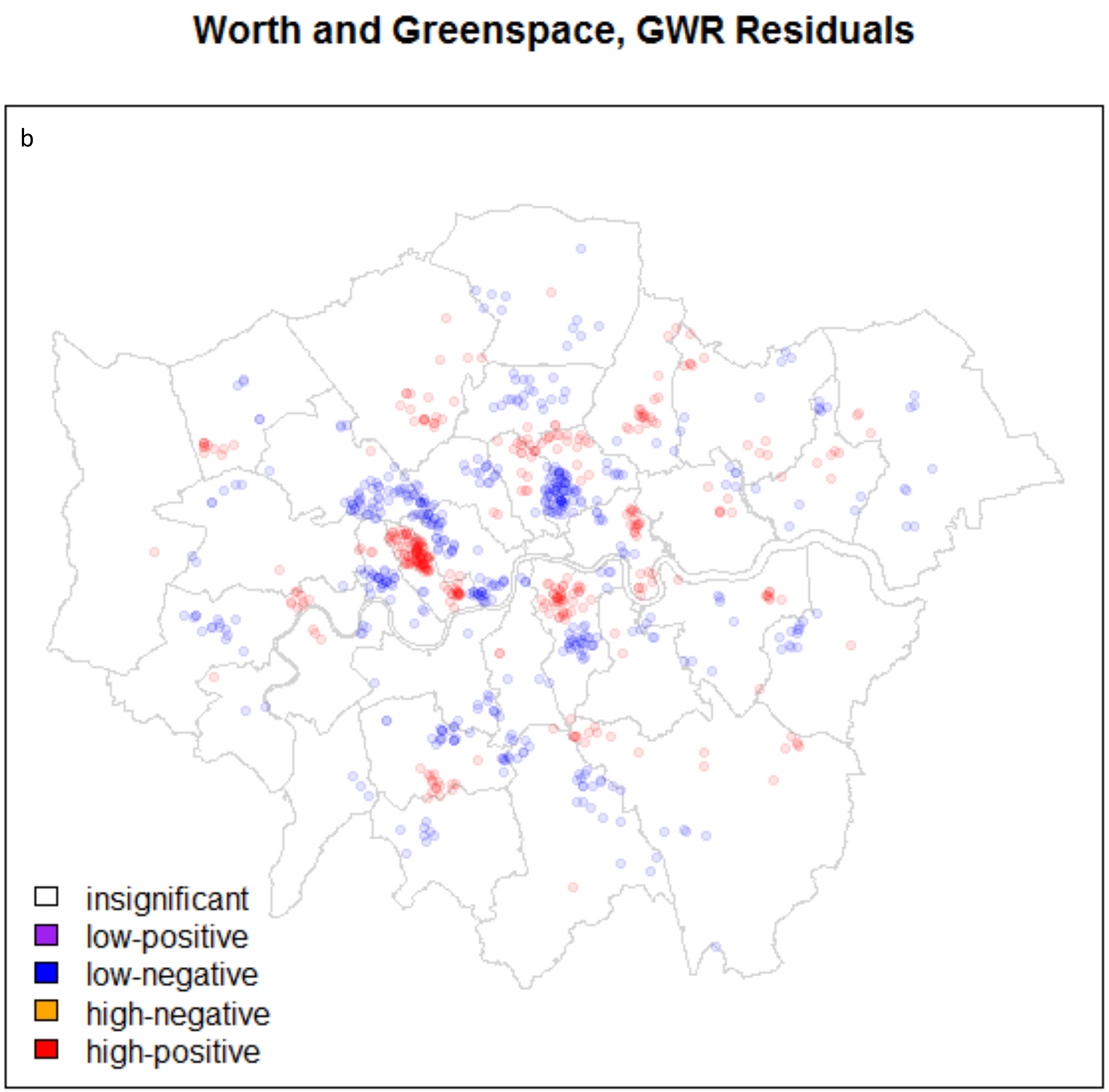


Figure 5.11b LISA cluster map of residuals of GWR models

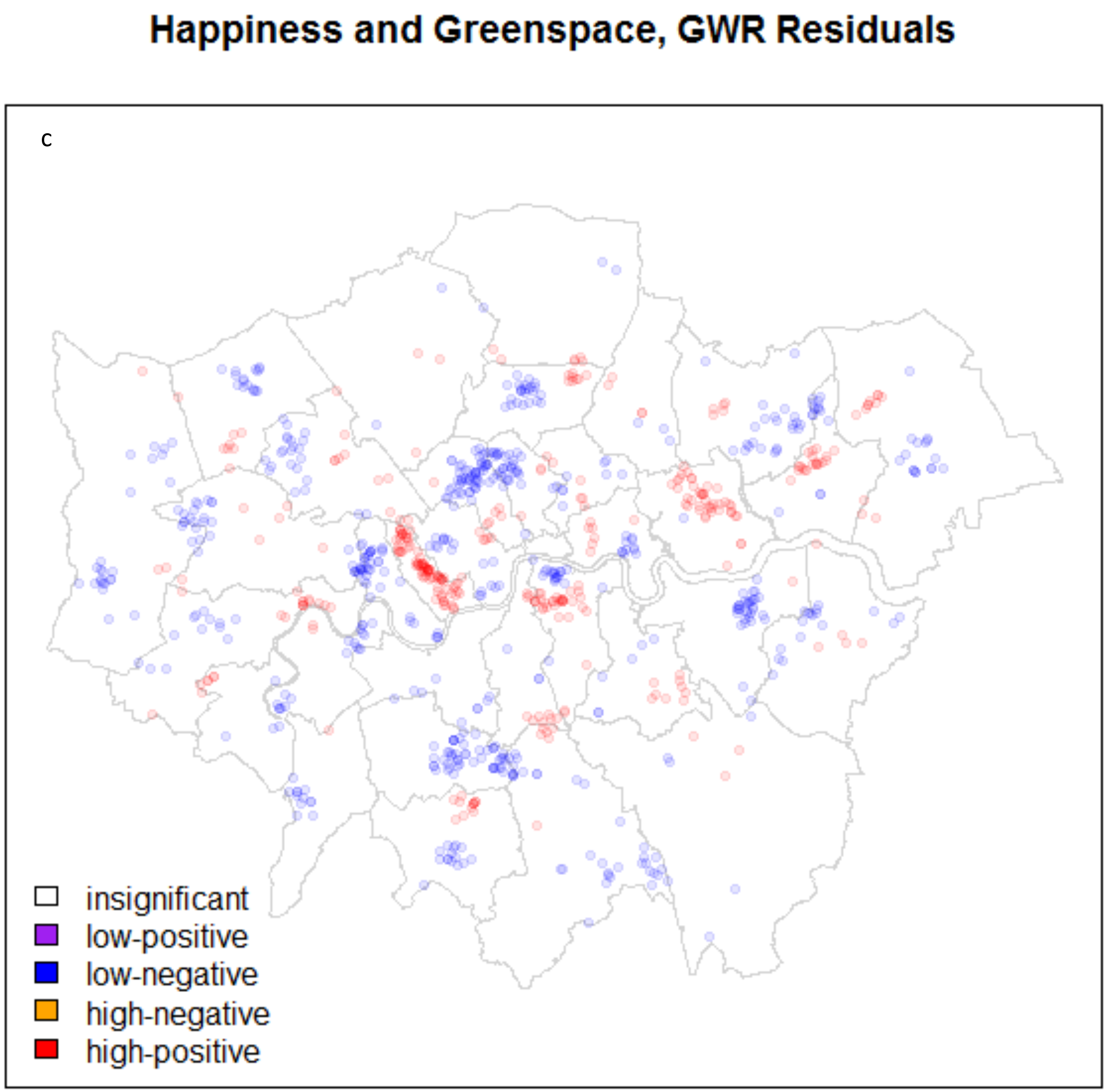


Figure 5.11c LISA cluster map of residuals of GWR models

5.4 Discussion

5.4.1 Key findings

A large body of evidence has previously linked local prevalence of greenspace to improved health outcomes [19, 24, 40], with many studies agreeing that mental health may be improved for those living in greener areas [101]. While studies of positive mental health have found associations between surrounding greenness and aspects of mental wellbeing such as life satisfaction and quality of life [16, 122, 123, 131], results of analyses using measures of both hedonic and eudaimonic wellbeing have so far remained inconclusive [38, 132, 133, 152]. However, these multidimensional studies have generally been restricted by their application of only local area greenspace, according to arbitrary statistical boundaries, rather than that surrounding an individual's home, which may have misclassified residents and masked associations [38]. Unlike these studies, this analysis measures greenspace at the individual level, and was able to detect such associations.

Using the three mental wellbeing measures, distributed through the UK's Annual Population Survey, this study examined the associations between greenspace at various distances from individuals' post codes, and their hedonic and eudaimonic wellbeing, in London. Government recommendations that greenspace should be provided within 300m of homes were tested, by conducting sensitivity analyses for greenspace within 300m and wellbeing measures of life satisfaction, worth and happiness.

Prevalence of greenspace was positively and significantly associated with measures of hedonic and eudaimonic wellbeing in linear models. Geographically Weighted Regression adjusted for present spatial autocorrelations in the data, and allowed the differences in associations between people and places to be observed. Examining Moran's *I* values revealed that the spatial autocorrelations of residuals present in the OLS models were significantly reduced, and non-significant, through the application of GWR models.

From the GWR models, associations with life satisfaction showed the best fit, as well as the highest regression coefficients, suggesting that greenspace may be most important for this aspect of mental wellbeing. Worth and happiness both had slightly lower goodness of fit, with worth more strongly associated with greenspace than happiness.

These findings begin to provide some evidence that government guidelines recommending greenspace provision within 300m of homes may be appropriate in designing for mental wellbeing, in London. With the strongest association detected for this distance, this suggests that closer greenspace may be more important for mental wellbeing, and life satisfaction in particular, than greenspaces located at greater distances from individuals.

Sensitivity analyses across different buffers revealed a potential dose-response effect, with the strength of associations decreasing with distance, thereby implying that greenspace closer to homes is potentially more important for mental wellbeing than that further away. As associations for greenspace within 1km were negligible, it could be suggested that interventions to maintain and improve greenspaces should be focussed within closer proximity to individuals.

Visually examining the distribution in GWR coefficients also revealed that the strength of association varies across the study space. Regression coefficients appeared higher towards the outskirts of London, with slightly weaker, and sometimes negative associations observed towards the centre. These results imply that the association between greenspace and mental wellbeing is not static and, although overall positive for these measures, the strength and direction may further differ according to the individual people and places.

It is possible that these spatial patterns depend on features of the environment, or greenspace in particular, which were not accounted for within these models. For example, the stronger, positive associations towards the edge of London may be due, in part, to difference in greenspace composition to that in the centre. Natural spaces have been shown to relieve stress [26], restore fatigued attention [25] and promote feelings of happiness [20]; it could therefore be suggested that greenspaces with more natural features may be more beneficial to mental wellbeing. It may be that central greenspaces are typically in the form of parks, but others may be larger or more natural towards the more suburban outskirts of London; these features may be important for mental health and wellbeing [19].

As well as the amount of 'nature', different types of greenspaces may be useful in different ways. For example, it is suggested that individuals who have more local sports facilities are likely to do more exercise, which is beneficial to both physical and mental health [28, 82], whereas parks and other such green meeting-places may facilitate social interactions, which foster a level of community support and may support better mental wellbeing [40, 93]. Therefore, the prevalence of various types of greenspace in different areas may be beneficial in a range of ways, to different people, and further analyses of these types may help uncover which associations between greenspace and mental wellbeing differ across space.

As well as composition, the size of each greenspace may be important of itself. This study only captured the total amount within a buffer, not the absolute size of each space. Kaplan and Kaplan's Attention Restoration Theory proposes that spaces much have sufficient *extent* to be beneficial [25]; it could be speculated that, due to building density, greenspace in central London may be smaller in size and thus more fragmented, with larger open spaces more prevalent towards the outskirts of the city. Further research, which examines the size of each individual greenspace, would be beneficial in deepening understanding of these relationships.

It may also be that other factors, such as the accessibility and use of greenspace, which were not captured in these analyses, may also be beneficial. By using only Euclidean buffers, actual travel distance, which is a key component of accessibility, was not captured in this study.

Further, although this study adjusted for deprivation, it is possible that there may be interactions between more deprived areas and availability of greenspace, which would be worthy of future investigation.

5.4.2 Strengths and limitations

While the UK Government has guidelines on greenspace provision, this is thought to be the first study to provide evidence to support the recommended greenspace within 300m, in relation to mental wellbeing. This study was also able to examine both hedonic (life satisfaction, happiness) and eudaimonic (worth) dimensions of wellbeing, which have so far only been examined with greenspace according to census boundaries (such as LSOAs or wards), which give no indication of greenspace within a set distance of the individual's home. This work therefore benefits from providing insights at the individual, rather than local, level. By generating buffers at multiple distances around the individual's post code, this research also provides the novel ability to observe how these associations changed for greenspace prevalence at increasing distances.

Previous studies have tended to examine relationships between greenspace and health using non-spatial techniques, such as linear or logistic regression. This is the first study which has applied spatial modelling techniques, to account for the inherently geographic clustering of individual and greenspace prevalence data. Results of both linear and geographically weighted regressions highlight that accounting for the underlying spatial processes may reveal associations which traditional methods may not be capable of detecting, and suggests that such associations may vary across the study region.

Although restricted to London, this analysis benefitted from a large sample size of over 25,000 individuals, from the Annual Population Survey, which contains detailed socio-economic individual level data, as well as each individual's post code centroid. This allowed a comprehensive dataset to be generated by merging information from local area, greenspace and individual sources. This study was also able to control for a large range of potentially confounding factors, from socio-economic status to health, living conditions, local area deprivation and population density. These findings, while insightful and statistically significant, are based on data from London only and should be interpreted with caution when considering the rest of the UK, or further afield.

However, while this analysis is novel in its application of individual-level, rather than traditional local area level greenspace, Euclidean distance does not take account of actual travel distance, which may simplify how close individuals are to a greenspace in real terms, and limit the interpretation somewhat. Further, greenspace may take many forms, from parks to nature reserves and sports facilities. While the data on greenspace typology was available from GiGL, application of this classification was not the focus of this research; future analyses of different types may reveal different associations. This project also did not allow for account to be taken of factors such as accessibility, quality or facilities of the greenspaces, all of which may be associated with mental health outcomes [40].

The APS measure provides information on self-reported hedonic and eudaimonic wellbeing; however, it only has one item (worth) relating to eudaimonic aspects. Other scales, such as the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS), for example, provide up to 14 items covering aspects including feeling useful, relaxed, close to other people, dealing with problems well, thinking clearly, and able to make up one's mind, may be more holistic [59].

Although applied to population surveys such as the UK's Longitudinal Household Panel Study, this survey is not available in datasets as large as the APS.

It should also be considered that, although geographically weighted regression was selected to account for the spatial patterns in the data, and its application to such analyses is still fairly experimental, other, more complex methods such as Floating Catchment Areas (FCAs), or Autoregressive Models, might also be appropriate, and may yield different results.

Finally, despite the depths and detail of this analysis, the cross-sectional nature of the data provides no indication of causality or direction of these associations.

5.5 Conclusions

While previous studies have been unable to detect any association between greenspace in an individual's local area and their mental wellbeing, this analysis applied spatial methods to reveal a positive association between greenspace around homes and hedonic and eudaimonic wellbeing. Positive, statistically significant associations were found for prevalence of greenspace within 300m and mental wellbeing, with the association becoming weaker over greater distances. Associations were also found to be generally weaker in the centre of London. While UK government guidelines recommend that greenspace should be provided within 300m of all residents to benefit health, these results provide evidence that this distance is also associated with higher levels of mental wellbeing. Future studies should continue to adopt methodological approaches which consider the spatial nature of the data, and expand on this work by considering actual travel distances and types of greenspaces.

6.0 Access to different types of greenspace and mental wellbeing

"Nature holds the key to our aesthetic, intellectual, cognitive and even spiritual satisfaction"
- E. O. Wilson

6.1 Introduction

Nature is thought to promote positive feelings, relaxation and reduced stress, as conceptualised through theories including Biophilia [20], Attention Restoration Theory [25, 73, 74] and the Stress Recovery Theory [26, 77]; these theories have been validated by a number of studies [72, 78, 211, 227-231]. Therefore, much of the early evidence on greenspace benefits for health focuses specifically on nature [19], while the terms 'nature' and 'greenspace' are commonly used interchangeably within the literature [37].

However, while greenspace itself is not restricted only to more 'natural' areas, but also includes a broader range of green features, including ornamental gardens, sports pitches, amenity areas and common land. While urban greenspace may therefore take many forms, the majority of existing research has focussed on local quantity of greenspace [37], which was also the focus of projects presented in Chapters 4 and 5. Within these studies, greenspace is considered as a single entity, which gives insight into greenspace prevalence and potential exposure within an individual's local environment, but is naïve in its approach to the composition of greenspace; it does not provide evidence for which types of greenspace, or indeed 'nature', are most important for mental wellbeing.

Aside from benefits associated with exposure to nature, greenspace may also promote mental health benefits by providing a location to pursue health-promoting activities, such as outdoor sports facilities facilitating exercise [85], while parks may be used for socialising and other activities [93]. Following evolutionary theory, organisms should be attracted to the environments in which they would have maximal success; therefore, the type of environment which most benefits an individual may also be influenced by their mood and inclinations [32, 75]. By investigating associations between different types of greenspace and mental wellbeing, it may be possible to tentatively infer which mechanisms may be important for this relationship. While recent years have seen rapid urbanisation, such environments have been traditionally designed to maximise aesthetics, mobility and accommodation, whereas which natural features offer the greatest benefit is still to be determined [4].

While several studies have begun categorising greenspace in an effort to unpick this association, many use self-derived classifications [134, 138, 140], or alternatively compare 'natural' and 'non-natural' environments [135, 139], often without providing detailed definitions of these terms [19, 37, 232]. Further, the vast majority of studies have used linear or logistic regression, which overlook the importance of any spatial structures within the data [37]. Only one study has been found through the systematic literature review which compares different types of greenspace in association with both hedonic and eudaimonic wellbeing, revealing a positive association between the number of sports facilities and natural spaces within a 1.6km Euclidean buffer and WEMWBS scores [133]; sports spaces showed the strongest relationship. However, this study was based on a small selective sample of less than 500 people living in Perth, Australia and did not consider spatial patterns in the data.

The study presented in Chapter 4 revealed that associations between greenspace and mental wellbeing could not be detected at the local census level, which may be partly caused by the imposition of arbitrary boundaries, which restrict observations of the real-world interactions between individuals and their surrounding greenspace. Building on this, Chapter 5 provided evidence that, when considered within a buffer surrounding the individuals' post codes, a positive association exists between prevalence of greenspace and mental wellbeing. However, this regression coefficient was found to vary in strength across London, implying that in some areas, greenspace may be more important for mental wellbeing than in others. This may be due in part to additional greenspace characteristics which were not accounted for within this study, such as type and absolute size of the greenspace. Furthermore, while the Euclidean buffer used in this study is computationally effective and provides a first insight into the amount of greenspace surrounding residents' homes, it is relatively simplistic in that it gives no indication of actual access distance or how individuals move around their local area. Studies of greenspace accessibility tend to use the Euclidean measure [37, 46, 129, 154], while measures of actual travel distance require more specific data and are more computationally intensive.

Therefore, this study was designed to investigate these spatial variances in associations between greenspace and mental wellbeing in London, by measuring local greenspace in more detail, in terms of actual travel distance, absolute size, and type.

Natural England's Accessible Natural Greenspace Standard specifies that all individuals should have available a 'natural' greenspace of at least 2 hectares in size within a 300m walk of their home, a recommendation based on pilot schemes, surveys and walking patterns. Current evidence suggests that those with greenspace within a walking distance of their homes are more likely to meet government recommendations for physical activity [233], but findings for potential mental health benefits are mixed and inconclusive, due to inconsistencies in the measurement of both greenspace types and wellbeing [37, 232].

While Chapter 5 found that greenspace within 300m Euclidean distance was positively associated with mental wellbeing, it is not yet known whether this holds for walking distance. Further, to investigate the assumption that 'nature' should be provided, this research aimed to investigate access to different types of urban greenspace, drawing comparisons between types. As there currently exists no standardised greenspace typology for use in research, the former Planning Policy Guidance provided by the UK government was used, which provides detailed, consistent and well-defined categories for greenspace planning, although it has not been found to as of yet be applied to research on mental wellbeing [37]. This study was therefore designed to address the final research question, specified in Chapter 1:

Research Question 4 - Are natural greenspaces more strongly associated with mental wellbeing than other, manmade, types of greenspace?

The following hypotheses were tested:

(1) That those with access to greater amounts of greenspace within 300m walking distance of their homes have higher mental wellbeing scores
(2) That access to natural greenspace is more strongly associated with mental wellbeing than other types of greenspace

6.2 Methods

6.2.1 Sample and setting

Data were drawn from the APS 2012-2015 Pooled Dataset, as in Chapter 5 [217]. After restricting the data set to include only residents of London, with available data, the final sample included 25,079 individuals. For full details of the initial sample and survey design, please see Chapter 5.

6.2.2 Study variables

6.2.2.1 Individual and local variables

Mental wellbeing was again measured through three ONS items: life satisfaction, happiness and worth [217], as in Chapter 5, which also describes the same individual, household and local are characteristics which are employed in this analysis.

6.2.2.2 Location and street network

The Code Point map [220], used in Chapter 5, again provided coordinates for each individual post code. This was linked with the Ordnance Survey Open Roads shapefile [234], which contains a street network for London and can be spatially connected to the post codes shapefile, APS and greenspace data, allowing the actual travel distance between individuals and greenspaces to be calculated.

6.2.2.3 Greenspace

Greenspace data were again obtained from the Greenspace Information for Greater London group (GiGL) [104].

In addition to the sizes and locations implemented in Chapter 5 greenspaces are also assigned an open space category, according to the UK Government's Planning Policy Guidance (PPG17) definitions [51], which is determined based on site surveys conducted by the Borough councils who provide the data for aggregation by GiGL [104]. Categories available are: Parks and Gardens, Natural and Semi-natural Urban Greenspaces, Green Corridors, Outdoor Sports Facilities, Amenity, spaces for Children and Teenagers, Allotments and Community Gardens and City Farms, Cemeteries and Churchyards, Other Urban Fringe, Civic Spaces, and Other [51]. For the purposes of this research, only the categories Parks and Gardens (hereafter referred to as Parks), Natural and Semi-natural Urban Greenspaces (Natural greenspace) and Outdoor Sports Facilities (Sports) were considered, with the remaining greenspaces assigned to the Other category; this was in order to test whether access to natural spaces was more strongly associated with mental wellbeing, compared to other types most commonly studied on the literature [22, 28, 78, 126, 127, 133] and allow the potential benefits of exposure to nature, social interaction and physical activity which may be facilitated by these spaces to be explored. These types were chosen to maximise the number of greenspaces within each grouping and provide the most informative data for analysis. Details of the Planning Guidance classification system are provided in Table 6.1.

PPG17 type	*Study name*	*Description and aggregation of sub-categories, taken from GiGL [51, 104]*
Parks and Gardens	Parks	**Park** is a traditional public open space laid out formally for leisure and recreation. Examples include the Royal Parks, municipal parks such as Battersea Park, and wider places such as Hampstead Heath **Formal garden** refers to spaces with well defined boundaries that display high standards of horticulture with intricate and detailed landscaping. It includes London squares common to central London, including Belgrave Square and Soho Square.
Natural and Semi-natural Urban Greenspace	Natural greenspace	**Common** is a formal designation. They are publically accessible open spaces with few if any facilities. They will typically be mainly rough open grass/woodland, less formal than parks. Examples include Wimbledon Common and Clapham Common. **Country Parks** are large areas set aside for informal recreation near or within towns and cities. **Public woodland** refers to woodland which is accessible for recreational use, but not managed for nature conservation. **Nature reserve** is a category reserved for an open space that is managed primarily for nature conservation.

Outdoor Sports Facilities	Sports	**Recreation ground** is an area of mown grass used primarily for informal, unorganised ball games and similar activities (including dog walking). **Playing fields c**omprise playing pitches, usually for football, but also for rugby and hockey, and in summer, for cricket. They often have changing rooms and pavilions. **Golf course** is a landscaped area for playing golf, often with other facilities. **Other recreational** refers to sites that are used exclusively or predominantly for other organised sports such as bows or tennis.
Green Corridors, Outdoor Sports Facilities, Amenity, spaces for Children and Teenagers, Allotments and Community Gardens and City Farms, Cemeteries and Churchyards, Other Urban Fringe, Civic Spaces, Other	Other	**Includes:** rivers, canals, railway cuttings and embankments, disused railway track bed, road island verge, walking/cycle route, amenity greenspace, village green, hospital grounds, educational grounds, landscaping around premises, reservoirs, play space, adventure playground, youth area, allotments, community garden, city farm, cemeteries, churchyards, equestrian centre, agriculture, nursery, horticulture, civic and market squares, other hard surfaced areas, sewerage and water works, disused quarries, gravel pits, vacant land, land reclamations, others including airfields.

Table 6.1 Greenspace type classification

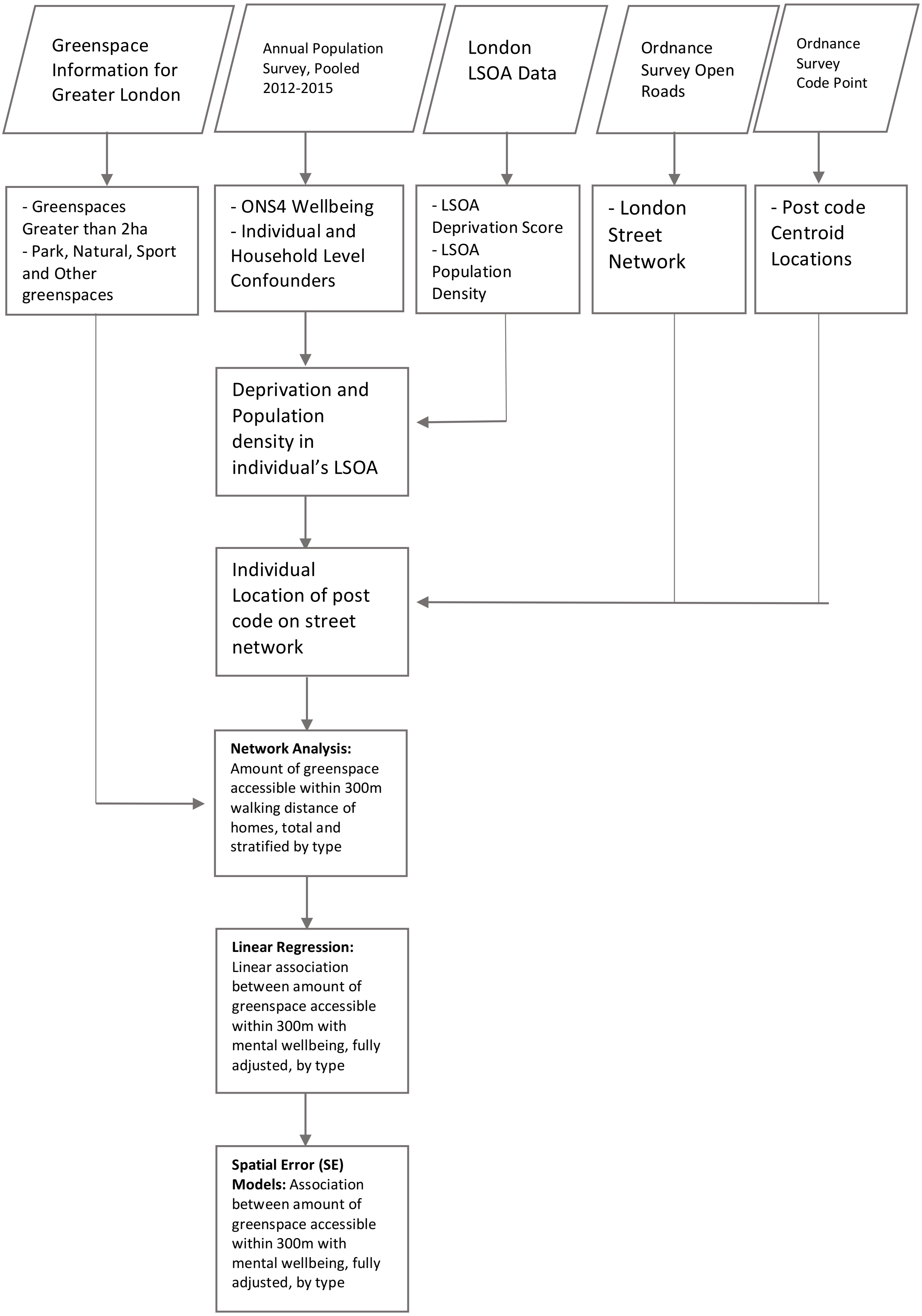


Figure 6.1 Data flow to final sample and analysis

6.2.3 Analysis

Using ArcGIS [221], the amount of greenspace within 300m walking distance of individual's homes was first calculated. Post codes in the APS data were spatially linked to the Code Point post code centroids and then with the Ordnance Survey Roads shapefile. The boundaries of greenspace polygons were assigned to their neighbouring roads. The ArcGIS Network Analyst extension was used to calculate distances along the street network and therefore identify which greenspaces were within 300m of each individual. Rather than intersecting the greenspaces with a buffer, as in Chapter 5, the whole area of each identified greenspace was retained and used to calculate the total amount of greenspace which may be accessed within 300m walking distance of individuals; this is in line with other studies of greenspace access on foot [133]. This resulting greenspace measure will hereafter be referred to as 'the amount of greenspace accessible within 300m'. The process of creating a network buffer with this data is visualised in Figure 6.2, with the background map obtained from OpenStreetMap [222].

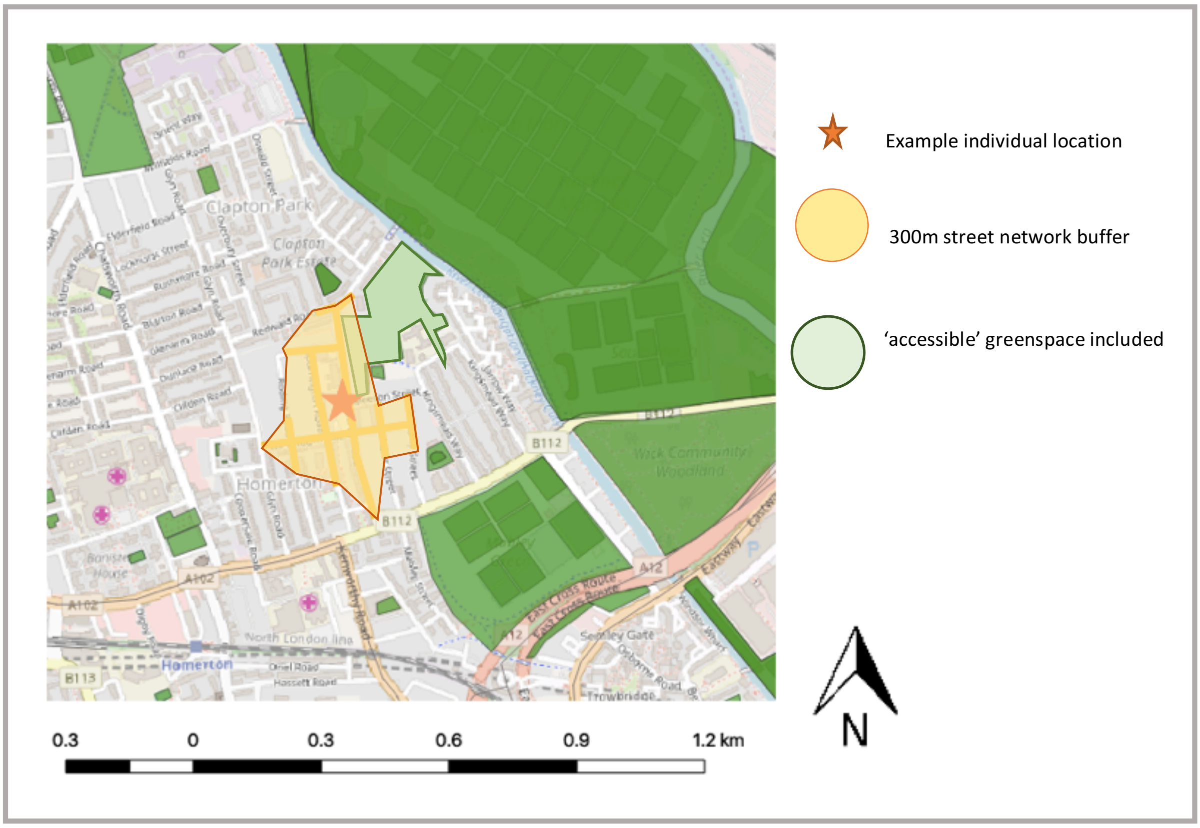


Figure 6.2 Calculating a 300m network buffer around an (example) individual

R [191] spatial and statistical packages were then used to combine all data and first examine, both statistically and visually, the distributions of all greenspace, wellbeing and potentially confounding variables. As well as total area, greenspace was also stratified by type (natural, parks, sports, other). To examine spatial variation in these greenspace indicators, geographically weighted means (see Chapter 5) of local accessible greenspace were calculated and mapped, both for the total and for natural greenspace, parks and sports spaces. A Gaussian-weighted kernel, with an optimised bandwidth of 2000m, was used to calculate a matrix of weights for each neighbour of every individual within the dataset, which is then applied to determine the mean accessible greenspace availability for each location.

Simple Ordinary Least Squares (OLS) regression models were calculated, to first predict mental wellbeing scores from the amount of greenspace accessible within 300m, for each wellbeing variable in turn (life satisfaction, worth, happiness). Tests for bivariate associations were then run, between each of the individual variables and mental wellbeing and then the amount of accessible greenspace in turn. The following were significantly associated with both, and therefore included in the models as potential confounders: age, sex, marital status, ethnicity, general health, education, employment status, income, housing tenure, housing type, LSOA level population density and finally LSOA level deprivation. Statistical tests revealed minimal evidence of multicollinearity between these factors. OLS multivariate models were then built, which include all socioeconomic and local area variables identified as potential confounders. Baseline models, including only these factors, were calculated, so the contribution of adding greenspace indicators could be observed; including greenspace significantly improved fit. The OLS models were then repeated, this time stratifying the amount of greenspace by type, in order to compare associations between mental wellbeing and natural greenspaces, parks and sports areas, compared to other types.

Moran's *I* tests (see Chapter 5 for a full description) were used to identify any spatial autocorrelations within the residuals of the linear regressions, to examine the fit and inform selection of an appropriate model; global and local Moran's *I* was calculated for the baseline, full OLS and stratified OLS models, revealing weak but statistically significant spatial clustering, though these improved slightly as greenspace was added to the model, and again after stratification by type.

Spatial Error (SE) Models, a type of Simultaneous Autoregressive models, were selected as an appropriate method to account for this slight but significant clustering of the residuals, while capturing a single model for the whole sample. This technique assumes that the residuals, rather than the data variable structures, are influenced by their neighbours [235]. A semi-variogram plot of residuals was created to examine the appropriateness of this technique, by observing reductions in spatial dependence over distance, as the model is refined from original data and linear regression [236]. This was plotted for the autocorrelations within the life satisfaction model, the OLS stratified model, and finally SEM stratified model, to examine the spread of residuals across each and identify the improvements of accounting for the residual clustering for each model. This implied that residuals were spatially dependent, which may be caused by underlying random processes and hence could effectively be captured through an SE model.

In practice, the SE technique accounts for these patterns by including an autoregressive parameter λ in a linear model, which incorporates the spatial autocorrelation structure; a positive value indicates positive autocorrelation, with negative indicative of dispersion and a value of 0 signifying no autocorrelation. This term is implemented with a spatial weights matrix, where the *K* nearest neighbours (as in Chapter 5, 160 was selected as standard, being the rounded square root of the number of data points) of each location and the weight of each neighbour, according to proximity, are defined. The spatial dependence of a location is then modelled with a variance-covariance matrix based on the spatial weights matrix. The spatial weights matrix in SE models therefore accounts for patterns in the response variable that are not predicted by explanatory variables, but in the case of Spatial Error Models are instead related to values in neighbouring locations, due to underlying error processes.

$$MWB_i = \beta_0 + \beta_1 GS_{1i} + \cdots \beta_m x_{mi} + u_i \qquad \text{for} \qquad i = 1, \dots, n \tag{6.1}$$

$$u_i = \lambda W u + \varepsilon_i \qquad |\lambda| \leq 1 \tag{6.2}$$

Equation (6.1) represents an SE model regression, which is identical to an OLS model except for the residual term u_i. MWB_i is the predicted value of individual *i*'s mental wellbeing score (life satisfaction, worth, happiness), β_0 is the calculated constant, β_1 is the greenspace coefficient, GS_{1i} is the amount of accessible greenspace within a 300m walk of the individual

i's post code centroid and $\beta_m x_{mi}$ represents the contribution of the potentially confounding factors. The residual term u_i is then calculated, as shown in Equation (6.2), with the autoregressive parameter λ, which specifies the extent of the spatial autocorrelation, the weighted matrix of 160 nearest neighbours W, while ε_i represents the random error.

As the stratified greenspace models had shown the strongest association with mental wellbeing, these were all calculated using the SEM process. Residuals were again analysed using measures of Moran's *I* and the improvements from the final model examined through the semi-variogram.

6.3 Results

There were 25,076 residents of greater London in the final sample, with complete data once the accessible greenspace had been calculated. On average, the mental wellbeing scores were fairly consistent for the three measures, with worth the highest at 7.7, with life satisfaction and happiness having mean scores of 7.4 and 7.3, respectively. Happiness had the highest standard deviation, at 2.1. The average amount of greenspace accessible within a 300m walk of individuals homes was 5.93 hectares, with a reasonably high standard deviation of 6.01. The largest descriptive category was sports (outdoor sports facilities), with a mean area of 1.2, followed by parks (formal parks and gardens), with 1.1. Individuals generally had access to much less natural greenspace, with an area of 0.5 on average and a standard deviation of 1.78. The percentage of females in the final dataset was again higher than males, at 55.8%, which is only slightly above the UK average [226]. The most common age group was 35-44 (20.6%), with almost 60% of the sample ages between 25 and 54.

The majority were also cohabiting (53.3%), white (66.8%) and employed (58.9%), although over a third (36.1%) were economically inactive, meaning they were either retired, in education/training, or signed off long-term from work. Full characteristics of participants are shown in Table 6.2.

Frequency histograms display the spread of mental wellbeing scores in Figure 6.3a-c. Distributions were comparable across all three measures, displaying negatively skewed curves, with local maxima around 5, though a higher local maximum is visible within the plot of happiness.

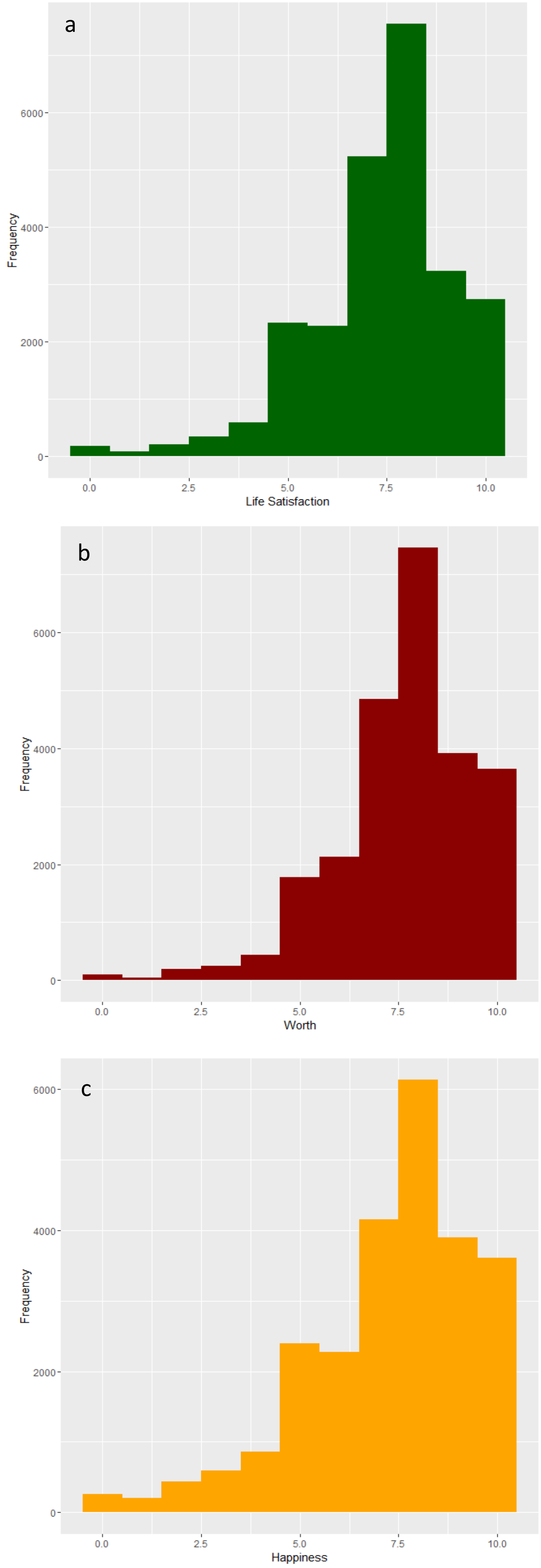


Figure 6.3 a-c Frequency distributions of wellbeing variables

Variable	*Value*	*n*	*Mean(sd) / %*
Wellbeing	Life Satisfaction	25,076	7.4(1.81)
	Worth	25,076	7.7(1.73)
	Happiness	25,076	7.3(2.12)
Age Group	16-24	1,667	6.6
	25-34	4,979	19.9
	35-44	5,177	20.6
	45-54	4,526	18.0
	55-64	3,568	14.2
	65-74	3,012	12.0
	75+	2,147	8.6
Sex	Female	13,993	55.8
Married/Cohabiting	Yes	13,361	53.3
Ethnicity	White	16,747	66.8
	Black	2,742	10.9
	South Asian	2,686	10.7
	Other Asian	997	4.0
	Mixed	472	1.9
	Other	1,404	5.6
Diploma/Degree	Yes	10,170	40.6
General Health	Very Good	8,503	33.9
	Good	10,335	41.2
	Fair	4,652	18.6
	Poor	1,225	4.9
	Very Poor	361	1.4
Economic Activity	Employed	14,772	58.9
	Unemployed	1,245	5.0
	Inactive	9,059	36.1
Income Quintiles	1	1,988	7.92
	2	1,936	7.7
	3	2,054	8.2
	4	1,873	7.5
	5	1,958	7.8
Housing Tenure	Owns Home	6,369	25.4
Housing Type	Detached	727	2.9
	Semi-Detached	2,510	10.0
	Terraced	5,344	21.3
	Flat	7,454	29.7
	Other	50	0.3
LSOA Variables	IMD	25,076	23.4(12.48)
	Population Density	25,076	98.9(63.88)
Greenspace	Total Area (ha)	25,076	5.9(6.05)
Natural Greenspace	Area	25,076	0.5(1.78)
Parks	Area	25,076	1.1(2.48)
Sports	Area	25,076	1.2(2.67)
Other greenspaces	Area	25,076	3.129(4.2446)

Table 6.2 Full descriptive statistics of the final sample

Due to the large standard deviations of the greenspace variables, frequency plots were constructed to compare the distributions across each type, revealing that most individuals had access to relatively little greenspace within 300m of their homes. Figure 6.4a shows individuals having up to 5 hectares of greenspace accessible to them, with local maxima at 0 and 4 hectares and a positively skewed distribution; this may be due to including only greenspaces greater than 2ha, in line with the Natural England guideline.

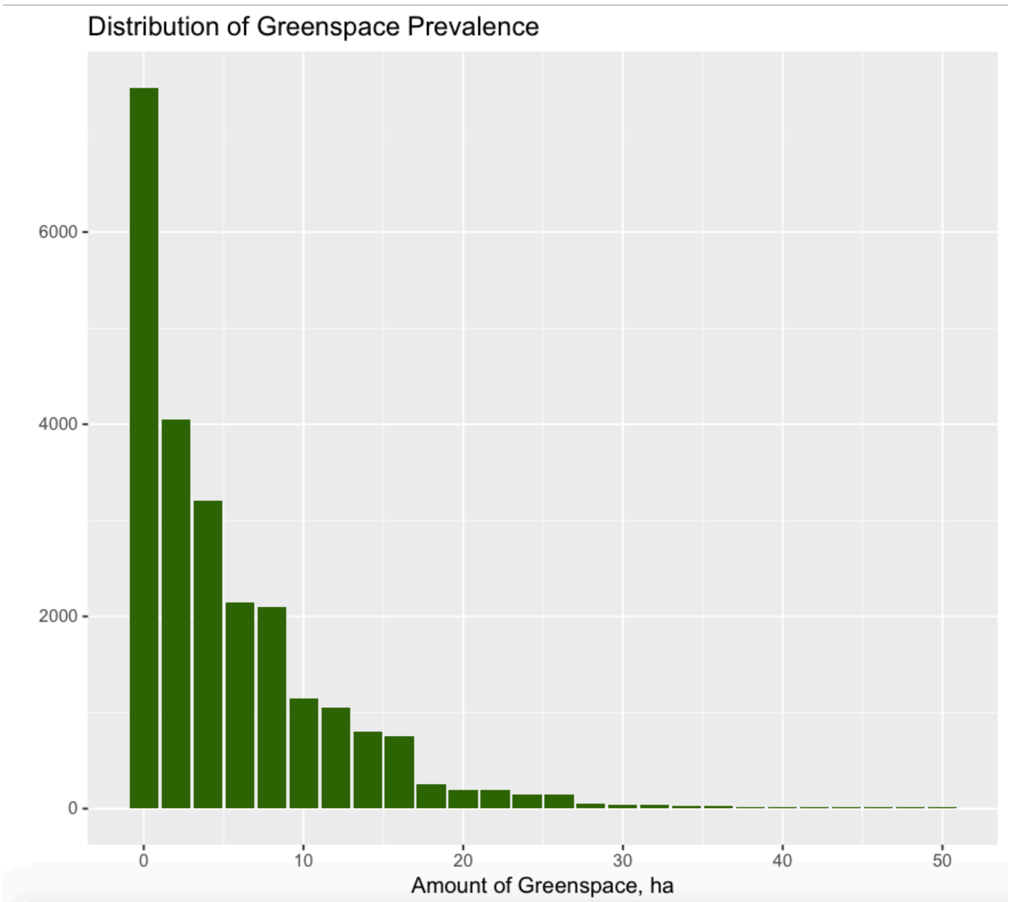


Figure 6.4a Frequency distributions displaying the amount of greenspace available within 300m of individuals

Figure 6.4b-e stratifies this data by greenspace type, revealing that all 4 types considered display similar distributions, at different scales, which reflect those in 4a. The majority of individuals have access to less than 3ha of each type of greenspace; due to these skewed distributions, natural log transforms were taken, although these did not change the results of the analysis, so the original values were used. 'Other' greenspace shows the weakest first peak but then become more prevalent at higher quantities, of above 3ha. Distributions reveal that most people have a smaller amount of greenspace, with a less spread across the sample, while parks and sports spaces showed a slightly wider distribution, aligning with the statistics presented in Table 6.2.

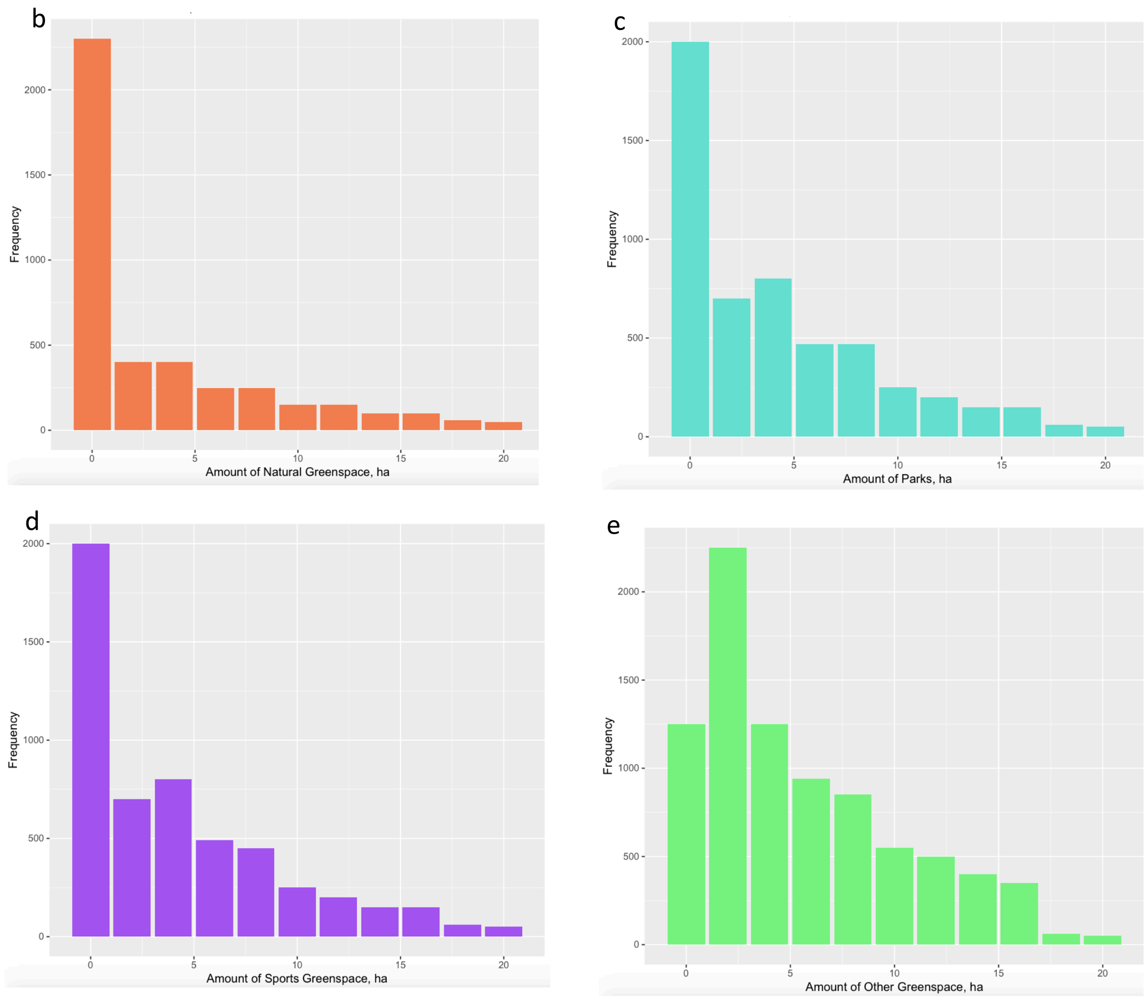


Figure 6.4b-e Frequency distributions displaying the amount of greenspace available within 300m of individuals

To investigate the spatial distribution of these variables, geographically weighted means were calculated and plotted in Figures 6.5 and 6.6a-c. Geographically weighted statistics allow measures of local variation to be obtained from point data, such as the individual locations within this data. The Euclidean distance between neighbouring points, within a set radius (here a 2000m bandwidth was selected for visual optimisation) is measured and a weight for each neighbour calculated according to a Gaussian distribution. The results in a matrix of weights for each location (individual) in the dataset, which is then used to calculate a local mean at each point (see Chapter 5 for a full statistical explanation).

As expected, the geographically weighted mean plot of total greenspace availability shows variation in the amount of greenspace across London (Figure 6.5), with less greenspace on average in the centre of the city and larger quantities available towards the outskirts. This calculation was repeated, stratifying by greenspace type, presented in Figure 6.6a-c. Again, access to natural greenspace was fairly low, but with clusters of much higher availability only towards the outskirts of London. Parks showed a similar pattern, although the variation between higher and lower availability was less pronounced. Prevalence of sports spaces displayed the most continual variation, with clusters of greater and lower availability across the city.

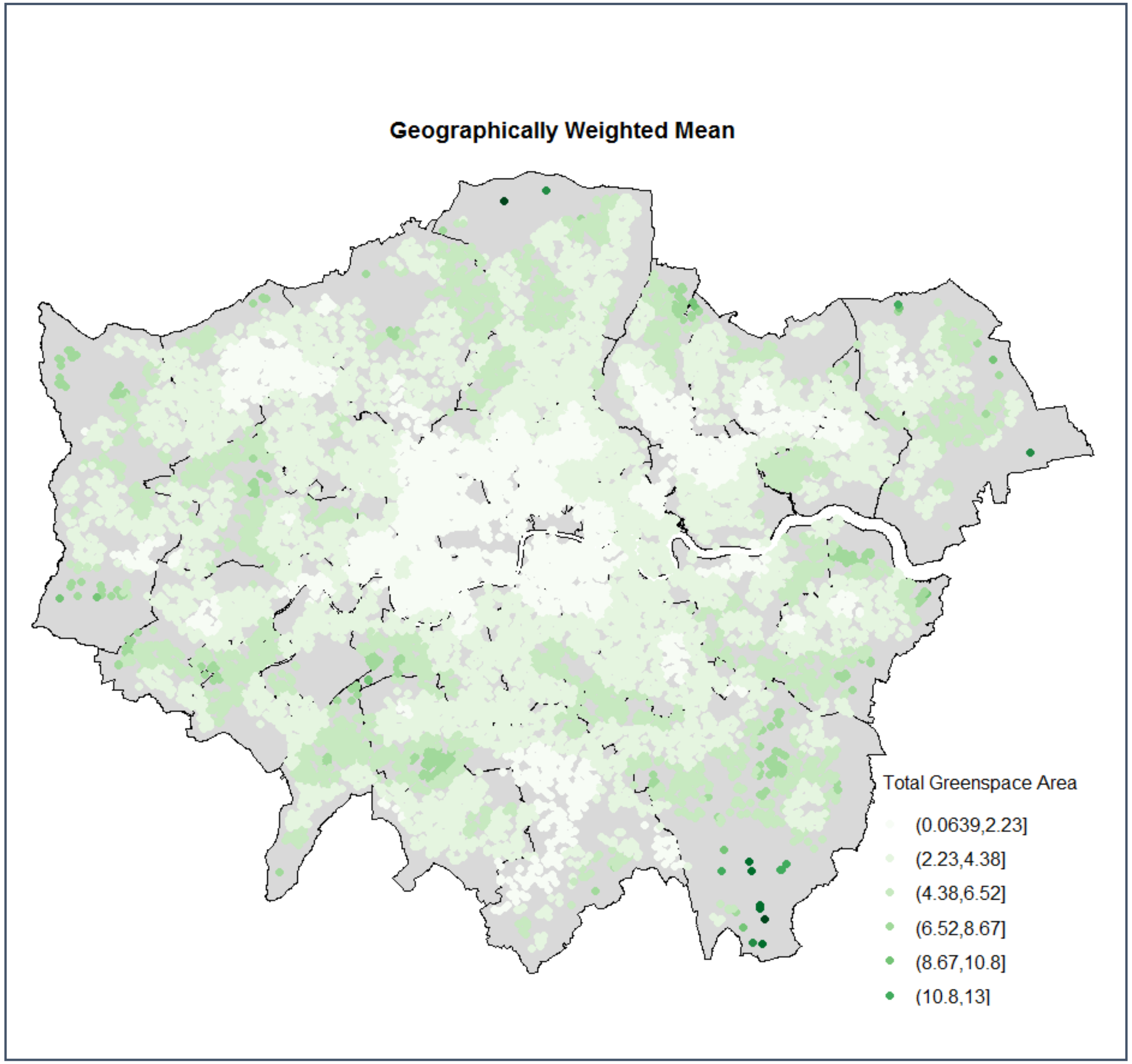


Figure 6.5 Mean total greenspace availability, plotted on a grey background

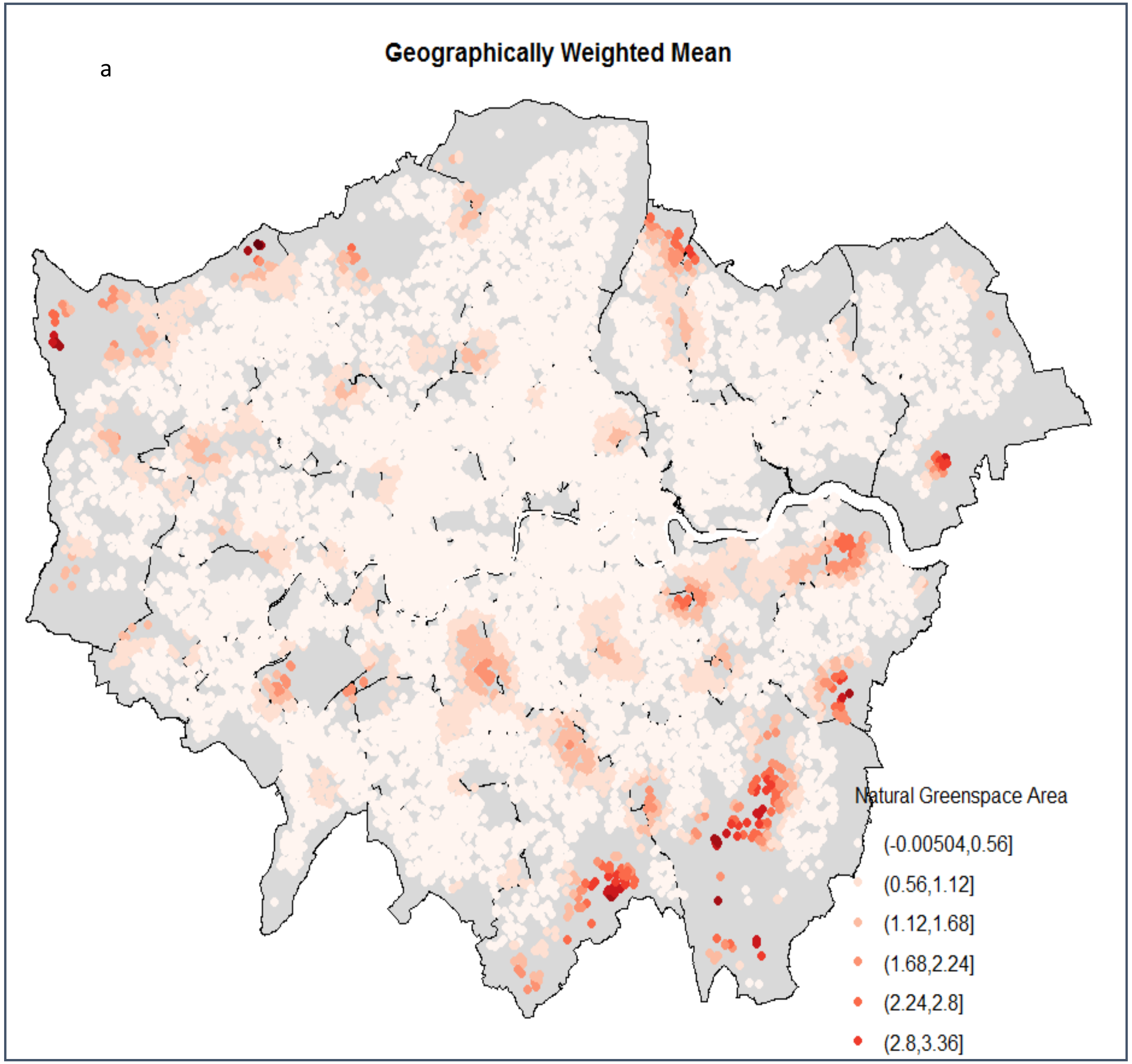


Figure 6.6a Mean greenspace availability

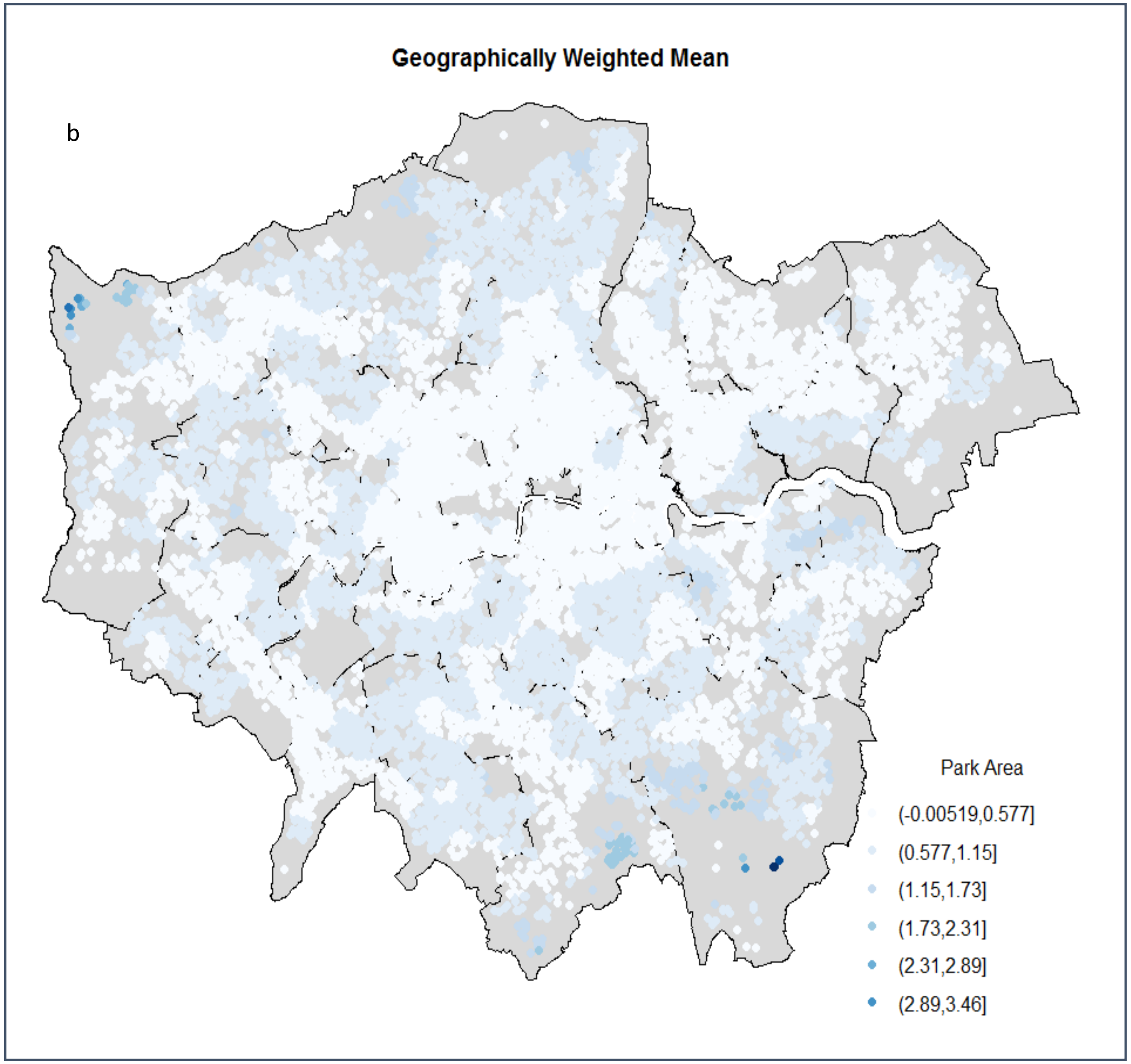


Figure 6.6b Mean greenspace availability

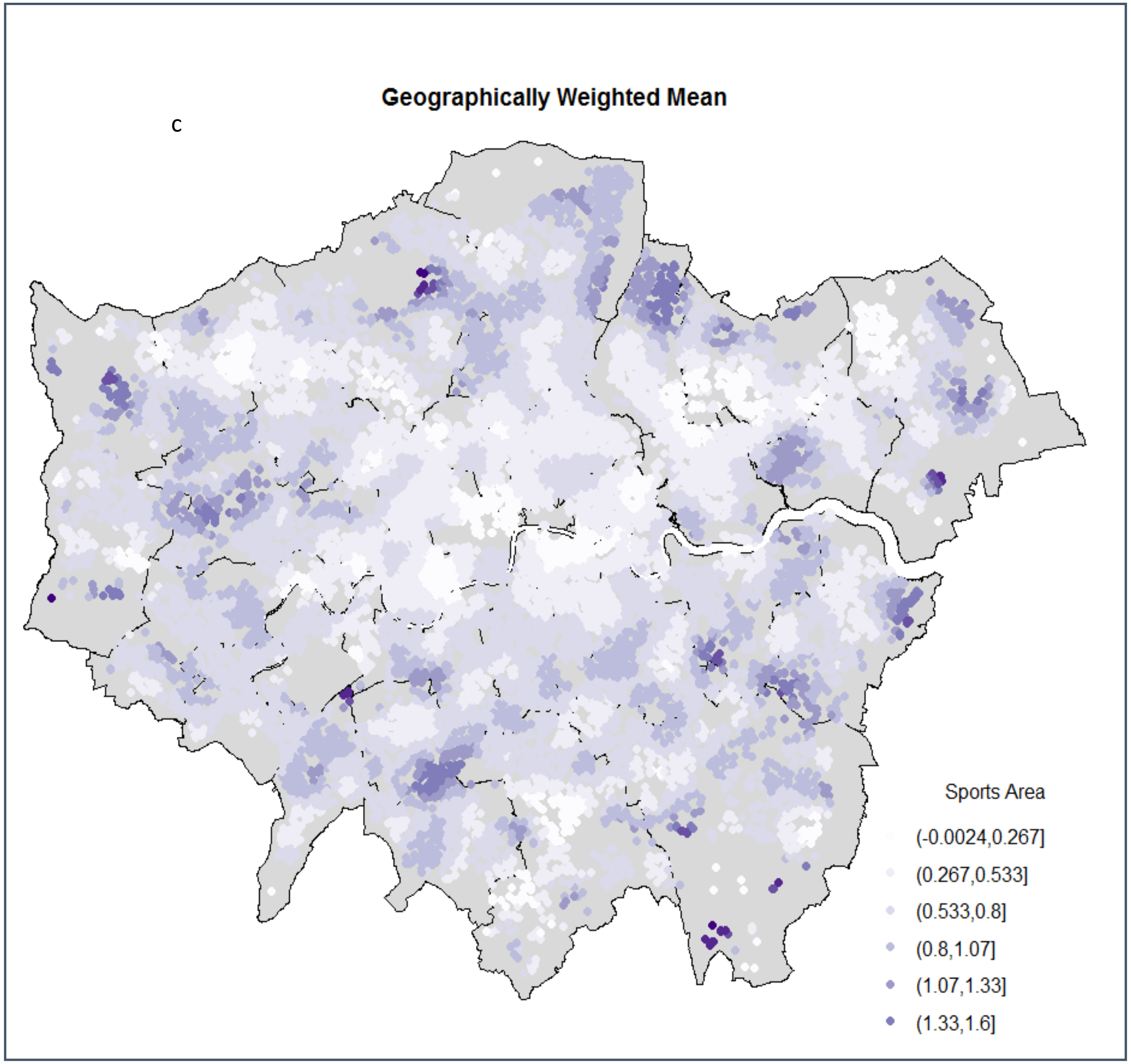


Figure 6.6c Mean greenspace availability

Baseline Ordinary Least Squares (OLS) regression models, which first include only the potentially confounding factors (age, sex, marital status, ethnicity, general health, education, employment status, income, housing tenure, housing type, LSOA level population density and deprivation) to predict mental wellbeing scores, allowed the individual contribution of the addition of greenspace to be observed. For life satisfaction, the baseline model had a modest R^2 value of 0.150, while Moran's *I* tests of the model residuals revealed a weak but statistically significant autocorrelation value of 6.475e-03 ($p < 0.001$). A LISA (Local Indicators of Spatial Association, see Chapter 5 for a full discussion) cluster map of Local Moran's *I* is presented in Figure 6.7, with results for worth and happiness also available, in Appendix B. The total greenspace availability was then added to the model, increasing the R^2 value to 0.158, although, while the greenspace variable was weakly positive, it was not statistically significant ($B = 0.001$, $p = 0.586$).

Greenspace	*Life Satisfaction*			*Worth*			*Happiness*		
	B	*p*	R^2	*B*	*p*	R^2	*B*	*p*	R^2
Greenspace within 300m	0.001	0.586	0.158	***0.005***	***0.043***	***0.098***	0.001	0.786	0.091

Table 6.3 Results of OLS models with network buffers of 300m

However, the Global Moran's *I* value was slightly reduced, revealing that greenspace did account for some of the spatial variation in the data (6.456e-03). Repeating this process for worth and happiness revealed similar patterns of slight reductions in the autocorrelations upon adding total greenspace to the model, although even in the full OLS models, the R^2 values were considerably lower (0.098 and 0.091 for worth and happiness, respectively). At this stage, greenspace was found to only be a statistically significant predictor of worth, with a regression coefficient *B* of 0.005 ($p = 0.043$); results are presented in Table 6.3.

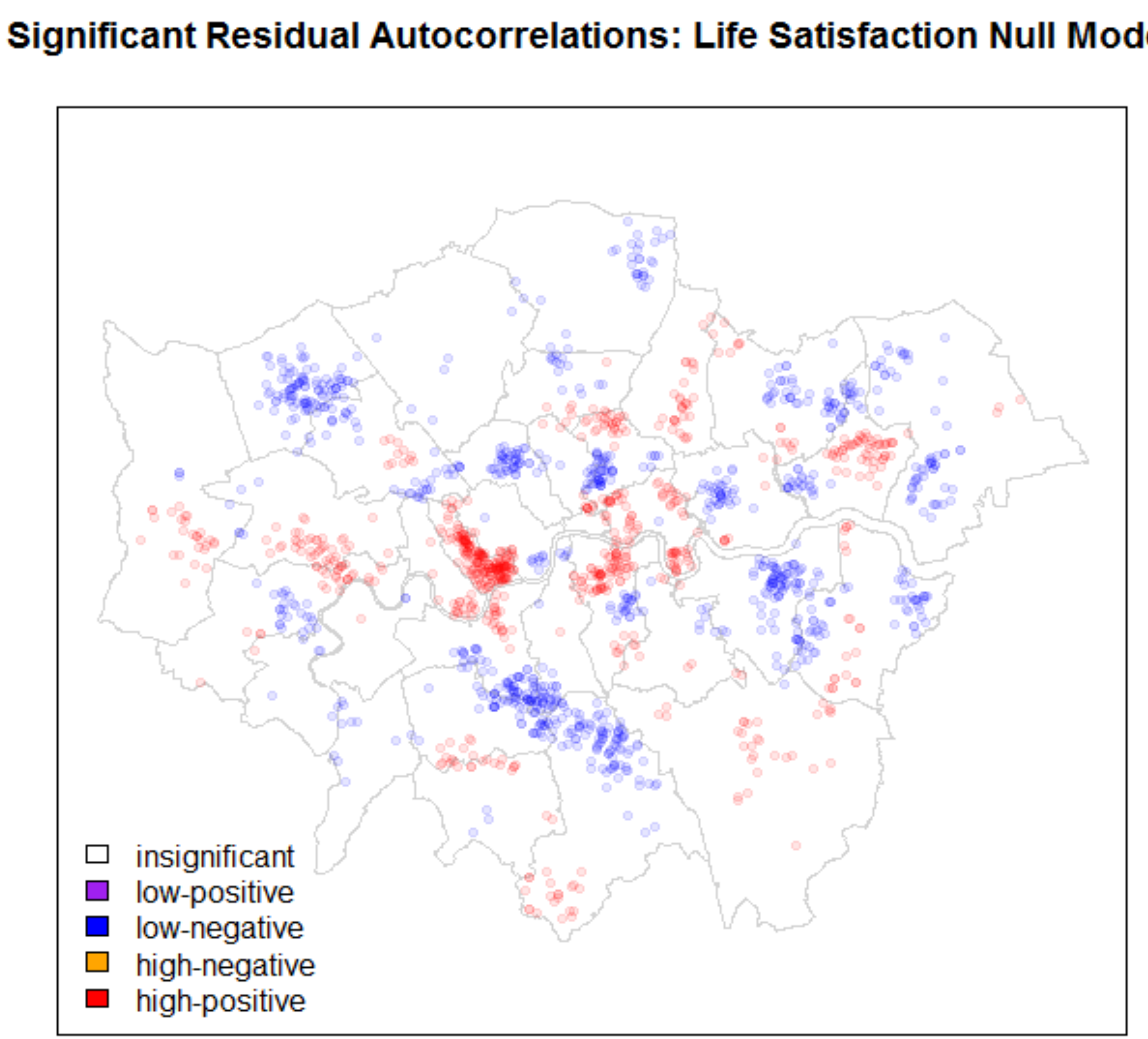


Figure 6.7 LISA cluster map of the residuals of the life satisfaction null model

OLS models were repeated, including the amount of greenspace stratified by type; these were first performed with only the three greenspace indicators, then again fully adjusted with the potentially confounding factors included in the null model. In unadjusted models, a 1ha increase in natural greenspace was statistically significantly associated with an increase of 0.034 in life satisfaction ($p < 0.001$) and 0.025 in happiness ($p = 0.013$); access to sports space was positively associated with worth ($B = 0.014$, $p = 0.015$). When fully adjusted, in the life satisfaction model, including greenspace increased the R^2 value to 0.159, and revealed a positive and significant association with area of natural greenspace ($B = 0.027$, $p = 0.001$). Similar results were obtained for happiness, while increased area of parks was associated with worth ($B = 0.015$, $p = 0.015$). Adding in type of greenspace also slightly decreased the Global Moran's *I* value of the residuals further; for the life satisfaction model, this was reduced to 6.320e-03 ($p < 0.001$). These results are presented in Table 6.4.

Greenspace	*Life Satisfaction*			*Worth*			*Happiness*		
	B	*p*	R^2	*B*	*p*	R^2	*B*	*p*	R^2
Unadjusted Models									
Natural greenspace	0.034	<0.001	0.027	0.015	0.068	0.021	0.025	0.013	0.018
Park space	-0.001	0.926		0.005	0.415		-0.008	0.312	
Sports space	0.008	0.209		0.014	0.015		0.008	0.257	
Fully Adjusted Models									
Natural greenspace	***0.027***	***0.001***	***0.159***	0.011	0.151	***0.098***	***0.020***	***0.035***	***0.092***
Park space	0.007	0.109		***0.015***	***0.015***		0.005	0.521	
Sports space	0.014	0.486		0.009	0.101		-0.004	0.585	
Moran's I	6.320e-03			7.304e-03			5.556e-03		

Table 6.4 Results of fully adjusted OLS regression models

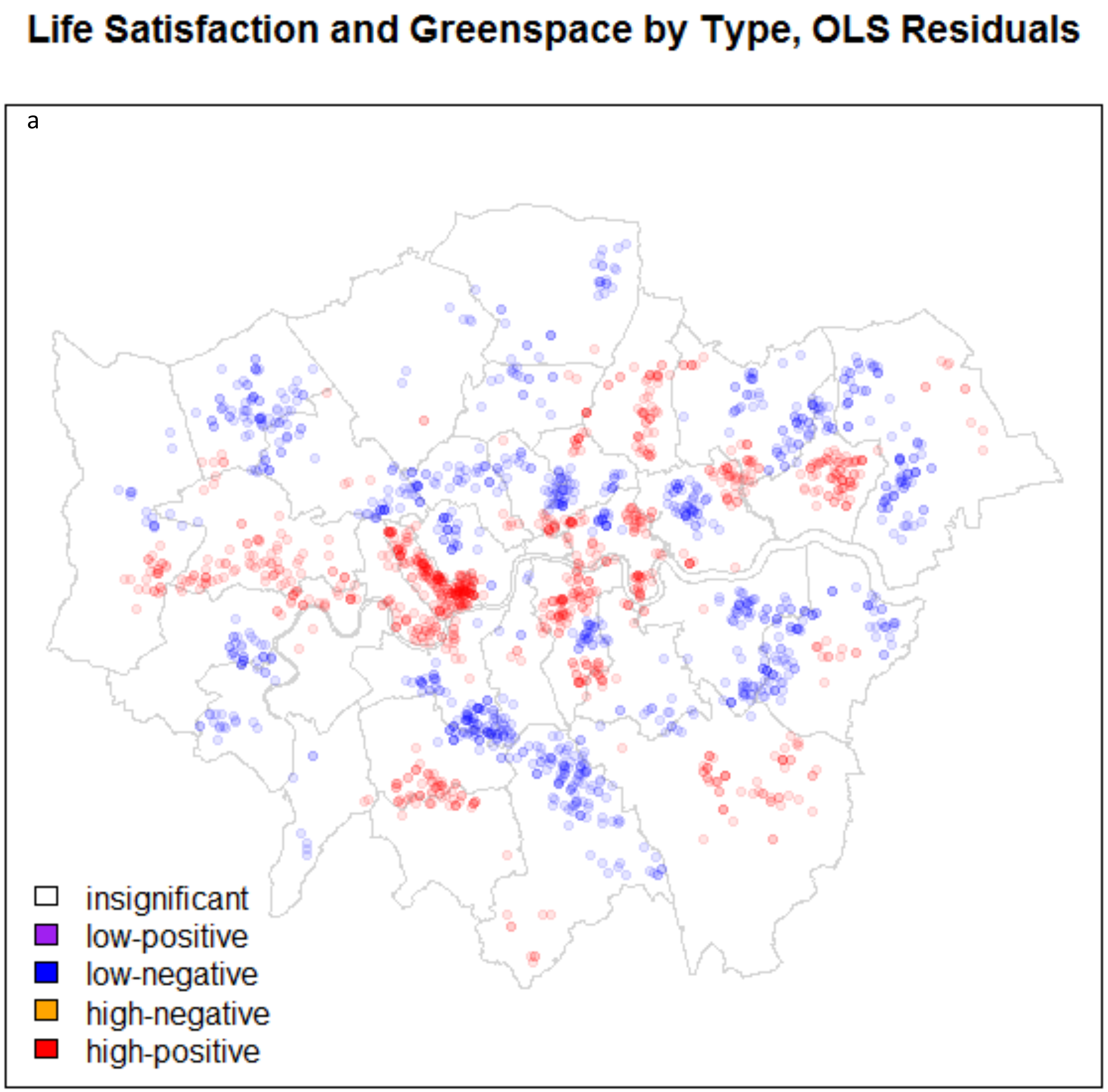


Figure 6.8a LISA cluster map of the residuals of the OLS regression models, adjusted for greenspace type

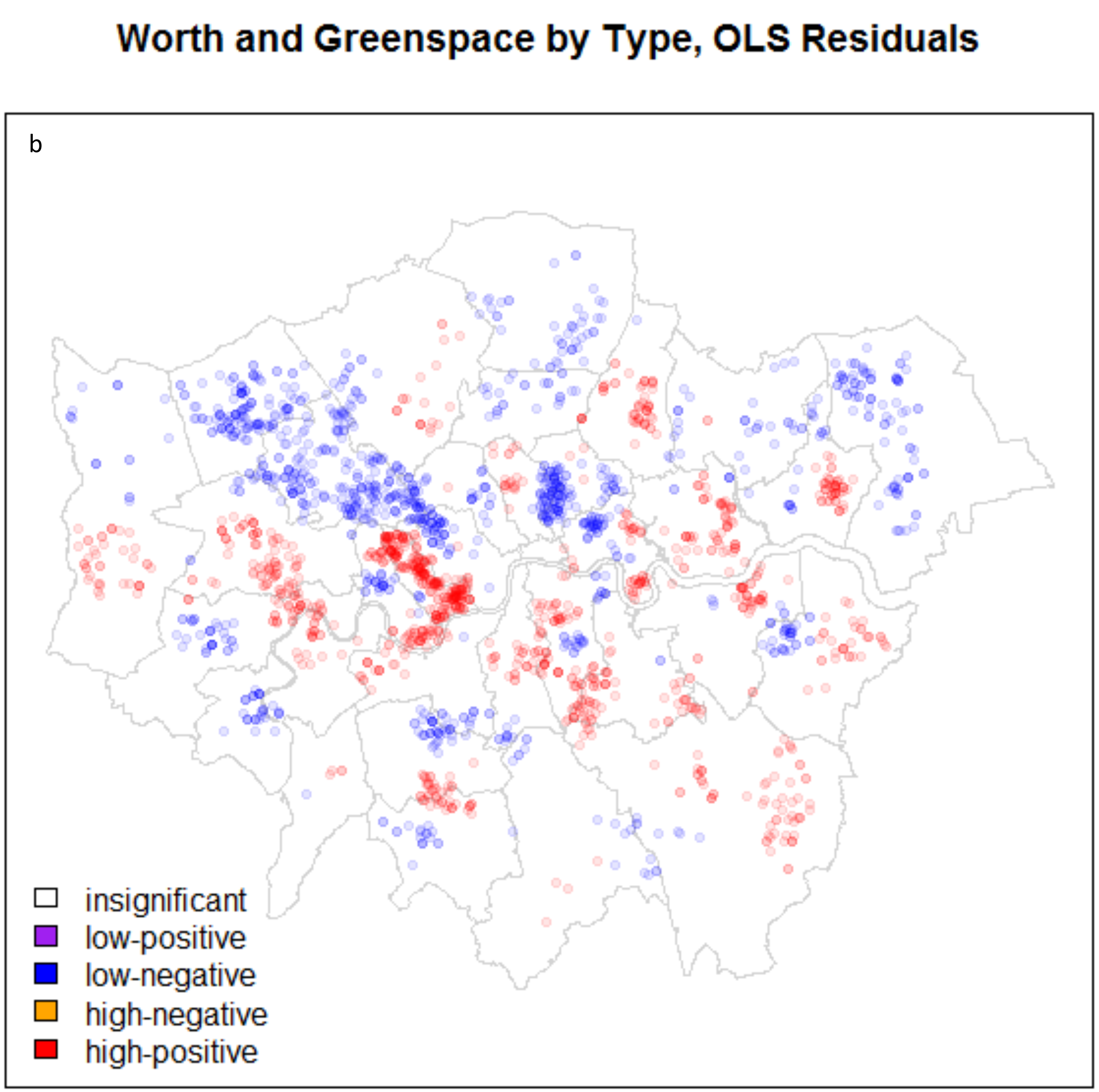


Figure 6.8b LISA cluster map of the residuals of the OLS regression models, adjusted for greenspace type

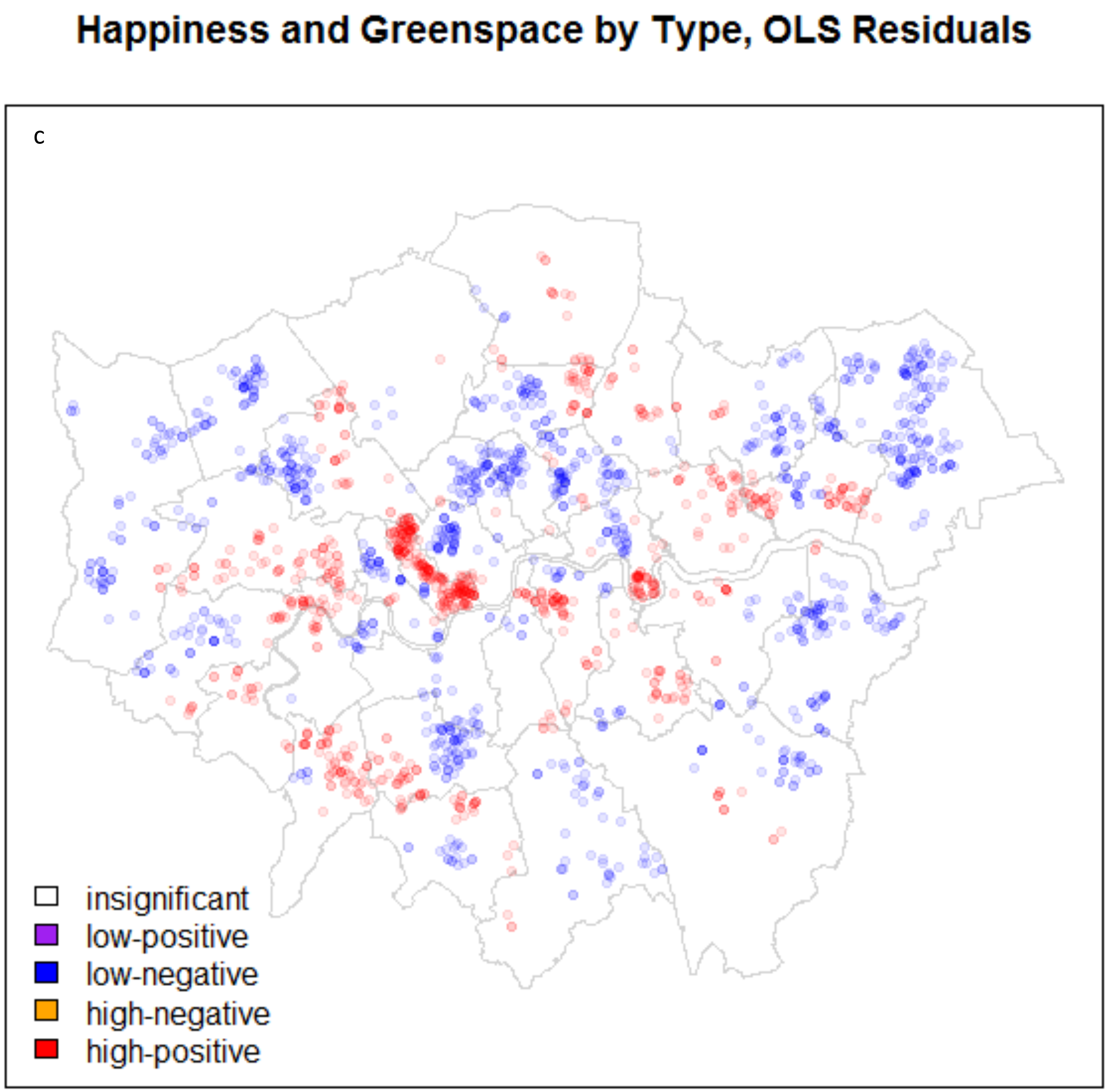


Figure 6.8c LISA cluster map of the residuals of the OLS regression models, adjusted for greenspace type

Local Moran's *I* was also calculated for the residuals of each of these three models, and LISA cluster maps again plotted; these are shown in Figure 6.8a-c and demonstrate similar patterns across the results for the three wellbeing measures. There are evidently several clusters of positive and negative significant autocorrelations in the residuals, highlighting where the Ordinary Least Squares models systematically over- and under-estimate the associations between greenspace and wellbeing. In the life satisfaction model, for example, the model appears to overvalue the mental wellbeing outcome across the centre of London, with areas of significant underestimation towards the outskirts, in particular the East and South of the city.

As the addition of greenspace types had accounted for some of the small but statistically significant autocorrelations, Spatial Error (SE) models were then run, to account for this spatial dependence in the structure of the residuals. Again, these were adjusted for the full range of potentially confounding factors.

Positive and statistically significant associations were observed for the amount of accessible natural greenspace within 300m walking distance of homes and mental wellbeing outcomes of life satisfaction and happiness. The model predicting life satisfaction showed the strongest association, with a regression coefficient *B* of 0.028 ($p < 0.001$), which was slightly lower for happiness ($B = 0.023$, $p = 0.019$); there were no statistically significant associations for other types of greenspace, or the model predicting worth.

Wellbeing Measure	*Greenspace*	*B*	*p*	*λ*	*Likelihood Ratio*	*p*	*Moran's I*	*p*
Life Satisfaction	Natural	***0.028***	***<0.001***	0.002	55.558	<0.001	-4.748e-04	0.738
	Parks	-0.002	0.794					
	Sports	0.006	0.281					
Worth	Natural	0.010	0.196	0.002	73.081	<0.001	-4.670e-04	0.735
	Parks	0.004	0.554					
	Sports	0.010	0.071					
Happiness	Natural	***0.023***	***0.019***	0.002	43.254	<0.001	-3.563e-04	0.679
	Parks	-0.009	0.210					
	Sports	0.007	0.338					

Table 6.5 Results of the fully adjusted Spatial Error models

The λ coefficient was weakly positive (0.002) but statistically significant for each model ($p < 0.001$), implying some spatial clustering in the residuals. Interestingly, accounting for these patterns increased the natural greenspace coefficients for both life satisfaction and happiness models. Aggregated results are shown in Table 6.5, with full results for each of these models presented in Tables 6.6-6.8.

Examining the Global Moran's *I* values of each model revealed that this term in the SE models had effectively captured the spatial autocorrelations in the residuals. For the life satisfaction model, the *I* value was reduced to -4.748e-04, and was no longer statistically significant ($p = 0.738$); similar patterns were observed for the remaining SE models (see Table 6.5). LISA cluster plots indicating the statistical significance and direction of Local Moran's *I* for each of these associations are presented in Figure 6.9a-c. There was clear reduction in the residual error local autocorrelations when compared to the linear model equivalents shown in Figure 6.8a-c, which demonstrates that the addition of greenspace and capturing of spatial processes as variables improves the capacity of the model to control for the spatial variation of the wellbeing scores. While some small areas still evidence slight over- and under-estimation of the model, these are much smaller than in the equivalent OLS models and are not statistically significant at the Global scale.

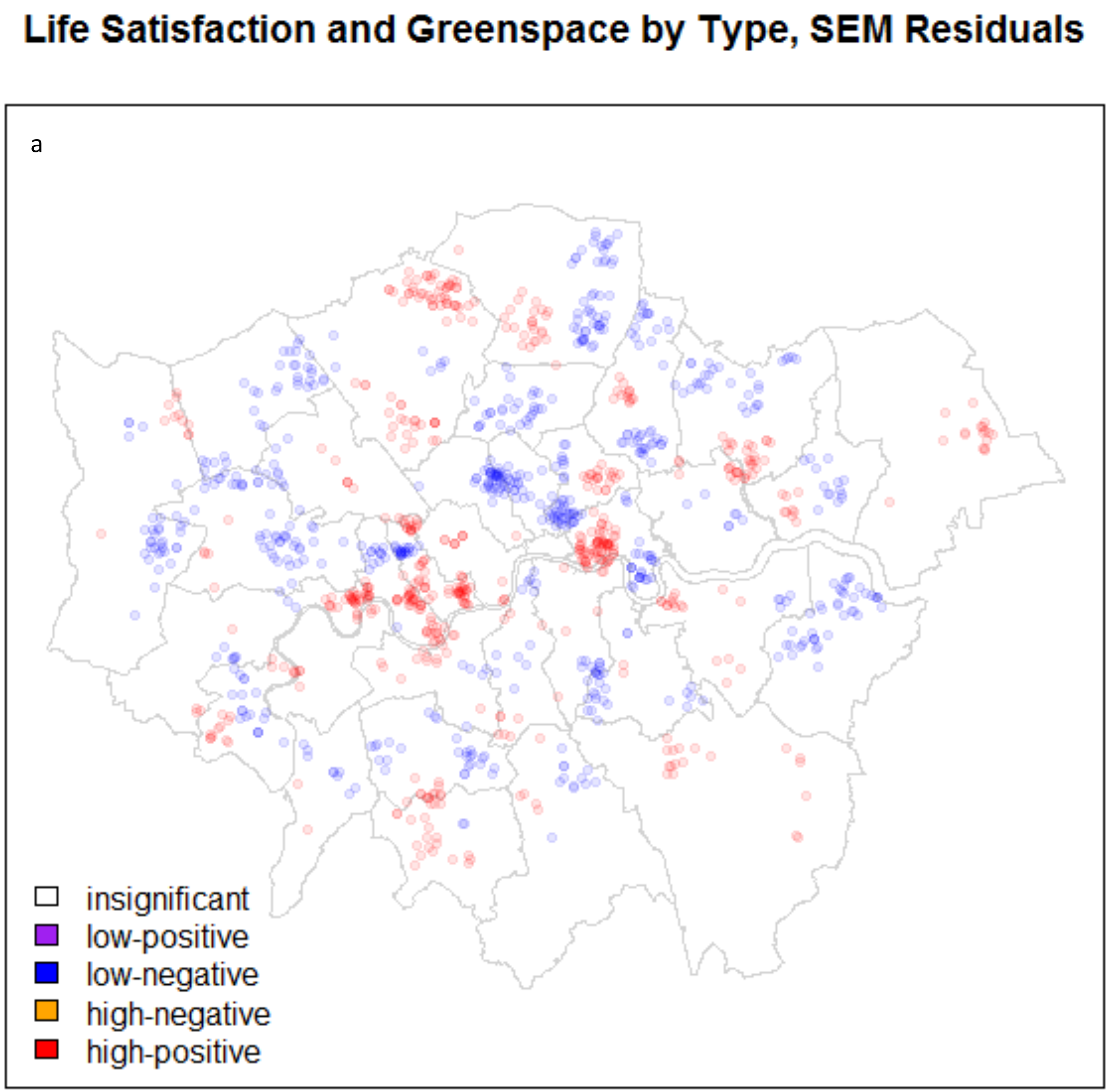


Figure 6.9a LISA cluster map of residuals of SE regression models, adjusted for greenspace type

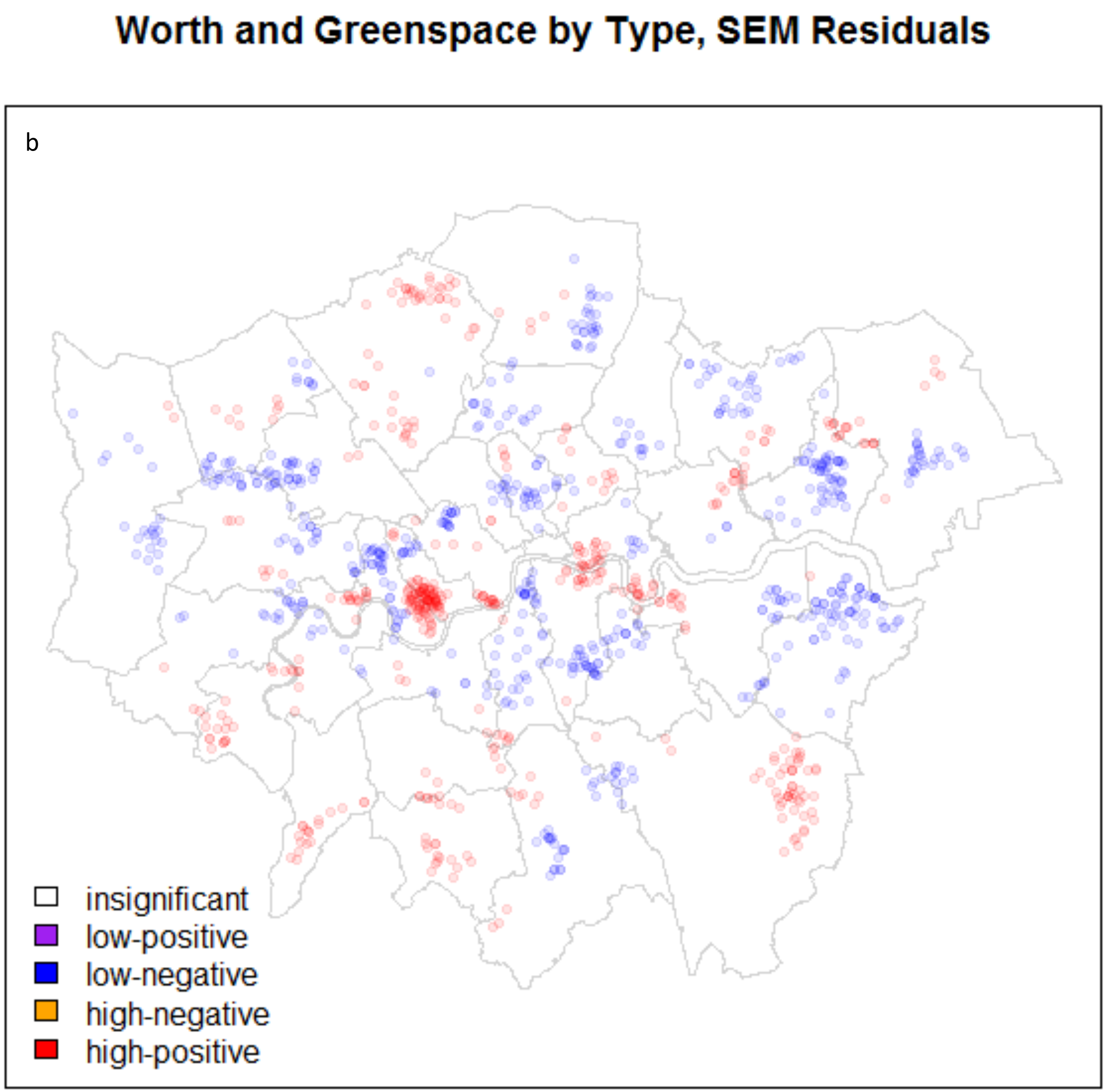


Figure 6.9b LISA cluster map of residuals of SE regression models, adjusted for greenspace type

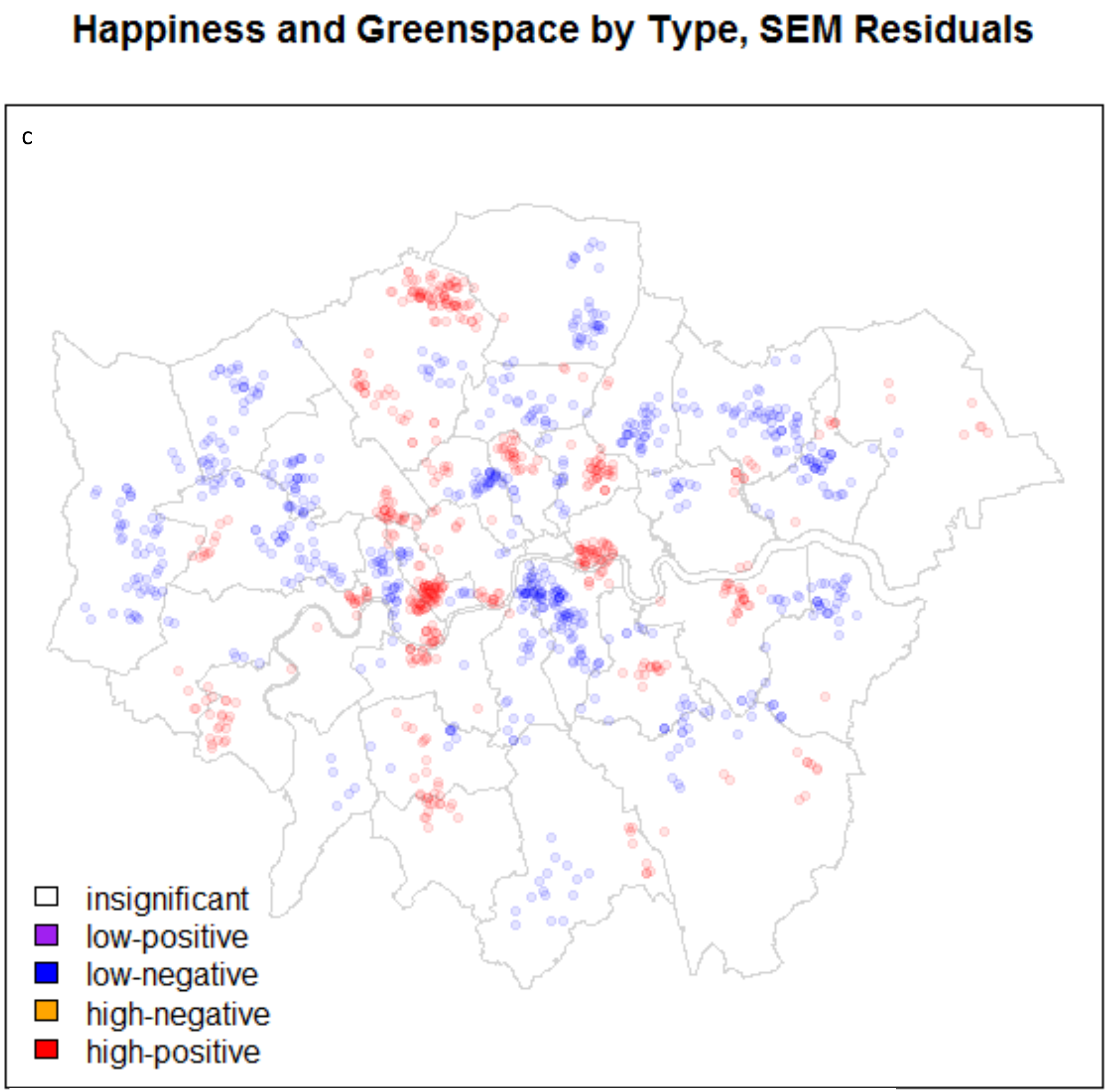


Figure 6.9c LISA cluster map of residuals of SE regression models, adjusted for greenspace type

Life Satisfaction

Variable	*Value*	*B*	*SE*	*p*
Area of Greenspace	Natural	0.028	0.008	<0.001
	Parks	-0.002	0.006	0.794
	Sports	0.006	0.006	0.281
Age	16-24 ,ref			
	25-34	-0.245	0.049	<0.001
	35-44	-0.425	0.049	<0.001
	45-54	-0.582	0.050	<0.001
	55-64	-0.194	0.053	<0.001
	65-74	0.214	0.056	<0.001
	over 75	0.300	0.061	<0.001
Sex	Female	0.078	0.022	<0.001
Married/Cohabiting	Yes	0.489	0.023	<0.001
Ethnicity	White British, ref			
	Black	-0.173	0.036	<0.001
	South Asian	0.178	0.037	<0.001
	Other Asian	0.049	0.055	0.375
	Mixed	-0.069	0.078	0.377
	Other	0.074	0.047	0.117
Health	Fair, ref			
	Very Good	1.037	0.033	<0.001
	Good	0.620	0.031	<0.001
	Poor	-0.886	0.054	<0.001
	Very Poor	-1.921	0.092	<0.001
Qualifications	Has Degree/Diploma	-0.078	0.024	<0.001
Economic Activity	Employed, ref			
	Unemployed	-0.708	0.055	<0.001
	Inactive	-0.080	0.036	0.025
Employed Full-Time	Yes	0.012	0.035	0.742
Income, Quintiles	1, ref			
	2	-0.157	0.044	<0.001
	3	0.002	0.044	0.968
	4	0.116	0.046	0.011
	5	0.241	0.046	<0.001
Housing Tenure	Owns Home	0.182	0.030	<0.001
	Detached, ref			
	Semi-detached	-0.010	0.071	0.893
	Terraced	-0.003	0.068	0.967
	Flat	-0.073	0.068	0.282
	Other	-0.092	0.066	0.160
Population Density		0.000	0.000	0.146
Deprivation		-0.003	0.001	0.026

Table 6.6 Results of fully adjusted Spatial Error model for life satisfaction and types of accessible greenspace

Table 6.7 Results of fully adjusted Spatial Error model for worth and types of accessible greenspace

Worth

Variable	*Value*	*B*	*SE*	*p*
Area of Greenspace	Natural	0.010	0.008	0.196
	Parks	0.004	0.006	0.555
	Sports	0.010	0.006	0.071
Age	16-24 ,ref			
	25-34	-0.160	0.049	0.001
	35-44	-0.155	0.049	0.001
	45-54	-0.284	0.050	<0.001
	55-64	0.112	0.052	0.030
	65-74	0.334	0.055	<0.001
	over 75	0.267	0.061	<0.001
Sex	Female	0.235	0.022	<0.001
Married/Cohabiting	Yes	0.341	0.022	<0.001
Ethnicity	White British, ref			
	Black	0.103	0.036	0.004
	South Asian	0.131	0.037	<0.001
	Other Asian	0.000	0.054	0.999
	Mixed	0.256	0.077	0.001
	Other	-0.006	0.047	0.893
Health	Fair, ref			
	Very Good	0.803	0.033	<0.001
	Good	0.417	0.030	<0.001
	Poor	-0.766	0.054	<0.001
	Very Poor	-1.502	0.090	<0.001
Qualifications	Has Degree/Diploma	-0.044	0.024	0.067
Economic Activity	Employed, ref			
	Unemployed	-0.554	0.054	<0.001
	Inactive	-0.186	0.035	<0.001
Employed Full-Time	Yes	-0.080	0.035	0.022
Income, Quintiles	1, ref			
	2	-0.127	0.043	0.003
	3	0.019	0.043	0.662
	4	0.081	0.045	0.074
	5	0.026	0.045	0.565
Housing Tenure	Owns Home	0.093	0.029	0.001
	Detached, ref			
	Semi-detached	-0.006	0.070	0.932
	Terraced	-0.025	0.067	0.704
	Flat	-0.112	0.067	0.094
	Other	-0.081	0.065	0.212
Population Density		0.000	0.000	0.483
Deprivation		-0.001	0.001	0.298

Happiness

Variable	*Value*	*B*	*SE*	*p*
Area of Greenspace	Natural	0.023	0.010	0.019
	Parks	-0.009	0.007	0.210
	Sports	0.007	0.007	0.338
Age	16-24 ,ref			
	25-34	-0.125	0.060	0.037
	35-44	-0.131	0.060	0.029
	45-54	-0.190	0.061	0.002
	55-64	0.088	0.064	0.166
	65-74	0.475	0.068	<0.001
	over 75	0.487	0.075	<0.001
Sex	Female	0.025	0.027	0.358
Married/Cohabiting	Yes	0.356	0.028	<0.001
Ethnicity	White British, ref			
	Black	0.117	0.044	0.008
	South Asian	0.300	0.045	<0.001
	Other Asian	-0.002	0.067	0.971
	Mixed	0.075	0.095	0.432
	Other	0.006	0.058	0.910
Health	Fair, ref			
	Very Good	1.085	0.040	<0.001
	Good	0.595	0.037	<0.001
	Poor	-0.997	0.066	<0.001
	Very Poor	-1.719	0.111	<0.001
Qualifications	Has Degree/Diploma	-0.059	0.030	0.046
Economic Activity	Employed, ref			
	Unemployed	-0.552	0.067	<0.001
	Inactive	-0.067	0.043	0.124
Employed Full-Time	Yes	-0.048	0.043	0.257
Income, Quintiles	1, ref			
	2	-0.093	0.053	0.080
	3	-0.010	0.053	0.859
	4	-0.061	0.056	0.274
	5	-0.035	0.056	0.528
Housing Tenure	Owns Home	0.090	0.036	0.012
	Detached, ref			
	Semi-detached	0.005	0.086	0.956
	Terraced	0.040	0.082	0.630
	Flat	0.008	0.082	0.919
	Other	0.006	0.080	0.944
Population Density		0.000	0.000	0.232
Deprivation		-0.002	0.001	0.074

Table 6.8 Results of fully adjusted Spatial Error model for happiness and types of accessible greenspace

As the SE model predicting life satisfaction from availability of different types of greenspace was found to be the strongest, a semi-variogram displaying the improvement of spatial variance patterns in the data was created, thereby demonstrating the suitability of the spatial error regression in modelling this relationship. Figure 6.10 displays the semi-variogram of the results of the original data (life satisfaction variable), the residuals of the fully adjusted OLS model of greenspace type, and finally the residuals of the fully adjusted SE model of greenspace type. This graph plots the average difference in residuals as the distance between two points increases, thereby representing the degree of spatial dependence within the model results [236]. In line with the examination of Moran's *I* autocorrelations, this plot clearly demonstrates how the OLS model (linear residuals) reduced the spatial dependence within the original data points, with the application of SE models were able to further capture the spatial processes within the residuals.

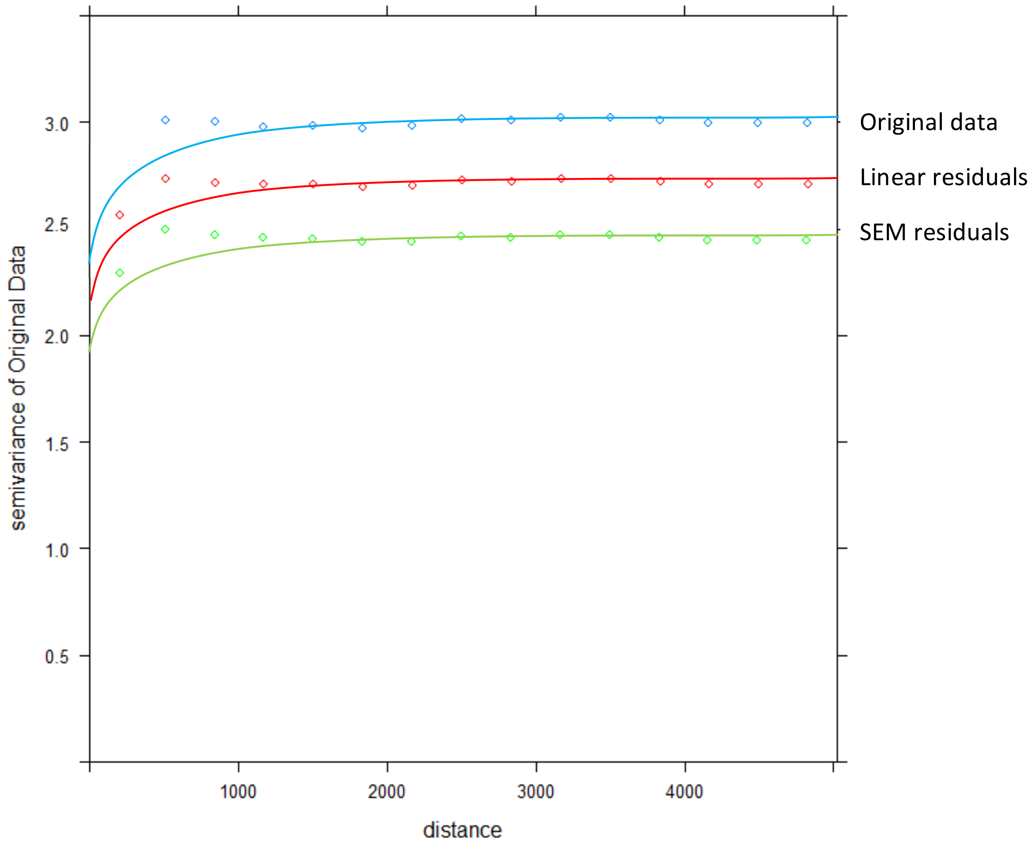


Figure 6.10 Semi-variogram displaying the semivariance over distance of the original data and fitted models

6.4 Discussion

6.4.1 Key findings

A large body of research into greenspaces and wellbeing is based upon the premise that exposure to nature may have salutogenic effects on individual and population health [19] and planning guidance for urban development is often designed to provide residents with easy access to 'natural environments' [9, 11, 50]. In urban settings, this is generally facilitated through the provision of greenspace, which may take many forms, including 'natural' areas, more formal parks and gardens and outdoor sports facilities. In fact, while many green features may appear 'natural', in an urban context they are often artificially constructed and maintained [19].

In Chapter 5, a study on greenspace within 300m of individuals revealed a positive and statistically significant association with mental wellbeing, although results of a Geographically Weighted Regression model revealed that the strength, and in some places the direction, of this correlation differed across London. It was speculated that this spatial variation may be partly explained by the distribution of distinctive types of greenspace available in different areas of the city. Previous research has examined the association between various green qualities and health, using bespoke classification systems, usually designed in relation to a specific research question [37] and only one study has been found which examined associations with multidimensional mental wellbeing [133]; this study included less than 500 participants in a small region of Australia, although it did find positive associations for natural and park greenspaces with mental wellbeing [133].

The current study was therefore designed to investigate the spatial variation in the apparent importance of greenspace for mental wellbeing, by investigating associations with different types of greenspace. The UK's Planning Policy Guidance (PPG17) greenspace typology was used to ensure a robust, consistent classification of greenspace characteristics, including natural, park and sport areas within London. This research was therefore able to investigate the hypothesis that natural greenspaces are more strongly associated with mental wellbeing than other types of greenspace.

To address another gap in knowledge, this study also calculated network distance between individuals and greenspace within 300m, to give a more detailed indication of accessibility on foot, than the Euclidean buffers applied in Chapter 5. Only greenspaces greater than 2ha in area were included, to further test the Natural England guideline that all individuals should be provided with 'a natural greenspace of at least 2ha within 300m walking distance of their home' [50]; if the boundary of the greenspace could be reached within this distance, the whole area of the greenspace was considered accessible. Including a lower limit on the size of greenspace is common in other studies [129, 153]. Dadvand et al.'s analysis, for example, included greenspaces of 0.5ha accessible within 300m as a binary variable; they identified a significant association with reduced risk of mental health issues, although satellite indicators of surrounding greenness (NDVI) without this limit on size revealed a stronger association [153]. It may therefore be interesting for future studies to examine different size greenspaces and compare findings across these.

Using three mental wellbeing measures, from the UK's Annual Population Survey, associations were modelled for the amount of greenspace, both in total and stratified according to type (natural, parks, sports), with life satisfaction, worth and happiness.

After studying the residual errors of preliminary linear regression models and identifying significant autocorrelations, Spatial Error (SE) models were used to account for the slight clustering within the data. This subset of Simultaneous Autoregressive Modelling assumes that the spatial patterning of the response variable is not predicted by the input explanatory variables, but is instead related to spatial locations; it outputs a further spatial regression coefficient which adjusts for the clustering, indicating the strength and direction. This technique therefore has the advantage of modelling second-order spatial processes and allowing one set of model parameters to be obtained for the whole sample. Results of the SE models revealed that access to natural greenspace was positively and statistically significantly associated with both life satisfaction and happiness; no other significant associations were identified. The autoregressive parameter, λ, indicated small but significant spatial patterns in the residuals and effectively captured the underlying local variation in error.

These findings therefore provide some evidence that natural greenspace within 300m is the most strongly associated with mental wellbeing, but opens up further questions regarding the significant results only for life satisfaction and happiness (hedonic wellbeing), but not sense of worth (eudaimonic wellbeing). While most previous research on mental wellbeing has focused only on life satisfaction [16, 37, 113, 139], this study therefore contributes to the evidence for the association between natural greenspace and hedonic wellbeing, although the findings on the eudaimonic wellbeing remain inconclusive, despite Chapter 5 concluding that total surrounding greenspace was associated with sense of worth.

Further research is therefore required to examine the relationship between greenspace characteristics and eudaimonic wellbeing in particular, to deepen understanding of why findings vary when greenspace is measured in different ways. It could be suggested that natural greenspace in particular is important for hedonic wellbeing, as it may have the potential to alter individuals' immediate feelings, by improving mood [148], reducing stress [26, 77] and restoring attention [25, 74]. Eudaimonic wellbeing, however focuses more on life meaning and achievement, which it could be suggested might be less related to natural greenspace in particular, but more generally associated with positive, potentially green, living environment [4]. It should also be considered that the data available included only one measure of eudaimonic wellbeing, which, while offering an insight into the two dimensions of wellbeing, is more simplistic than other scales built on multiple items, which may provide a deeper understanding of the relationship between nature and multidimensional mental wellbeing.

There may also be further characteristics of greenspace which were not considered within the scope of this research, such as usage patterns, facilities and objective quality, which may be associated with mental wellbeing, the eudaimonic dimension in particular, while individual-level attributes such as social connections and physical activity may further moderate these relationships [40]. Future studies should therefore seek to examine these qualities, to support the robust evidence required for greenspace design in urban settings.

6.4.2 Strengths and limitations

With Natural England recommending natural greenspace to be included close to urban residents' homes, this is believed to be the first study to test this guideline by examining associations between different types of accessible greenspace, within a 300m walking distance of individuals. This study benefited from the inclusion of a strategic and justified classification of greenspace types, allowing quantities of natural greenspace to be compared to parks, sports spaces, and other greenspaces. While many other studies examine greenspace prevalence and local area or even Euclidean buffer level [16, 38, 93, 113, 126], this research was also able to characterise the total amount of greenspace within a 300m walking distance, using network analysis of GIS shapefiles. Due to the granular level of data available, this network distance was calculated starting at the post code centroid, an assumption which may over- and under-estimate the absolute distance in different cases. Greenspaces were also considered 'accessible' if their boundary could be reached within the specified distance, which overlooks the importance of entrances, which were not available within the GiGL data. Future research, using, for example, the recently released Ordnance Survey Open Greenspace map, may allow access points to be considered and provide an even more accurate indication of actual walkability. Analysing the street network also did not consider crossing major roads, or pedestrian alleyways, which may both influence accessibility on foot.

SE models were selected after examining the patterns in the residuals of OLS models and, by accounting for second-order spatial processes in the structure of the data, allowed the association between natural greenspace and mental wellbeing to be investigated. However, as with all models, assumptions regarding the structure of the data are made; in this case, that the clustering of residuals was due mostly or wholly to error processes that increase the probability of residual values to be similar to the ones in neighbouring locations. While enabling detailed individual-level analyses to be performed, other methods, such as Floating Catchment Areas (FCAs), which are more complex gravity-based models of spatial interactions, may allow consideration of high-order spatial patterns, across individual and local area levels.

Previous research has demonstrated that the consideration of geographical boundaries, such as LSOAs, to be ineffective in capturing individual-level associations between greenspace and mental wellbeing [38], but methods which allow aggregation to non-arbitrary boundaries, such as those related to a more organic conception of a neighbourhood (for example, being calculated according to spatial patterns), may call for spatial interactions between units to be considered more directly that the inclusion of the spatial autoregressive parameter in the SE model. For example, some effects, such as neighbourhood-level wellbeing, may also be affected by the local environment, and there may be interactions between individual and local wellbeing which may not always be as evident at the individual level. For example, residents may self-select into attractive localities, which may have an impact both upon the individual and their neighbourhood environment.

Although restricted to London, this analysis benefitted from a large sample size of over 25,000 individuals, from the Annual Population Survey, which contains detailed socio-economic individual level data, as well as each individual's post code centroid. This allowed a comprehensive dataset to be generated by merging information from local area, greenspace and individual sources. This study was also able to control for a large range of potentially confounding factors, from socio-economic status to health, living conditions, local area deprivation and population density. These findings, while insightful and statistically significant, are based on data from London only, and should be interpreted with caution when considering the rest of the UK, or further afield. Further research is therefore needed to explore these relationships in more detail, as well as expanding studies to other areas of England, to observe whether these associations follow similar patterns in other areas of the country.

The APS measure provides information on hedonic and eudaimonic wellbeing; however, as previously discussed, its multidimensionality may be limited by including only one item for eudaimonia. Future research may therefore benefit from including greater numbers of questions to examine these dimensions more holistically. Questionnaires such as the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS) provide up to 14 items, although at time of writing, the relevant population surveys are not available at a level of granularity comparable to the APS.

Only greenspaces with an area greater than 2ha were included in this analysis, in line with Natural England's recommendations for 'accessible greenspace'; this also had the advantage of simplifying the computational intensity and improving time efficiency of the calculations and has been used by other studies of greenspace accessibility [129, 153]. However, it may over simplify the issue of accessibility, as greenspaces smaller than this may still be useful and have an effect on mental wellbeing. Data analysis also suggested that this restriction may be associated with the skewed distributions, which limit the strength of the results and the generalisability of these outcomes. Further, by considering the size, type and travel distance of greenspace within one analysis, this does not allow for direct comparisons with the results of Chapter 5, where greenspace within a Euclidean, rather than network, buffer was evaluated. While more challenging to accomplish, future analyses which include different limits of greenspace may provide further insight into which sizes and travel distances are most important for mental wellbeing, as well as allowing comparisons with other measures of greenspace accessibility.

Finally, the cross-sectional nature of the data provides no indication of causality or direction of these associations. Future longitudinal studies, which monitor mental wellbeing in those moving between environments with different greenspace qualities, may be able to provide more conclusive evidence of the effects of exposure to different types of greenspace on individual mental wellbeing.

6.5 Conclusions

The UK Government recommends that individuals should be provided with an accessible, natural greenspace of at least 2ha in size, within a 300m walk of their home. While this guideline is based on more general health promotion and accepted standards of walking distance, this study is thought to be the first to test the recommendation for its potential mental wellbeing benefit. Stratifying greenspace according to type, positive and statistically significant associations were observed for the amount of natural greenspace and hedonic wellbeing indicators of life satisfaction and happiness; associations with other types of greenspace were not statistically significant. No associations were found for eudaimonic wellbeing. Spatial Error models were applied, to account for the second-order spatial clustering within the data, enabling robust estimations of these associations to be calculated, revealing slight but significant underlying geospatial processes within the structure of the data. The field would benefit from future studies which examine mental wellbeing, and eudaimonic wellbeing in particular, with a greater number of items, and characterise greenspace accessibility more thoroughly, by including greenspace access points and quality indicators. Studies which are able to consider the relationships not just in London, but across other cities in the UK, may also support this research by determining whether these patterns may be more widely generalisable.

7.0 Discussion and contribution

"there is

nothing left

to worry about

the sun and her flowers are here"

- rupi kaur

With urbanisation increasing, city planners and policy makers are being challenged to accommodate increasing numbers of residents in an effective and healthy way. This thesis aimed to deepen understanding of the potential health benefits of urban greenspace, by identifying associations between different greenspace characteristics and mental wellbeing.

Four research questions were developed to provide a detailed understanding of these relationships, as defined in the introduction to this thesis:

Research Question 1 - How has greenspace been studied and conceptualised in previous research, and therefore what is the existing evidence for associations with validated mental wellbeing measures?

Research Question 2 - Is the quantity of greenspace in a local (census) area associated with multidimensional mental wellbeing?

Research Question 3 - Measuring the amount of greenspace within a radius of individuals' homes, do associations with mental wellbeing differ to what is detected at an aggregated, local area, level?

Research Question 4 - Are natural greenspaces more strongly associated with mental wellbeing than other, manmade, types of greenspace?

This chapter reflects on the research undertaken to address these current gaps in knowledge, providing a detailed response to each question and identifying further potential areas of investigation, which have developed as a result of these findings.

7.1 Research undertaken in response to Question 1

There is a large body of evidence linking exposure to green and natural environments with potential salutogenic health outcomes, with some other literature reviews aggregating the findings for general and mental health outcomes [10, 11, 19, 101]. The review in Chapter 3 was therefore designed to systematically identify the ways in which greenspace has been characterised in the literature and synthesise the quantitative evidence for associations between these greenspace measures and validated mental wellbeing tools. After searching 5 databases and screening abstracts, the results of 52 studies were narratively synthesised, revealing a surprising dearth of evidence for multidimensional wellbeing. Six different ways in which greenspace is commonly studied were identified: (a) amount of local area greenspace (most commonly the proportion of local areas covered by greenspace); (b) greenspace type; (c) views of greenspace; (d) visits to greenspace; (e) accessibility (proximity to greenspaces and self-reported 'access'); and (f) subjective connection to nature. However, while local area greenspace was found to be adequately associated with life satisfaction, the evidence for the remaining characterisations of greenspace was either limited or insufficient. Although the evidence is currently not sufficient or specific enough to guide planning decisions, this review highlighted the need to examine multidimensional wellbeing measures and greenspace at an individual level. There is also a gap in knowledge regarding which types (and other characteristics) of greenspace are most important for mental wellbeing, as well as which attributes specifically make greenspace accessible to local residents.

7.2 Research undertaken in response to Question 2

Previous research has examined the association between local area (LSOA) level greenspace and mental distress, as well as life satisfaction, but no studies had previously examined multidimensional mental wellbeing at a national level [37]. The majority of studies have also examined only urban or rural environments, not comparing across these; therefore, this Chapter was designed to study these differences by further stratifying by urban and rural area. Using LSOA-level proportion of greenspace and the shortened Warwick-Edinburgh Mental Well-Being Scale (SWEMWBS), spatially-adjusted (by sampling unit) Ordinary Least Squares (OLS) regression models revealed a positive association which was attenuated to the null after adjusting for a range of individual and household-level factors. While there was some evidence of differences in the associations when stratifying by level of urbanity, this was not statistically significant. Despite some evidence, as presented in Chapter 3, that greenspace may be associated with mental wellbeing, the analysis suggests that these associations could not be detected at LSOA level, due to the imposition of arbitrary, data collection boundaries, which do not reflect the real-world local neighbourhoods of individuals.

7.3 Research undertaken in response to Question 3

Research question 3 is addressed in Chapter 5, where the amount of greenspace surrounding individuals' homes in London is measured and spatially examined; this study also allowed individual-level associations to be analysed. Using a Euclidean buffer, the amount of greenspace within 300m of individuals' post codes was calculated and associations with hedonic and eudaimonic wellbeing (life satisfaction, happiness and worth) were predicted using Ordinary Least Squares regression, revealing a positive association with life satisfaction and worth. Statistically significant autocorrelations highlighted spatial clusters in the results, so Geographically Weighted Regression (GWR) models were used to adjust for these geospatial patterns and allow the strength of the associations to vary across the study space. The strongest, positive associations were detected for life satisfaction and were slightly lower with worth and again for happiness, although each association was statistically significant. Spatially plotting these results showed slight variation in the strength (and, in some small areas, the direction) of associations across London, implying that greenspace may be more important for mental wellbeing in some areas than others. This variation may be due, in part, to further characteristics of greenspace which were not considered here, such as type and accessibility.

7.4 Research undertaken in response to Question 4

Much of the literature on greenspace and health is based on the premise that exposure to nature may be beneficial for individuals [19]. The final research question was addressed in Chapter 6 by testing the Natural England guideline that individuals should have at least 2ha of natural greenspace available within 300m walking distance of their homes. Greenspace was classified into 4 types, which were compared: natural greenspace, formal parks and gardens, outdoor sports facilities, and other. The area of a greenspace was included in the analysis if its boundary could be reached within a 300m network distance of individuals' post code centroids. In OLS models, the total amount of accessible greenspace was positively and statistically significantly associated with worth. Further, when stratifying by greenspace type, the amount of natural greenspace was associated with life satisfaction and happiness, suggesting that considering greenspace as a single entity may mask significant associations with nature in particular. In order to account for underlying second-order processes, Spatial Error Models were applied, allowing the residuals to cluster. Having access to greater amounts of natural greenspace was again significantly associated with improved hedonic wellbeing (life satisfaction and happiness), but not eudaimonic wellbeing (worth). In this model, the spatial autoregressive parameter showed very slight spatial variation in the residuals of the model.

7.5 Implications for urban science

The research undertaken within this thesis provides a detailed insight into the complexities of designing and maintaining urban greenspaces for potential mental wellbeing benefits, drawing together large population data sets with multidimensional mental wellbeing measures and comprehensive greenspace shapefiles. These geospatial datasets allowed for the consideration of more abstract spatial constructs, models and patterns such as clustering and variation in the associations between land use and health to be examined.

The findings of this work emphasise the necessity of considering health, particularly mental health, as an important area of urban science when understanding how to create effective environments where individuals live and work. Previous research has demonstrated lifestyles and illnesses to be associated with the urban environment [2, 11], while this thesis highlights the potential salutogenic effects of a well-designed, green city.

Taking inspiration from both the health services and geoinformatics literature, it was possible to examine greenspace accessibility using spatial tools, demonstrating the importance of looking beyond an individual scientific field to select the appropriate analytical methods and maximise the implications of research. While urban science has traditionally been an interdisciplinary sphere, concerned with the intricacies of modern society and infrastructure, studies of urban health have mainly focussed on simple, area-aggregated associations between land use and wellbeing indicators. The combination of health science concepts and spatial methods is therefore novel in that it draws together an understanding of the multidimensional nature of individual wellbeing, amenity provision and the complexities of geographical information, to model and understand how individuals may access and therefore benefit from their local built environment.

The discovery of statistically significant, positive associations between greenspace and multidimensional mental wellbeing at the individual level, but not local area, highlights the potential difficulties encountered when aggregating residents to arbitrary boundaries which do not adequately represent a neighbourhood living environment. This is known as the Modifiable Areal Unit Problem, which states that any spatially summed values will be influenced by both the shape and the scale of the grouping unit [197]. In the context of this thesis, this reinforces the necessity of data which describes the lifestyles of residents to be examined at an appropriate level, which can realistically capture the environment under examination.

7.6 Implications for the field of health and wellbeing in the built environment

The main contribution of this thesis is in expanding knowledge within the field of urban and wellbeing. While previous research has focused on general health and mental distress with regards to the urban environment, this research provides evidence for mental wellbeing outcomes, measured using multidimensional, validated scales. Further, it was also possible to address potential differences in outcomes for hedonic and eudaimonic dimensions of wellbeing. The literature on therapeutic landscapes suggests that some environments may not only improve symptoms of ill-health, but also have salutogenic effects on individuals. While the optimal healing landscape may vary for different people, the research herein thereby demonstrates that greenspace, and natural greenspace in particular, might be therapeutic at a societal level, helping to reduce health inequalities.

A systematic literature review provided, for the first time, a detailed synthesis of current research on greenspace and mental wellbeing. In particular, it highlighted a dearth of studies on eudaimonic wellbeing, as well as a range of greenspace characterisations, which were often measured inconsistently.

Original research demonstrated that associations between greenspace and mental wellbeing cannot always be detected at local area level, as these spatial units misclassify individuals. The proposed solution is to conduct studies at the individual level, by considering an appropriate granularity which adequately reflects the real living environment of individuals. In particular, street-level accessibility of local amenities, such as greenspace, should not be overlooked.

The research within this thesis also advanced the traditional methods applied to the field by taking advantage of more interdisciplinary geospatial methodologies. Much of the previous work in the area has overlooked and therefore underrepresented the importance of space, in particular when studying population datasets, which are often inherently clustered. Earlier studies which fail to account for spatial autocorrelations, for example, are likely to overestimate the significance of their results, which is an important consideration for studies of place-effects on health, in particular. By examining the spatial distribution of preliminary linear model outcomes, this work was able to apply methods which reflect and account for the structure of the data, thereby providing more robust estimates of the association between built environment features and wellbeing variables.

7.7 Implications for urban planning and policy

As urban greenspaces are generally provided at the expense of buildings, it is vital that their design is well informed, to offer the greatest benefit to the widest population. While there are no legal requirements for the inclusion of greenspace into built environments, current planning guidance makes some recommendations, which are based on surveys and pilot schemes rather than robust scientific evidence. Therefore, is it believed that the research presented within this thesis is the first to test the Natural England guidelines for potential implications for mental wellbeing.

In Chapter 5, the recommendation that greenspace should be available within 300m of homes was examined using Euclidean buffers, providing evidence that this distance revealed the strongest associations with mental wellbeing, and may therefore offer a solution for creating therapeutic landscapes within the urban environment. Consideration of greater distances revealed weaker results, therefore providing some evidence that 300m may be an effective distance for greenspace provision to promote mental wellbeing.

To the best of the author's knowledge, the research presented here is also the first to utilise Planning Policy Guidance greenspace categories for analyses of associations between provision and mental wellbeing. Natural England recommend provision of natural greenspace in particular; by comparing associations between accessible greenspace of different types, according to the PPG17 classification, this study demonstrated that natural greenspace was more strongly associated with mental wellbeing than other, obviously man-made urban greenspaces. Although further research is required to validate these findings in other areas of England, and determine whether different types of greenspace may benefit different people, it may be suggested that natural spaces could be given preference when providing urban greenspaces, for potential mental wellbeing benefits.

Therefore, this thesis benefits Urban Planning and Policy by being one of the first bodies of research to provide evidence for greenspace design specifically with mental wellbeing in mind.

7.8 - Limitations

7.8.1 Limitation 1 – *locational and greenspace accuracy*

In Chapter 4, LSOA-level data was available for individuals and greenspace prevalence; Chapters 5 and 6 extended the accuracy of this analysis by examining the locations of individual post codes and greenspaces. As data was not available for the specific residence, locations were assumed at the post code centroid. Although this is typically the most granular level of data available within the UK, it may under- or over-estimate distances when estimating surrounding greenspace. In Chapter 6, when calculating the network distance to greenspace boundaries, the study was not able to account for greenspace access points, meaning that travel distances may also be slightly misinterpreted. While the boundary was sufficient for this study, it does somewhat simplify the issue of accessibility and therefore provides potential for future research to obtain this information and investigate whether associations may differ. Accessibility is also assumed based on travel distance, which does not allow for the types of routes which must be traversed, in particular for older or less mobile people. The time of year and weather patterns may also discourage use for ageing individuals, where shorter days and adverse weather inhibit activity, and may even cause frustration for those unable to enjoy their local area [33].

Further, different attributes of greenspace were considered within each study, which does not allow for direct comparison of the results between chapters. For example, in Chapter 5, greenspace was measured as the total amount within 300m of individuals' homes, while in Chapter 6, although here network distance was used, only greenspaces greater than 2ha in size were included. This was in order to test the Natural England guideline, as well as slightly reducing the complexity of a large and computationally intensive network analysis to make the operation feasible at this scale [50]. These methods allowed for broadening of the scope of this thesis to consider different conceptualisations of accessible greenspace, although limits the comparability of these measures. This does, however, present a future opportunity to observe variation in associations when accessibility is operationalised in different ways.

The work presented in this thesis also assumes that greenspace close to individuals' homes is most important for mental wellbeing. Literature on place-effects argues that home, work and leisure environments may all be instrumental in contributing to health outcomes; this research therefore only focuses on one aspect of a more holistic depiction of place [12, 13]. Adults, particularly of working age, are likely to spend large parts of the week at their workplace; therefore, greenspace in these environments, as well as areas traversed while commuting, may be worthy of future investigation.

7.8.2 Limitation 2 – *mental wellbeing measures and individual preference*

Mental wellbeing is a multidimensional concept encompassing aspects of hedonia and eudaimonia. In Chapter 4, the shortened Warwick-Edinburgh Mental Well-Being Scale (SWEMWBS) was used to measure wellbeing through 7 questions [61]. In Chapters 5 and 6, only 3 items were used, which cover aspects of life satisfaction, worth and happiness. While also covering both domains, this tool is evidently less detailed and includes only one measure of eudaimonic wellbeing (sense of worth) [36]. With increasing availability of large population datasets, there may therefore be an opportunity for future research to examine more holistic mental wellbeing outcomes which cover both dimensions in greater detail.

While all studies within this thesis attempted to control for many individual and local area potentially confounding factors, there may be further variables, such as individual personality traits or personal connection to nature, which may cause some individuals to benefit from greenspace more greatly than others, or indeed lead to an inverse association. The Prospect-Refuge theory of evolution suggests that individuals may have a preference for either wide vistas or sheltered enclaves [32], and any associated benefits may further depend on the individual's current mood. Mealey and Theis propose that subjects in positive moods (cheer, energetic) may feel more motivated to explore, and thus prefer expansive landscapes with good prospect, whilst those in lower moods (tired, sad) may desire more enclosed, protected spaces (refuge), which might provide a sense of safety and reduced stress [32]. Therefore, while availability of urban greenspace may have the potential to promote wellbeing, the type of environment which is most beneficial could be different according to the individual themselves, as well as their current state of mind. While this research was able to compare associations for four different types of greenspace, future studies might examine further greenspace characteristics for different demographic sets, to identify which features may be most beneficial to whom.

Further, with urbanisation expanding and evolving, preferences and trends with urban greenspace may also change over time. While the research presented herein suggests that natural greenspace may be most beneficial to mental wellbeing, new constructions and compositions of cities and their populations may facilitate different interactions between people their environments to become accessible.

7.8.3 Limitation 3 – *mechanisms and mediators*

The research presented in Chapter 6 provided evidence that natural greenspace may be more important for mental wellbeing than other, more obviously manmade, types. This may be due to *biophilia*, the human desire to connect with other forms of life, which may cause individuals to feel more positive in natural environments [20]. While nature itself may in this way be therapeutic, other research has suggested that greenspace acts as a facilitator for activities which benefit mental wellbeing, such as physical activity and social interactions [40]. However, the final study within this thesis did not find statistically significant associations between sports facilities and mental wellbeing, suggesting that, in this case, physical activity in such spaces may not have a mechanistic effect which can be captured in such a model. Mechanisms which provide more of an explanation for these associations were not studied in detail, so it cannot be concluded whether exercise, socialising or any other factor mediates the association between greenspace and mental wellbeing. Future work should investigate these mechanisms, in order to identify how greenspaces may improve wellbeing and make recommendations for the inclusion and use of space in urban environments.

Spatial differences in associations between greenspace and mental wellbeing were considered, particularly in Chapter 5, although this method still assumes that it is the differences within the environmental features, as opposed to between individuals, which is most important. As previously discussed, people may have different preferences for environments which offer either prospect or refuge, and this may be further influenced by their demographic [32]. In the systematic literature review, presented in Chapter 3, some authors reported variation in associations between greenspace and aspects of wellbeing by age and gender, and Pearce also argues that places may affect health differently at various critical points in the life course [13]. The studies in subsequent chapters did not stratify models by demographic or consider interactions with these factors. It is possible that some of the observed variation within the models may be mediated by different types of environment changing in importance or being therapeutic at different stages in life.

As well as this, individual mood may influence whether a certain environment is compatible with one's inclinations, as suggested by Mealey and Theis [32]. Converseley, research by Collins and Kearn has demonstrated some spaces may be both healthy and unhealthy at the same time, depending on the opinions and feelings of specific visitors [237]. For example, water features may appear calming for some, whilst being a potential danger to others, particularly those with young children [237, 238]. As demonstrated in Chapter 5, associations between greenspace and mental wellbeing not only varied in strength but in some places also the direction of effect. The studies within this thesis are designed upon the premise that greenspace may be beneficial to mental wellbeing, although some research has shown that certain configurations of greenspace may evoke negative emotions; for example, dense woodlands may appear to some intimidating, or else require tiring, directed attention where pathways are uneven or tree roots present trip hazards [204]. Other spaces which are isolated, dark or untended may appear to some unsafe and therefore discourage use [93, 203, 204]. Furthermore, older people in particular report finding greenspace inaccessible during darker evenings or poorer weather [33]. In this case, the wider local area and climate, as well as individual mobility, ought to be given future consideration as potential moderating influences. Broader social factors, such as prejudices regarding race, lifestyle and weight may cause certain individuals to feel marginalised or unwelcome in certain greenspaces, particularly those decided to facilitate exercise; this could lead to negative associations with green environments which may be detrimental to mental wellbeing [239]. Although potentially difficult to capture, more complex issues of socio-political factors are worthy of future study as moderating variables.

7.8.4 Limitation 4 – *causality*

Although all of the individual level data within these studies was obtained from large, population data sets, the analyses undertaken have all been cross-sectional in nature. It was therefore not possible to draw any conclusions regarding causality or the direction of the associations between greenspace and mental wellbeing.

The issue of self-selection could not be accounted for; while having a higher income may provide more opportunities to live in a greener environment, individuals with a preference for nature may be more likely to move to a greener area, spend more time in their local greenspace, or value greenspace more highly than others. Adjusting for income and deprivation within the analyses may begin to address these concerns, although the remaining possibility of some selection bias should not be discounted and hence results should be interpreted with some caution.

7.8.5 Limitation 5 – *generalisability*

Due to limitations of data availability (in particular, access to detailed greenspace data), the analyses conducted within Chapters 5 and 6 were restricted to London. Associations within other cities may therefore be different, and as such it is not possible to directly generalise these findings to other areas of the UK. Studies should begin to focus on case studies within other parts of the country, or national studies to examine whether people may benefit from their local environment in the same way across different cities.

Furthermore, although potentially confounding factors were adjusted for within all models, the associations cannot necessarily be generalised to all individuals; associations may further depend on individuals' preferences, mood, or life stage.

7.9 Recommendations for future work

Drawing on the limitations identified above, there are a range of extensions of this work which would further benefit the field. Several suggestions are outlined below.

Firstly, future work is required to continue to examine validated multidimensional wellbeing outcomes in the context of greenspace. In particular, measures such as the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS), which allow both hedonic and eudaimonic domains to be studied in detail, may provide a more holistic evaluation of positive mental health.

Characterisation of greenspace itself must also be developed. Studies should continue to be conducted at a level appropriate to the study, as this thesis has shown that such associations may not be detected at local authority level. Qualitative investigations of individual greenspace preferences on a larger scale may also provide a beneficial insight into what is valuable, where and to whom, while consistent and justified classification of greenspace is vital to ensure interpretability of future analyses. As the studies within the thesis have shown variation in associations across space, further analyses that examine greenspace types and interactions with individual characteristics may help untangle which green features are could be most beneficial to different demographics or other subgroups of the population.

Greenspace usage patterns and indicators of quality and facilities may also help explain which features and habits may be most beneficial. Studies of potential mechanisms, such as the use of greenspace for activities including physical exercise, social interaction and relaxation may provide further insight into how individuals gain mental wellbeing benefits from using or being exposed to urban greenspaces. In addition, greenspace accessibility should be further characterised by designing studies which allow different indicators, such as Euclidean and network distance, to be directly compared. Mediating factors, such as life course stage, mobility, and personality may also provide further insight into whether associations further differ between people.

While two studies within this thesis were restricted to London, larger scale data sets should be analysed to investigate whether these findings may be replicated at a national scale, or vary between different cities.

Longitudinal studies, in particular those to track individuals moving between environments, or undertaking new habits through the use of greenspace, are recommended to begin investigating the issue of causality. It may be possible to observe how individual wellbeing changes in response to a new environment, potentially enabling identification of which amounts, types or usages of greenspace seem to improve mental wellbeing.

Finally, having identified spatial patterns within the survey and geographical data, it is vital that future studies continue to examine the structure of their data and select methods which account for any geospatial distributions, thereby allowing valid and robust results to be generated.

7.10 Conclusions

With urbanisation and living patterns evolving at an unprecedented rate, land within cities is at a premium. It is therefore imperative that health-promoting features within such environments are designed according to evidence-based recommendations, to accommodate increasing numbers of residents in an effective and positive way.

This thesis has expanded the field of health and wellbeing in the built environment by exploring the relationship between greenspace and mental wellbeing. In addressing the 4 research questions outlined above, it has been possible to identify and investigate characteristics of urban greenspaces which may have salutogenic effects on individual-level mental health. These questions were addressed through individual chapters, after Chapter 2 provided a detailed background on defining and measuring both greenspace and mental wellbeing, discussing how and why they may be related.

A systematic review was undertaken to identify how greenspace is commonly characterised and how these measures have previously been associated with mental wellbeing. A national-level study into local area greenspace and mental wellbeing then concluded that associations could not be detected where arbitrary boundaries have been imposed on the individual level data. To overcome this limitation, the amount of greenspace within 300m of individuals homes was calculated, revealing a positive and statistically significant association with mental wellbeing, a result which varied in strength across London, according to Geographically Weighted Regression models. This analysis was extended by then measuring this distance along the street network and stratifying greenspace by type. Natural greenspace was found to be positively and statistically significantly associated with hedonic wellbeing, while other types were not. Spatial Error Models revealed slight spatial variation in the residuals, thereby accounting for second-order processes within the data.

In combination, these contributions expand the current knowledge of greenspace design for mental wellbeing, being the first studies to examine Natural England's planning recommendations for potential associations with mental wellbeing. These results provide evidence that greenspace is associated with improved mental wellbeing scores, when studied at the individual level. The strength of these associations may further depend on characteristics of the individuals and their local greenspaces. Natural greenspace, within

300m of individuals homes, may be important for mental wellbeing, and hedonic wellbeing in particular.

Future work should expand on this body of research by including detailed measures of multidimensional mental wellbeing and greenspace, investigating aspects of greenspace use, quality and changes in environment.

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Appendix A: Full Results of Geographically Weighted Regression Models

Greenspace within Buffer	Life Satisfaction B	p	R^2	Worth B	p	R^2	Happiness B	p	R^2
300m	0.601	0.037	0.013	0.874	0.002	0.020	0.299	0.382	0.005
300m, adjusted	***0.914***	***0.001***	***0.388***	***0.721***	***0.009***	0.307	0.508	0.142	0.288
500m	0.287	0.008	0.017	0.421	<0.001	0.025	0.178	0.166	0.009
500m, adjusted	***0.344***	***0.001***	***0.387***	***0.282***	***0.008***	0.307	0.204	0.126	0.288
1km	0.060	0.054	0.012	0.088	0.003	0.019	0.045	0.227	0.008
1km, adjusted	0.025	0.827	0.387	0.007	0.819	0.308	0.011	0.763	0.288

*Table A.1: Summary of Results and Greenspace Coefficients for Unadjusted and Fully Adjusted OLS Associations between Greenspace and Mental Wellbeing. Adjusted models include controls for: age, sex, marital status, ethnicity, general health, qualifications, economic activity, full time employment, income, housing tenure, living with children, housing type, LSOA population density and LSOA deprivation. (*Statistically significant fully adjusted results are highlighted in bold italics)

Greenspace within Buffer	Life Satisfaction B	p	R^2	Worth B	p	R^2	Happiness B	p	R^2
300m	0.4840	<0.001	0.012	0.8212	<0.001	0.010	0.2985	<0.001	0.010
300m, adjusted	***0.8034***	***<0.001***	***0.305***	***0.7398***	***<0.001***	***0.170***	***0.5208***	***<0.001***	***0.136***
500m	0.2934	<0.001	0.012	0.4089	<0.001	0.010	0.1649	<0.001	0.010
500m, adjusted	***0.3300***	***<0.001***	***0.305***	***0.2922***	***<0.001***	***0.170***	***0.1682***	***<0.001***	***0.136***
1000m	0.0918	<0.001	0.011	0.1070	<0.001	0.009	0.0542	<0.001	0.009
1000m, adjusted	***0.0421***	***<0.001***	***0.305***	***0.0261***	***<0.001***	***0.170***	***0.0077***	***<0.001***	***0.137***

*Table A.2 Summary of Results and Greenspace Coefficients for Unadjusted and Fully Adjusted GWR Associations between Greenspace and Mental Wellbeing. Adjusted models include controls for: age, sex, marital status, ethnicity, general health, qualifications, economic activity, full time employment, income, housing tenure, living with children, housing type, LSOA population density and LSOA deprivation. (*Statistically significant fully adjusted results are highlighted in bold italics)

LIFE SATISFACTION, 500m

Variable	Value	Global B	p
Greenspace	500m	0.8034	<0.001
Age	*16-24, as ref*		
	25-34	-0.3296	<0.001
	35-44	-0.5181	<0.001
	45-54	-0.6633	<0.001
	55-64	-0.2554	<0.001
	65-75	0.1841	<0.001
	over 75	0.3064	<0.001
Sex	*Male, as ref*		
	Female	0.0918	<0.001
Married/Cohabiting	*No, as ref*		
	Yes	0.4826	<0.001
Ethnicity	*White, as ref*		
	Other Asian	0.0592	<0.001
	Black	-0.1983	<0.001
	Mixed	-0.109	<0.001
	Other	0.0535	<0.001
	South Asian	0.1707	<0.001
General Health	*Very Poor, as ref*		
	Poor	1.083	<0.001
	Fair	1.9515	<0.001
	Good	2.5822	<0.001
	Very Good	2.9968	
Qualifications	*No degree, as ref*		
	Degree/Diploma	-0.0736	<0.001
Economic Activity	*Employed, as ref*		
	Economically Inactive	-0.0915	<0.001
	Employed	-0.7221	<0.001
Full Time Employment	*No, as ref*		
	Yes	0.0098	<0.001
Income, Quintiles	1st	-0.127	<0.001
	2nd	-0.1125	<0.001
	3rd	-0.0367	<0.001
	4th	0.0984	<0.001
	5th	0.2218	<0.001
Living with Children	*No, as ref*		
	Yes	0.0429	<0.001
Housing Tenure	*Does not own current home, as ref*		
	Owns current home	0.1653	<0.001
Housing Type	*Detached, as ref*		
	Flat	-0.0694	<0.001
	Other	-0.0852	<0.001
	Semi Detached	-0.0263	0.781
	Terraced	-0.0136	<0.001
Population Density		0.0006	<0.001
Deprivation		-0.0019	<0.001

Table A.3 Results of Fully Adjusted Geographically Weighted Regression Model for Life Satisfaction and Greenspace within 500m

LIFE SATISFACTION, 1000m

Variable	Value	*Global B*	*p*
Greenspace	1000m	0.0412	<0.001
Age	*16-24, as ref*		
	25-34	-0.3283	<0.001
	35-44	-0.5171	<0.001
	45-54	-0.6624	<0.001
	55-64	-0.2547	<0.001
	65-75	0.1844	<0.001
	over 75	0.3078	<0.001
Sex	*Male, as ref*		
	Female	0.092	<0.001
Married/Cohabiting	*No, as ref*		
	Yes	0.4825	<0.001
Ethnicity	*White, as ref*		
	Other Asian	0.0603	<0.001
	Black	-0.1969	<0.001
	Mixed	-0.1088	<0.001
	Other	0.0528	<0.001
	South Asian	0.1684	<0.001
General Health	*Very Poor, as ref*		
	Poor	1.0834	<0.001
	Fair	1.9516	<0.001
	Good	2.5823	<0.001
	Very Good	2.9974	<0.001
Qualifications	*No degree, as ref*		
	Degree/Diploma	-0.0736	<0.001
Economic Activity	*Employed, as ref*		
	Economically Inactive	-0.0921	<0.001
	Employed	-0.7218	<0.001
Full Time Employment	*No, as ref*		
	Yes	0.01	<0.001
Income, Quintiles	1st	-0.1276	<0.001
	2nd	-0.1135	<0.001
	3rd	-0.0358	<0.001
	4th	0.0981	<0.001
	5th	0.2221	<0.001
Living with Children	*No, as ref*		
	Yes	0.043	<0.001
Housing Tenure	*Does not own current home, as ref*		
	Owns current home	0.1652	<0.001
Housing Type	*Detached, as ref*		
	Flat	-0.0699	<0.001
	Other	-0.0873	<0.001
	Semi Detached	-0.0291	0.2453
	Terraced	-0.0168	<0.001
Population Density		0.0005	0.3943
Deprivation		-0.0016	<0.001

Table A.4 Results of Fully Adjusted Geographically Weighted Regression Model for Life Satisfaction and Greenspace within 1000m

WORTH, 500m

Variable	Value	*Global B*	*p*
Greenspace	500m	0.2922	<0.001
Age	*16-24, as ref*		
	25-34	-0.1883	<0.001
	35-44	-0.2465	<0.001
	45-54	-0.3153	<0.001
	55-64	0.1398	<0.001
	65-75	0.3874	<0.001
	over 75	0.367	<0.001
Sex	*Male, as ref*		
	Female	0.2297	<0.001
Married/Cohabiting	*No, as ref*		
	Yes	0.2845	<0.001
Ethnicity	*White, as ref*		
	Other Asian	-0.0647	<0.001
	Black	0.0443	<0.001
	Mixed	0.1715	<0.001
	Other	-0.0398	<0.001
	South Asian	0.0928	<0.001
General Health	*Very Poor, as ref*		
	Poor	0.8596	<0.001
	Fair	1.5884	<0.001
	Good	2.0185	<0.001
	Very Good	2.3917	<0.001
Qualifications	*No degree, as ref*		
	Degree/Diploma	-0.0158	<0.001
Economic Activity	*Employed, as ref*		
	Economically Inactive	-0.1223	<0.001
	Employed	-0.5083	<0.001
Full Time Employment	*No, as ref*		
	Yes	-0.0051	<0.001
Income, Quintiles	1st	-0.0241	<0.001
	2nd	-0.0638	<0.001
	3rd	0.0184	<0.001
	4th	0.0611	<0.001
	5th	0.0418	<0.001
Living with Children	*No, as ref*		
	Yes	0.2532	<0.001
Housing Tenure	*Does not own current home, as ref*		
	Owns current home	0.1078	<0.001
Housing Type	*Detached, as ref*		
	Flat	-0.1248	<0.001
	Other	-0.0887	<0.001
	Semi Detached	-0.0615	<0.001
	Terraced	-0.0448	<0.001
Population Density		0.0002	0.0194
Deprivation		-0.0012	<0.001

Table A.5 Results of Fully Adjusted Geographically Weighted Regression Model for Worth and Greenspace within 500m

WORTH, 1000m

Variable	Value	Global B	p
Greenspace	1000m	0.0261	<0.001
Age	*16-24, as ref*		
	25-34	-0.1874	<0.001
	35-44	-0.2458	<0.001
	45-54	-0.314	<0.001
	55-64	0.1412	<0.001
	65-75	0.3881	<0.001
	over 75	0.3681	<0.001
Sex	*Male, as ref*		
	Female	0.2301	<0.001
Married/Cohabiting	*No, as ref*		
	Yes	0.2845	<0.001
Ethnicity	*White, as ref*		
	Other Asian	-0.0647	0.0554
	Black	0.0449	<0.001
	Mixed	0.1701	<0.001
	Other	-0.0411	<0.001
	South Asian	0.0894	<0.001
General Health	*Very Poor, as ref*		
	Poor	0.8594	<0.001
	Fair	1.5885	<0.001
	Good	2.0185	<0.001
	Very Good	2.3918	<0.001
Qualifications	*No degree, as ref*		
	Degree/Diploma	-0.0165	<0.001
Economic Activity	*Employed, as ref*		
	Economically Inactive	-0.1223	<0.001
	Employed	-0.5074	<0.001
Full Time Employment	*No, as ref*		
	Yes	-0.0049	<0.001
Income, Quintiles	1st	-0.024	<0.001
	2nd	-0.0649	<0.001
	3rd	0.0187	<0.001
	4th	0.0604	<0.001
	5th	0.0414	<0.001
Living with Children	*No, as ref*		
	Yes	0.2542	<0.001
Housing Tenure	*Does not own current home, as ref*		
	Owns current home	0.1082	<0.001
Housing Type	*Detached, as ref*		
	Flat	-0.1282	<0.001
	Other	-0.0921	<0.001
	Semi Detached	-0.0644	<0.001
	Terraced	-0.0486	<0.001
Population Density		0.0001	0.0194
Deprivation		-0.0009	<0.001

Table A.6 Results of Fully Adjusted Geographically Weighted Regression Model for Worth and Greenspace within 1000m

HAPPINESS, 500m

Variable	Value	Global B	p
Greenspace	500m	0.1682	<0.001
Age	*16-24, as ref*		
	25-34	-0.1303	<0.001
	35-44	-0.1813	<0.001
	45-54	-0.2315	<0.001
	55-64	0.0930	<0.001
	65-75	0.4729	<0.001
	over 75	0.5099	<0.001
Sex	*Male, as ref*		
	Female	0.0274	<0.001
Married/Cohabiting	*No, as ref*		
	Yes	0.3699	<0.001
Ethnicity	*White, as ref*		
	Other Asian	0.1111	0.0554
	Black	0.0970	<0.001
	Mixed	-0.1031	<0.001
	Other	0.0382	<0.001
	South Asian	0.2372	<0.001
General Health	*Very Poor, as ref*		
	Poor	0.9837	<0.001
	Fair	1.8973	<0.001
	Good	2.4758	<0.001
	Very Good	2.9740	<0.001
Qualifications	*No degree, as ref*		
	Degree/Diploma	-0.0578	<0.001
Economic Activity	*Employed, as ref*		
	Economically Inactive	0.0402	<0.001
	Employed	-0.3321	<0.001
Full Time Employment	*No, as ref*		
	Yes	0.0290	<0.001
Income, Quintiles	1st	0.0847	<0.001
	2nd	-0.0461	<0.001
	3rd	-0.0087	<0.001
	4th	-0.0869	<0.001
	5th	0.0038	0.3710
Living with Children	*No, as ref*		
	Yes	0.0569	<0.001
Housing Tenure	*Does not own current home, as ref*		
	Owns current home	0.0694	<0.001
Housing Type	*Detached, as ref*		
	Flat	-0.0113	0.0034
	Other	0.0283	<0.001
	Semi Detached	0.0295	<0.001
	Terraced	0.0456	<0.001
Population Density		0.0006	<0.001
Deprivation		-0.0026	<0.001

Table A.7 Results of Fully Adjusted Geographically Weighted Regression Model for Happiness and Greenspace within 500m

HAPPINESS, 1000m

Variable	Value	*Global B*	*p*
Greenspace	1000m	0.0077	<0.001
Age	*16-24, as ref*		
	25-34	-0.1297	<0.001
	35-44	-0.1808	<0.001
	45-54	-0.2305	<0.001
	55-64	0.094	<0.001
	65-75	0.4734	<0.001
	over 75	0.5107	<0.001
Sex	*Male, as ref*		
	Female	0.0276	<0.001
Married/Cohabiting	*No, as ref*		
	Yes	0.3699	<0.001
Ethnicity	*White, as ref*		
	Other Asian	0.1107	<0.001
	Black	0.0971	<0.001
	Mixed	-0.1041	<0.001
	Other	0.0372	<0.001
	South Asian	0.2348	<0.001
General Health	*Very Poor, as ref*		
	Poor	0.9834	<0.001
	Fair	1.8972	<0.001
	Good	2.4757	<0.001
	Very Good	2.9739	<0.001
Qualifications	*No degree, as ref*		
	Degree/Diploma	-0.0583	<0.001
Economic Activity	*Employed, as ref*		
	Economically Inactive	0.0403	<0.001
	Employed	-0.3315	<0.001
Full Time Employment	*No, as ref*		
	Yes	0.0291	<0.001
Income, Quintiles	1st	0.0849	<0.001
	2nd	-0.0467	<0.001
	3rd	-0.0085	<0.001
	4th	-0.0873	<0.001
	5th	0.0035	0.5876
Living with Children	*No, as ref*		
	Yes	0.0577	<0.001
Housing Tenure	*Does not own current home, as ref*		
	Owns current home	0.0697	<0.001
Housing Type	*Detached, as ref*		
	Flat	-0.0141	0.0050
	Other	0.0258	<0.001
	Semi Detached	0.0274	<0.001
	Terraced	0.0428	<0.001
Population Density		0.0005	<0.001
Deprivation		-0.0025	<0.001

Table A.8 Results of Fully Adjusted Geographically Weighted Regression Model for Happiness and Greenspace within 1000m

Appendix B: LISA Cluster Maps of OLS Null Models

Significant Residual Autocorrelations: Life Satisfaction Null Model

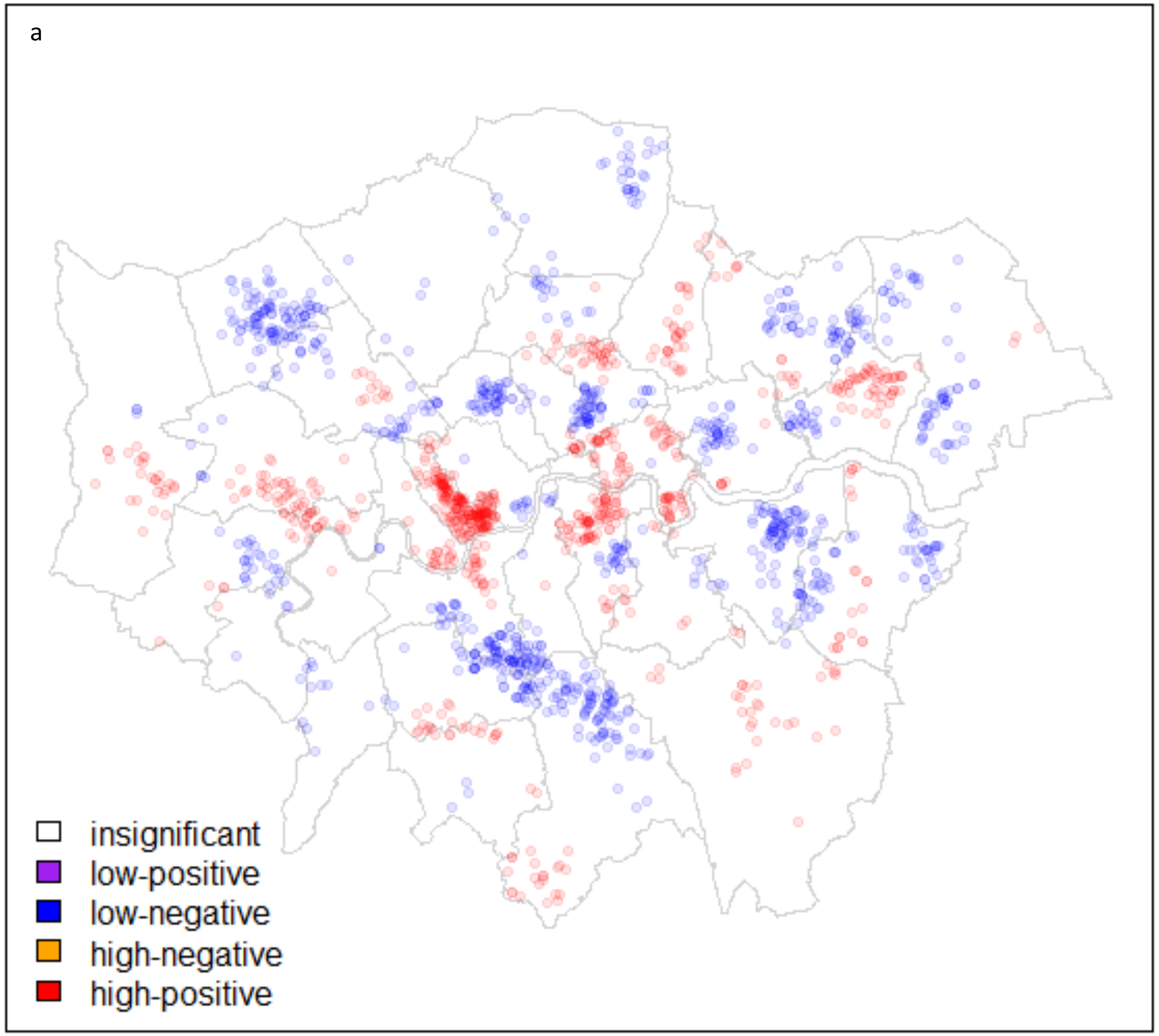

Figure B.1a LISA cluster maps of the residuals of null models

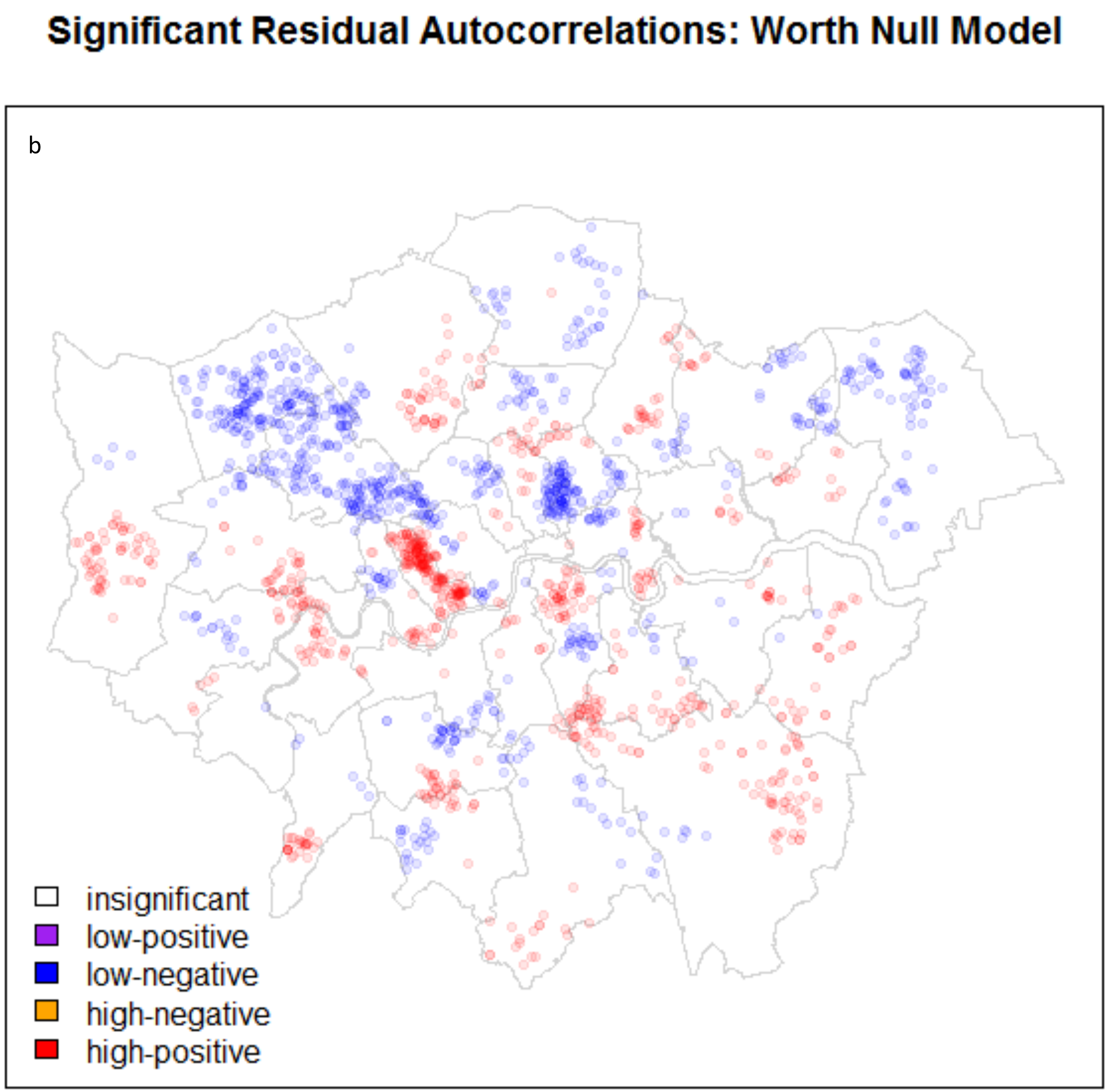

Figure B.1b LISA cluster maps of the residuals of null models

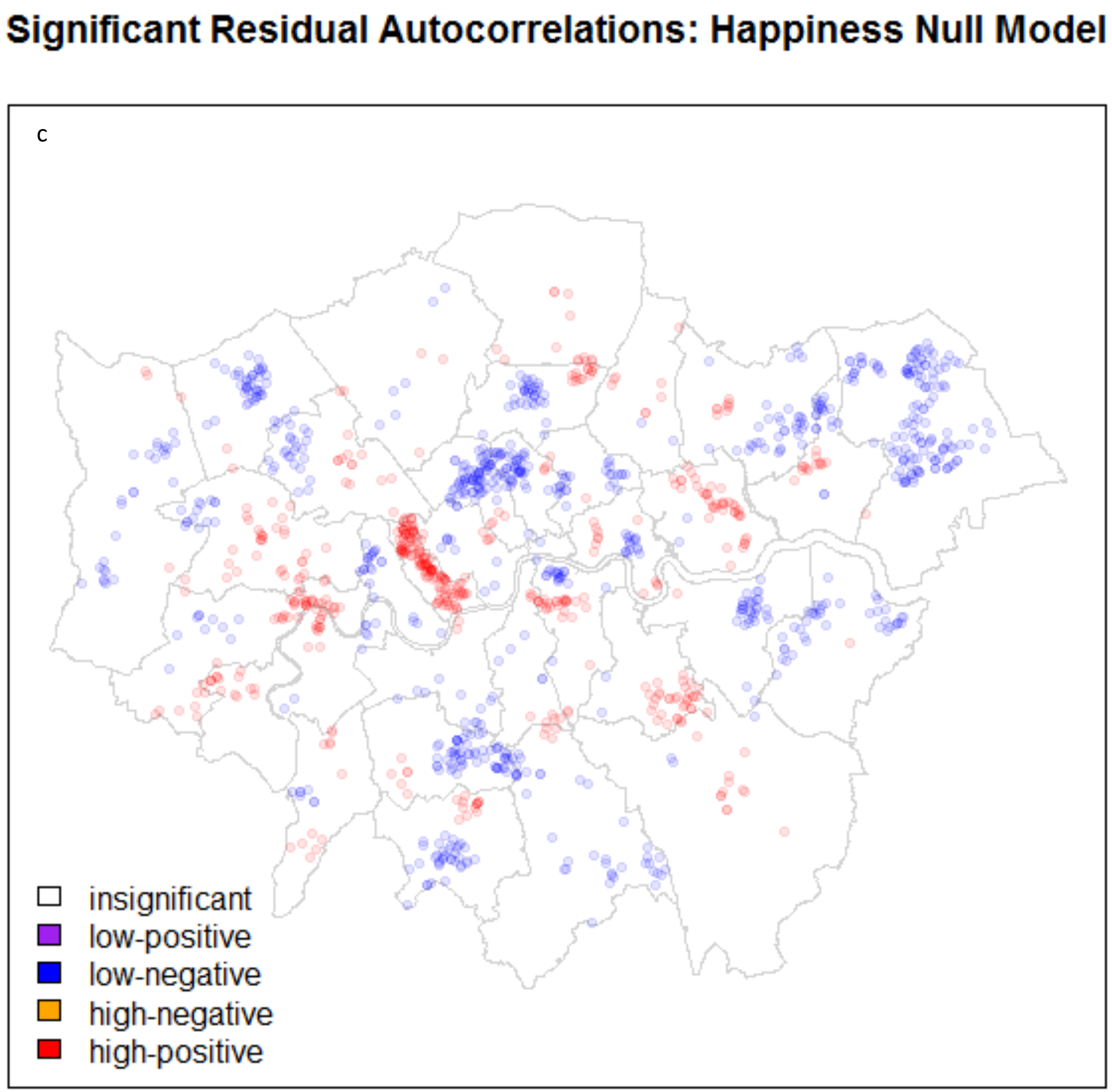

Figure B.1c LISA cluster maps of the residuals of null models