Investigation on Index of Multiple Deprivation Health Variation with Green-Space Quality and Healthcare Services in London

Yutong Wang

Augest, 2025

Contents

List of Figures

A dissertation submitted in partial fulfillment of the requirements of the Masters Degree in Urban Data Science and Analytics of the University of Leeds

Abstract

Spatial health inequalities persist across urban areas, yet the combined effects of environmental amenities and healthcare accessibility on health outcomes remain poorly understood. This study examined how green space quality and healthcare service provision jointly explain spatial variation in health deprivation across London's Lower Layer Super Output Areas (LSOA). We analyzed neighborhoods using comprehensive indicators through an analytical pipeline combining Principal Component Analysis, Random Forest modeling, and Shapley Additive Explanations to predict Index of Multiple Deprivation (IMD) health scores and identify key determinants. The integrated model explains 57% of health outcome variance, substantially exceeding single-factor approaches. Green space quality and accessibility emerge as more important than total coverage, while community pharmacy density and core medical services are the strongest healthcare predictors. Evidence suggests synergistic effects, with neighborhoods strong in both domains experiencing lowest health deprivation. Results support integrated urban planning approaches coordinating green infrastructure development with healthcare service provision to maximize population health benefits across London's diverse neighborhoods.

1 Acknowledgements

I would like to express my sincere gratitude to my supervisor Dr. Huang, for his invaluable guidance and support throughout this dissertation process. His expertise and encouragement have been instrumental in shaping this work. I would also like to thank my family and friends Dr.Chen, for their unwavering support and understanding during this challenging journey. Finally, I extend my appreciation to the University of Leeds for providing the resources and environment conducive to academic growth.

2 Introduction

London is a prosperous global city, yet health inequalities are clear across its neighborhoods. The Health Deprivation and Disability subdomain of the IMD shows marked differences at the LSOA level. A persistent divide runs from east to west. Many of the most health-deprived areas are in the east, with additional hotspots in parts of the north and south. Central and southwest boroughs tend to perform better. These patterns suggest that where people live matters for health in London, not only who they are.

This dissertation examines two urban determinants together. The first is green space, measured by coverage, proximity, connectivity, and a composite quality index. The second is healthcare services, measured by the availability and diversity of points of care and their clustering. The central question is how these two sets of features jointly explain spatial variation in IMD Health Deprivation scores across London's neighborhoods.

Most prior work studies environmental or service factors on their own. This project takes a different approach and focuses on their combined and interactive effects. The aim is not to repeat the detailed evidence, which is covered in the literature review, but to motivate why a joint perspective is needed. In short, green space is linked with better physical and mental health, and the quality and accessibility of green space appear to matter as much as the total area (Mitchell & Popham, 2008; Nguyen et al., 2021). Recent UK findings also point to unequal distribution of green space in deprived communities (Ngan et al., 2025). At the same time, access to core medical services is associated with better outcomes, and primary care and pharmacies are key points of everyday care (Nicodemo et al., 2021; Todd et al., 2014). These brief references set the scene; fuller discussion follows later.

What is less well understood is how environment and services work together in place. Urban health is shaped by multiple systems that may reinforce each other. The benefits of nearby, high-quality parks may be larger where primary care and pharmacies are easy to reach. Gaps in one domain may also limit the gains from the other. Evidence from multi-domain assessments suggests that combined improvements can yield larger health gains than single interventions (Mueller et al., 2017). This supports testing for synergy rather than assuming simple add-up effects.

London is a suitable setting because contrasts in both green-space provision and healthcare access are pronounced at small area scale. By analysing these features together, the study aims to clarify how built and natural environments jointly shape health equity across the city. Methods and data are presented in later sections. The next part reviews the relevant literature and policy context in more detail, which provides the theoretical basis for the variables and hypotheses introduced here.

3 Literature Review

3.1 The IMD Health Subdomain and Spatial Health Inequality

The Index of Multiple Deprivation (IMD) is one of the most widely used composite indicators to capture area-level disadvantage in England, and its health subdomain specifically reflects outcomes related to morbidity, premature mortality, and disability. By combining routinely available health statistics, the IMD health subdomain provides a robust measure of health inequalities at small-area levels and is often applied to highlight spatial disparities across regions. For example, research has shown that health-related deprivation measured through the IMD is not only persistent over time but also exhibits a clear north-south divide, with northern regions consistently experiencing poorer health outcomes (Kontopantelis et al., 2018) .

Beyond describing inequalities, the IMD health subdomain has been employed to investigate links between environmental and social exposures and health behaviors. For instance, studies using the UK Biobank revealed that higher deprivation in IMD health and related subdomains (e.g., income, education, living environment) is associated with higher rates of smoking, indicating that the index captures structural determinants shaping health-related behaviors (Pan et al., 2024).

Internationally, similar indices such as the New Zealand IMD also highlight geographic variations in deprivation and its strong associations with health outcomes (Exeter et al., 2017) . Collectively, these findings demonstrate that the IMD health subdomain functions as both a diagnostic tool to identify persistent health inequalities and an analytical framework to examine how environmental and social determinants contribute to health disparities

3.2 Green Space Access, Quality, and Health Inequality

Urban green spaces have become important predictors of health and wellbeing. Accumulating evidence from 2015 to 2024 suggests that neighborhoods with greater green coverage tend to experience improved health outcomes, including lower mortality rates, fewer chronic diseases, and improved mental health (Vargas Adorno et al., 2025; Nguyen et al., 2021)

These benefits are not equally distributed. Green spaces appear to help disadvantaged communities the most, potentially reducing health inequalities (Rigolon et al., 2021). Recent UK studies provide strong evidence for this pattern. In England, Scotland, Northern Ireland, and Wales, researchers found that just a 1% increase in local grass cover led to significant health improvements in deprived areas. Among the most disadvantaged urban communities in England, each percentage point increase in grassland was linked to a 37% decrease in preventable deaths (Ngan et al., 2025).

This confirms the idea of green space as an "equigenic" resource that helps close health gaps. A landmark 2008 study first showed that income-related mortality differences were much smaller in England's greenest areas (Mitchell & Popham, 2008). The newer research supports investing in urban greening to achieve bigger health gains for low-income populations who have fewer other health resources (Rigolon et al., 2021).

However, not all green space is equally beneficial. Quality and usability matter greatly. Tree-covered areas and well-maintained parks provide more health benefits than unmanaged vacant lots or simple mowed grass (Nguyen et al., 2021). A 2021 review of 59 studies found that neighborhoods with greater tree canopy cover consistently showed better health outcomes compared to areas with just open grass fields. Trees were associated with lower rates of heart and lung diseases and better mental health(Nguyen et al., 2021).

Park accessibility is also crucial. Having a public park within walking distance increases physical activity and reduces stress. This can be measured by indicators like the percentage of people living within 500 meters of a green space (Vargas Adorno et al., 2025).

Subjective qualities of green spaces may be even more important. Factors like cleanliness, safety from crime, amenities such as benches and lighting, and visual appeal strongly influence how much people actually use these spaces. Well-lit, clean parks that feel safe encourage regular use for exercise and relaxation, leading to better mental health and fitness. Poorly maintained or unsafe green spaces often go unused, reducing their health impact (Nguyen et al., 2021).

Urban health researchers now include both objective measures like tree cover and walking paths, and subjective factors like resident satisfaction in their studies. The literature shows that green space contributes to urban health through both quantity and quality, emphasizing the need for equitable distribution and good design that encourages actual use (Nguyen et al., 2021).

This dual perspective of quantity and quality highlights why urban greening must be analyzed not only as a physical presence but also through the lens of social equity and usability, particularly in deprived neighborhoods

3.3 Healthcare Facility Distribution and Health Inequality

Recent UK studies reveal complex statistical correlations between health Points of Interest (POI) density and Index of Multiple Deprivation (IMD) health subdomains, with correlation coefficients ranging from r = -0.19 to r = 0.59 depending on service type (Todd et al., 2014).

3.3.1 Facility-specific correlation patterns

GP clinic density: A large-scale analysis covering over 35,000 GP practices and 32,000 Lower Super Output Areas found a significant negative correlation (r = -0.19, p¡0.001) between GP accessibility and overall IMD scores (Todd et al., 2015). While 98.2% of populations in the most deprived areas had GP access within 20-minute walking distance compared to 81.2% in least deprived areas (Todd et al., 2015)), longitudinal workforce data (2015-2020) showed GP distribution inequalities have been widening, with deprived areas experiencing undersupply totaling 118.3 fewer hours per week of direct patient care (Nussbaum et al., 2021).

Community pharmacy density: Pharmacy distribution shows the strongest positive correlation with deprivation, with nearly full coverage in the most deprived areas (around 99.8%) compared to about 90% in the least deprived areas, highlighting a significant equity gap (Todd et al., 2014; Todd et al., 2015). However, recent evidence shows this relationship is eroding as pharmacy availability decreased from 1.60 to 1.51 per 10,000 people, with most deprived areas being 1.65 times more likely to lose pharmacies (Zied Abozied et al., 2025).

Hospital and ambulatory care: Although the mean density of ambulatory care facilities increased between 2000 and 2014, predominantly minority and high-poverty neighborhoods were more likely to experience facility losses (adjusted odds ratio 2.37 for predominantly Black areas), underscoring persistent inequalities in healthcare provision (Tsui et al., 2020).

3.3.2 POI density and health outcomes

Healthcare facility density correlates significantly with population health indicators. Higher GP density shows reduced emergency hospital admissions in the most deprived areas (Nicodemo et al., 2021), while GP density correlates with lower mortality and higher life expectancy at regional levels, with adding 10 primary care doctors per 100,000 people associated with roughly 1% decrease in all-cause mortality (Basu et al., 2019). Facility density measures show significant spatial correlation with age-standardized mortality rates (Asthana & Gibson, 2008).

These complex and evolving relationships between health facility density and health outcomes underscore the need for comprehensive spatial analysis of POI distribution patterns. Understanding how different POI types and densities interact with health deprivation across London's neighborhoods is essential for developing targeted, evidence-based health equity interventions that address spatial disparities effectively.

Like green space, healthcare POI distribution reveals spatial inequities that intersect with deprivation, suggesting that health-promoting resources in cities must be studied both in terms of access and quality to fully understand their relationship with the IMD health subdomain

3.4 Interactions and Mediating Mechanisms Between the Three Factors

Recent research reveals complex mediation pathways where green spaces influence health primarily through stress reduction and social cohesion rather than physical activity alone (Chen et al., 2021). A Singapore study using structural equation modeling found that emotional regulation mediated 52% of associations between green space exposure and mental health, while social interaction mediated 100% of associations with general health (Zhang et al., 2022). Advanced multivariate analyses demonstrate that combined environmental factors explain 2-5 times more health outcome variance than single-factor models. The Barcelona UTOPHIA study found that nearly 20% of annual mortality could be prevented through compliance with recommendations across multiple environmental factors, with cumulative economic impact reaching €9.3 billion annually (Mueller et al., 2017). Green spaces consistently provide protective buffering against air pollution, noise, and heat stress through multiple mechanisms including filtration, sound barriers, and psychological restoration (Dadvand & Nieuwenhuijsen, 2018; Dzhambov & Dimitrova, 2014).

3.5 Research Gaps and Challenges

Most studies continue examining single environmental determinants rather than simultaneous multi-factor approaches, despite clear evidence that interaction effects exceed additive impacts. A systematic review of 94 urban environmental health studies found that 78% had high risk of bias, primarily due to single-variable focus and inadequate confounding control (Salgado et al., 2020).

Very few studies simultaneously incorporate POI density, green space quality, and IMD health subdomains. Current research typically examines these factors independently rather than understanding their complex spatial and social interactions (Feng & Astell-Burt, 2018). Green space quality consistently outperforms quantity measures, with a 15-year longitudinal study finding quality showed significant associations with mental health while quantity showed no association (Feng & Astell-Burt, 2018). Most research focuses on larger-scale indicators, lacking fine-scale spatial analysis, while the missing quality dimension of green spaces represents a critical blind spot in current research.

This study addresses these gaps by simultaneously examining the spatial relationships between health POI density, green space quality, and IMD health subdomain scores across London neighborhoods.

4 Data and Methodology

This study utilizes five primary datasets to examine spatial relationships and socioeconomic patterns within the study area. The Index of Multiple Deprivation (IMD) data, sourced from the UK Data Service, provides comprehensive deprivation scores across multiple domains including income, employment, health, and education, enabling robust socioeconomic analysis at the small area level.

Spatial context is established through Lower Layer Super Output Area (LSOA) boundaries obtained from the ONS Geography Portal, which serve as the primary geographic units for analysis. These boundaries are supplemented by Statistical GIS Boundary Files for London from the Greater London Authority, providing additional administrative geography layers.

Points of Interest (POI) data from Ordnance Survey delivers detailed location information for various facilities and amenities, supporting accessibility and service provision analysis. Environmental factors are captured through OS Open Greenspace data from data.gov.uk, which provides comprehensive coverage of parks, gardens, and other green infrastructure.

Together, these datasets create a multi-dimensional analytical framework combining socioeconomic indicators, geographic boundaries, facility locations, and environmental assets. All datasets represent official government or authorized sources, ensuring data quality and reliability for academic research purposes.

In order to address the complex interplay between green space quality, healthcare accessibility, and health deprivation in London, this study proposes a multi-faceted analytical framework that integrates several machine learning techniques. Figure 1 illustrates the analytical pipeline designed to predict health outcomes and identify key determinants of health disparities. This workflow consists of three main steps: (1) Data preprocessing and dimensionality reduction, where the sparsity of POI features and multicollinearity of green space features are addressed through PCA dimensionality reduction. (2) Predictive modeling, where a Random Forest model is trained to predict health outcomes using the reduced feature sets. (3) Feature importance analysis, where SHAP TreeExplainer generates feature importance scores in the reduced space, which are subsequently mapped back to original feature interpretations with PCA component matrices. This approach enables comprehensive analysis of both compressed feature relationships and original feature contributions to health outcomes prediction.

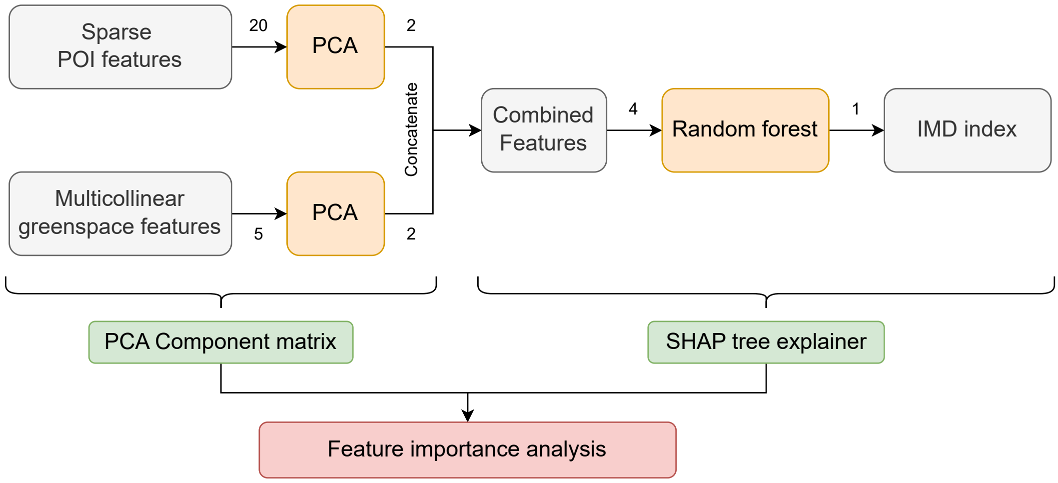

Figure 1: Analytical pipeline for predicting health outcomes and key determinants identification. The number on each arrow represents the number of features within each step.

The analysis reveals compelling evidence for the effectiveness of multi-factor approaches in explaining urban health inequalities across London neighborhoods.

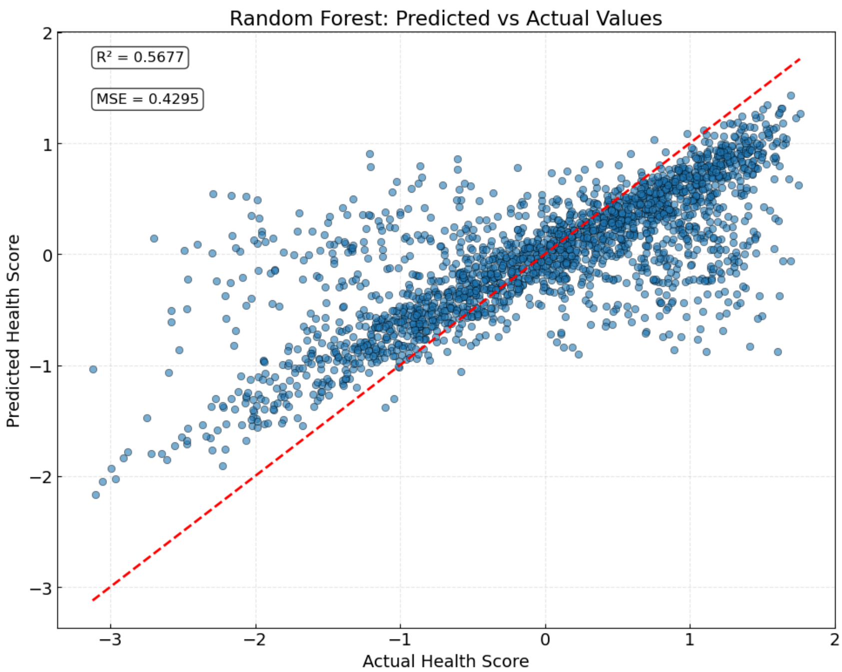

Figure 2: Random Forest Performance

The Random Forest model demonstrates robust predictive performance (R^2=0.5677, MSE=0.4295), accounting for approximately 57% of the variance in health outcomes through integrated analysis of green space characteristics and health-related POI density. This explanatory power substantially exceeds that typically observed in single-factor urban health models, underscoring the critical importance of examining environmental and healthcare accessibility factors simultaneously when investigating spatial health disparities.

5 Key Findings Summary

5.1 Geographic Patterns of Health Deprivation across London

Health deprivation data shows clear spatial patterns across London. Figure 3 highlights the spatial variation that the most deprived areas are mainly located in East London, parts of South London, and the northwest areas. These areas form clear "health hotspots". Central London and Southwest London have better health outcomes. This creates a strong "east-west health divide" and "north-south differences" in London's health geography.

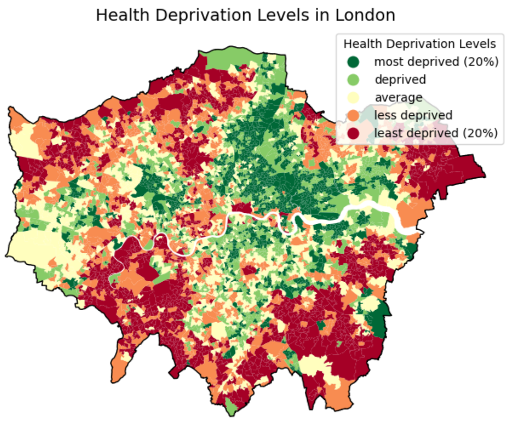

Figure 3: Health Deprivation Levels in London

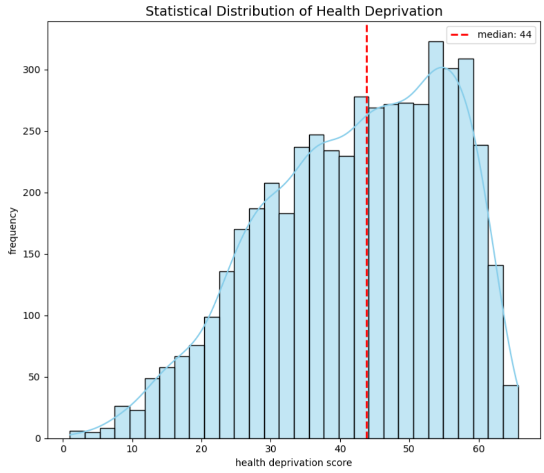

Figure 4: Distribution of Health Deprivation Scores

The statistical distribution (Figure 4) reveals significant health inequalities across London's neighborhoods. The data peaks around scores of 50-55, with a median of 44, indicating that many areas experience above-average health challenges. The right tail of the distribution shows that a considerable number of neighborhoods face severe health deprivation with scores exceeding 55.

This concentration creates clear opportunities for targeted policy interventions. Rather than spreading resources thinly across all neighborhoods, policy makers can focus efforts on the high-scoring areas where improvements would benefit the most vulnerable residents effectively.

5.2 Green Space Quality Distribution across London

Green space analysis reveals significant spatial variations in environmental quality across London. As shown in Figure 5, the comprehensive quality index, which combines coverage, accessibility, connectivity, quantity and area metrics, shows marked geographic disparities. High-quality green spaces are predominantly located in Southwest and Northwest London, while lower quality areas concentrate in East London and parts of Central London.

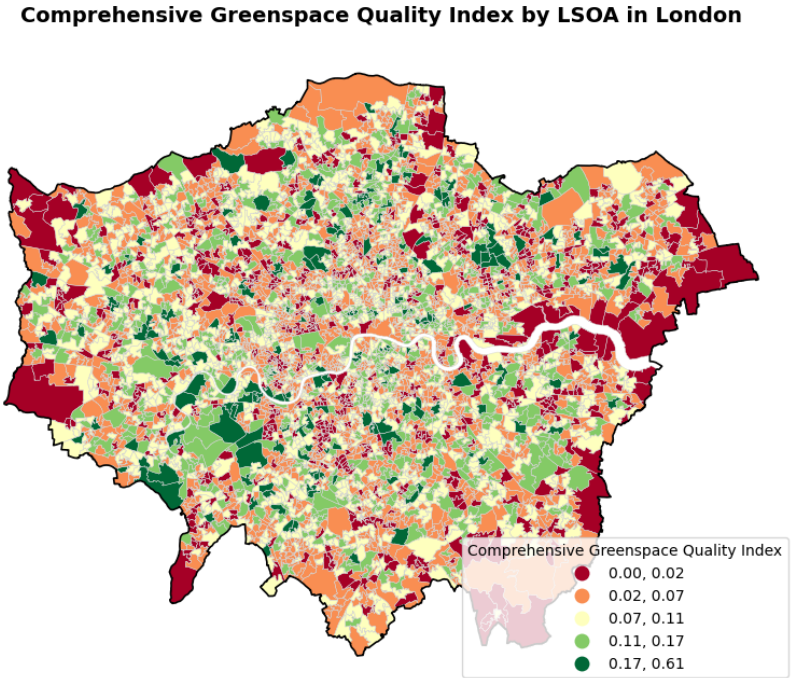

Figure 5: Comprehensive Greenspace Quality Index by LSOA in London

As shown in Figure 6, the statistical distribution of the quality index shows a right-skewed pattern with a mean of 0.069 and median of 0.061. This indicates that most London neighborhoods have relatively low green space quality scores, with only a small proportion achieving high-quality ratings. The distribution suggests substantial room for improvement across the majority of areas.

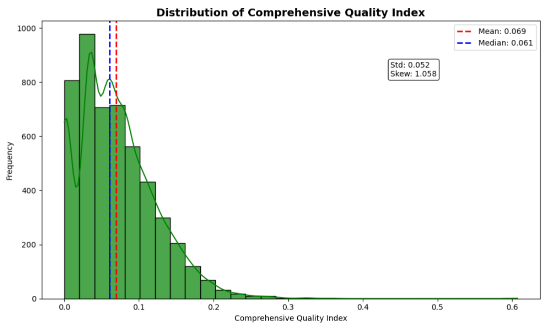

Figure 6: Statistical Distribution of the Comprehensive Green Space Quality Index

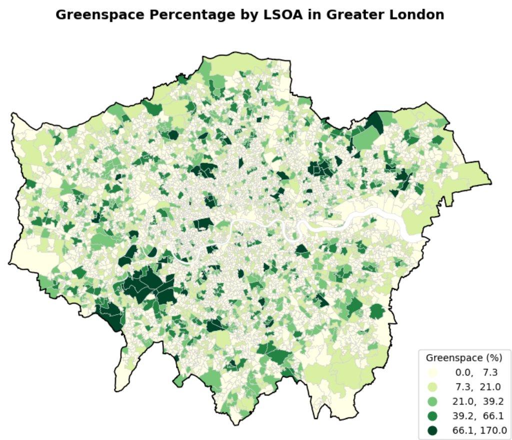

Figure 7: Green Space Coverage Percentage by LSOA in London

As shown in Figure 7, the basic green space coverage presents a different spatial pattern from the quality assessment. Many areas across London show moderate to high green space percentages, with particularly notable coverage in outer London boroughs and some central areas. However, comparing this coverage pattern with the comprehensive quality index reveals important gaps where areas with adequate green space quantities still score poorly on overall quality measures.

The spatial pattern of green space quality shows a clear inverse relationship with the health deprivation hotspots identified earlier. Areas with the poorest health outcomes consistently correspond to neighborhoods with lower green space quality, suggesting that environmental factors play a crucial role in health inequality in London.

5.3 Healthcare Facility Distribution Patterns across London

London's healthcare infrastructure reveals a clear hierarchy in how medical services are distributed across the city. As shown in Figure 8, hospitals dominate with 15,389 facilities, followed by pharmacies in 11,464 locations. This reflects the critical importance of emergency care and prescription services in daily healthcare needs. Dentist practices (9,986) and gyms (8,984) form the next level of provision, showing a strong representation of both essential medical and preventive health services.

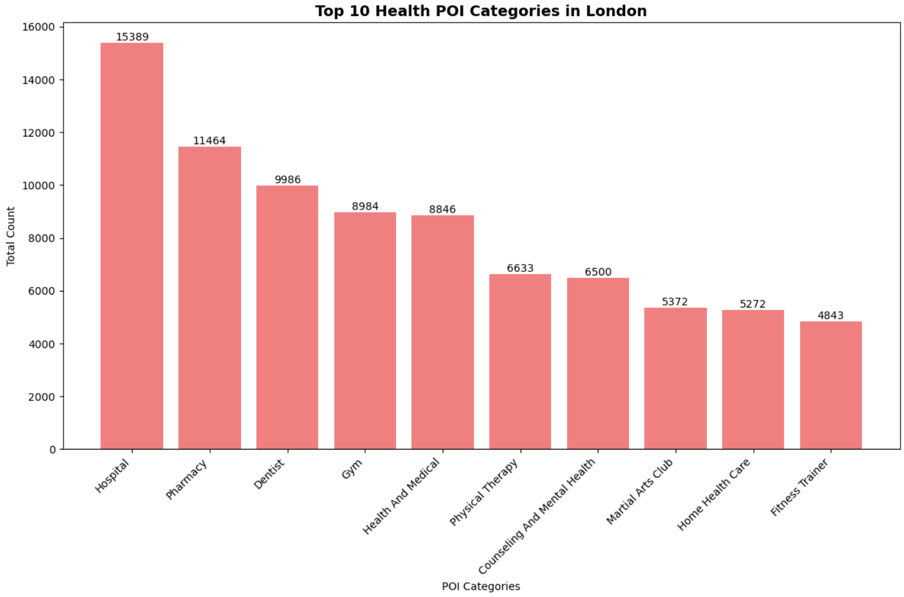

Figure 8: Top 10 Health POI categories in London

However, specialized services tell a different story. Physical therapy facilities number only 6,633, while mental health services reach 6,500 locations. This pattern highlights a key challenge: while basic medical care is widely available, specialized treatments are much harder to access across London neighborhoods. This pattern demonstrates the challenge of accessing specialized care compared to basic medical services (Guagliardo, 2004).

The distribution of these facilities across London is far from equal. As shown in Figure 9, most neighborhoods have relatively few healthcare options, while a small number of areas concentrate many services. Figure 10 shows that the average London neighborhood has access to only 3.3 different types of healthcare facilities, and approximately 1,200 areas have just one or two service categories available.

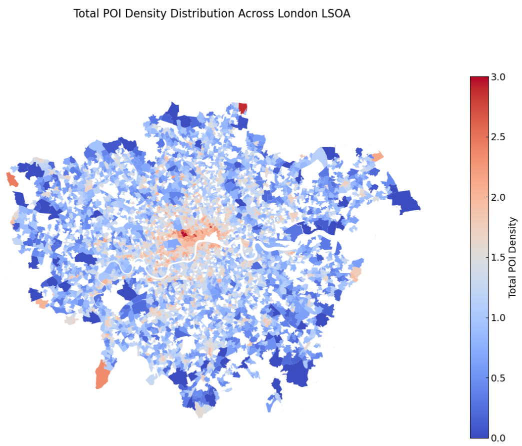

Figure 9: Total POI Density Distribution Across London

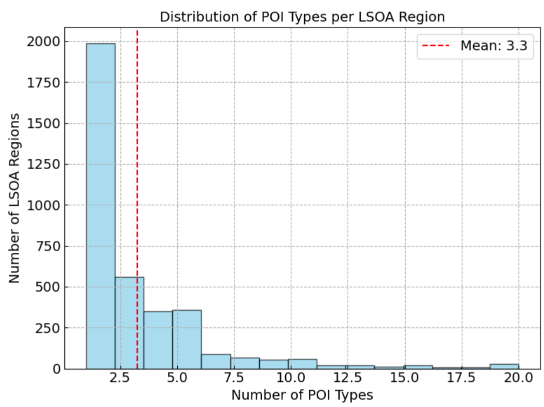

Figure 10: Distribution of POI type per LSOA region

Research demonstrates that healthcare accessibility and service diversity significantly influence population health outcomes and utilization patterns (Luo & Wang, 2003; Starfield et al., 2005).

The uneven distribution of London's facilities therefore has real consequences for residents' health. Areas with the poorest outcomes often coincide with neighborhoods that lack service diversity. While hospitals and pharmacies provide essential emergency and prescription services, the scarcity of mental health and preventive care facilities leaves many communities without comprehensive support.

6 Implications for Policy and Practice

The model performance suggests that environmental determinants operate through complex, interconnected pathways rather than as independent predictors. By combining green space quality measures with healthcare service clustering patterns, the analysis achieves neighborhood-level health prediction capabilities that provide robust foundations for evidence-based urban health planning interventions.

6.1 Combined Effects of Green Space and Healthcare Services

To understand how green spaces and healthcare services work together, we used a technique called SHAP analysis. This helps us see how different combinations of factors influence health outcomes in real neighborhoods across London. Figure 11 shows the overall patterns we found.

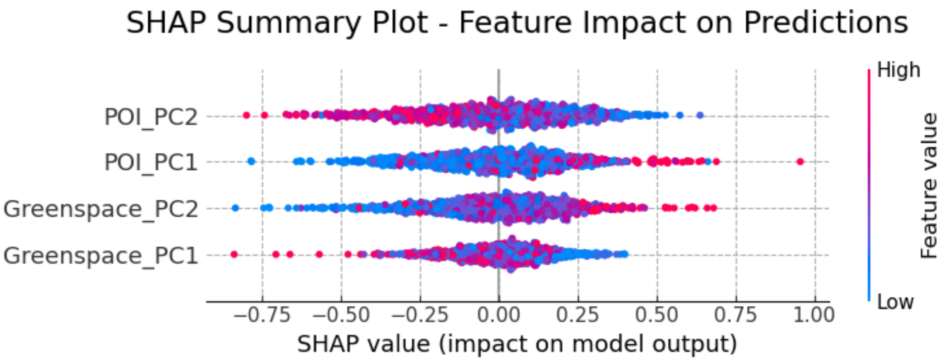

Figure 11: SHAP Summary Plot

The plot reveals that both green space quality and healthcare accessibility consistently influence health outcomes, but their effects vary significantly across different neighborhoods. Importantly, these factors appear to work together rather than independently, suggesting that the combination of environmental and healthcare resources creates stronger health benefits than either factor alone.

To make it clearer, we can illustrate this with two specific examples. Figure 12 shows a neighborhood that performs well on health outcomes. This area has high-quality green spaces, good access to basic medical services like pharmacies and hospitals, and moderate access to alternative healthcare options. When these factors combine, they create a strong positive effect on health.

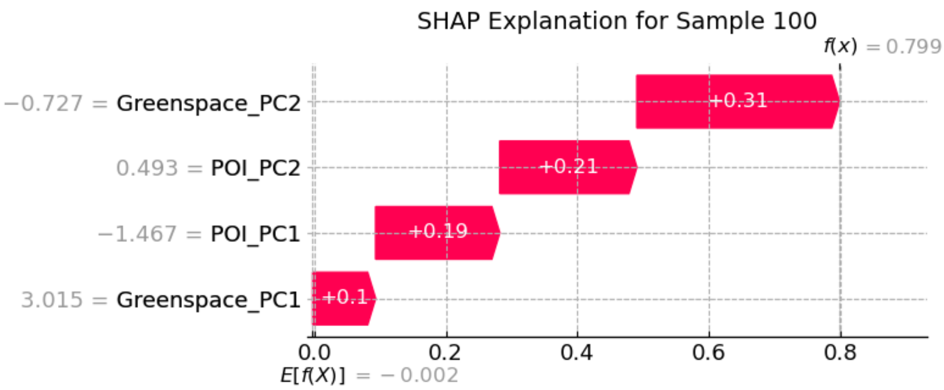

Figure 12: SHAP Explanation for sample 100

In contrast, Figure 13 shows a different neighborhood pattern. This area also has high-quality green spaces and good basic medical services, but it has very limited alternative healthcare options and lower green space coverage. The combination creates a different health impact. These examples show us that getting the best health outcomes requires balanced combinations of environmental quality and healthcare access, rather than just being excellent in one area.

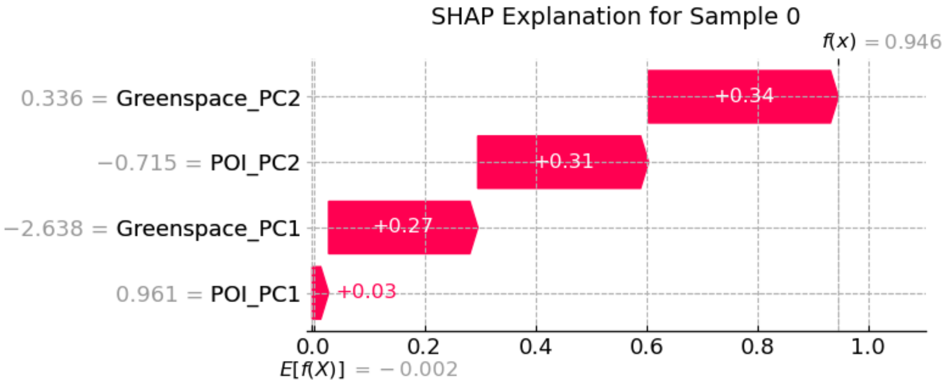

Figure 13: SHAP Explanation for sample 0

What we found suggests that green spaces and healthcare services can enhance each other's benefits. For example, having quality parks near healthcare facilities might encourage more physical activity and provide places for recovery and relaxation. Similarly, knowing that good healthcare is nearby might reduce stress and make people more likely to use local green spaces. This means that neighborhoods with both high-quality environments and accessible healthcare services tend to see the greatest health benefits.

6.2 Green Space Quality Dimensions and Their Relative Contribution to Health Outcomes

Our analysis looked at which aspects of green space matter most for health outcomes. Figure 14 shows that green space coverage has the strongest influence on health, but quality-related factors like connectivity and proximity also play important roles. When we add up all the quality measures, they account for about 25% of green space's total influence on health.

This finding suggests that the traditional planning approach of simply maximizing green space area might not be the most effective strategy. Instead, planners could benefit from considering both the amount of green space and how well connected and accessible it is. The importance of connectivity and proximity indicates that how green spaces link together and relate to each other might be just as important as their individual features.

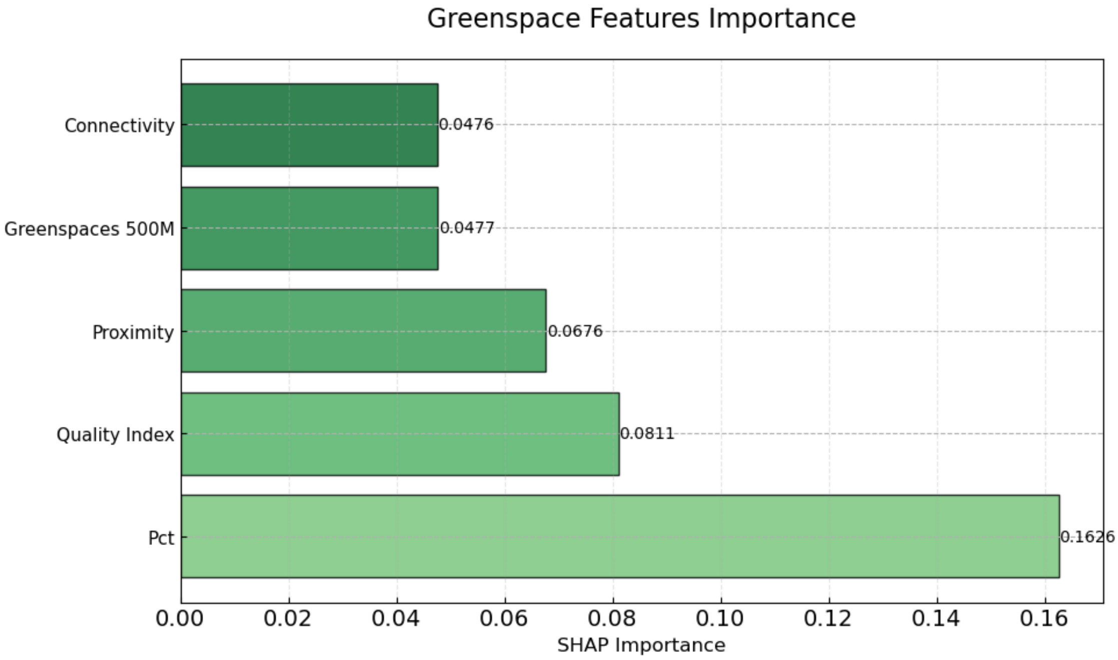

Figure 14: Every Green Space Feature Importance

6.3 Healthcare Service Spatial Distribution Patterns and Predictive Significance

When we examined which healthcare services have the strongest connection to neighborhood health outcomes, pharmacy accessibility clearly emerged as the most important factor. As shown in Figure 15, pharmacies had nearly twice the influence of the next most important service. The ranking continues with hospitals, dental services, and general medical services, creating a clear pattern of healthcare importance.

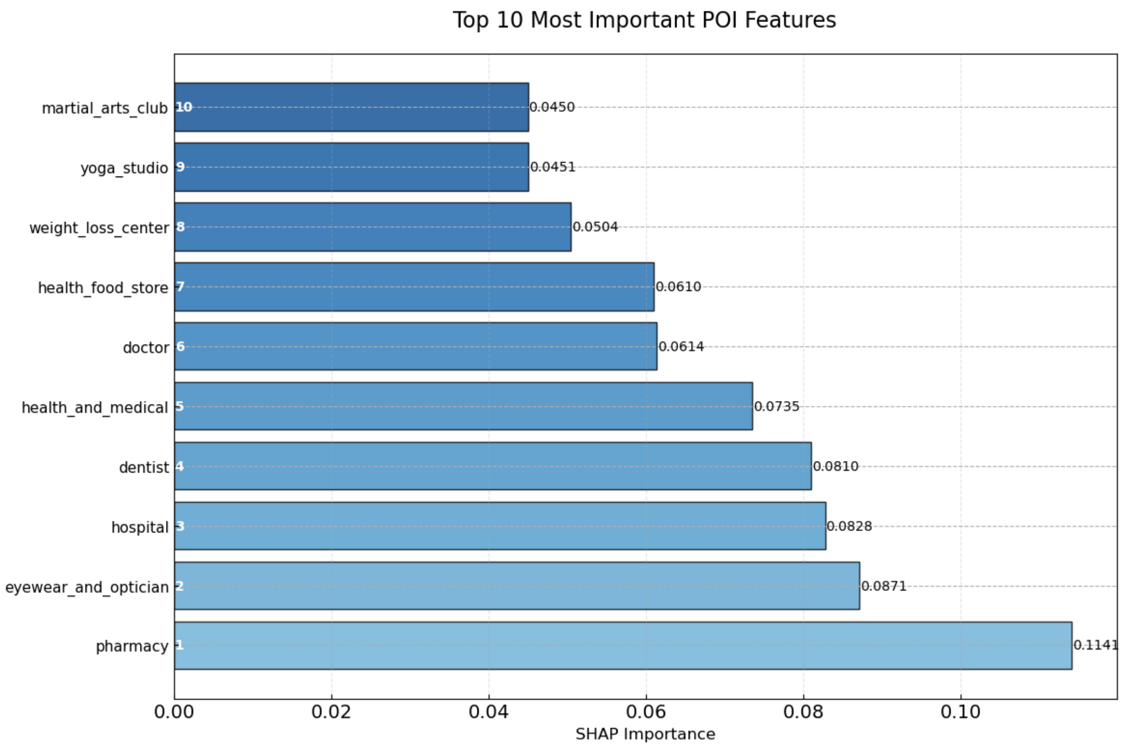

Figure 15: Top 10 Most Important POI features

This strong role of pharmacies makes sense when we consider how people actually use healthcare services. Unlike hospitals or specialist services, pharmacies provide daily healthcare support and medication access. They often serve as the first point of contact for health concerns. Since they have longer opening hours and are more widely distributed, pharmacies tend to be the most accessible healthcare resource for many communities.

Our analysis also reveals something interesting about preventive and wellness services. Health food stores, weight loss centers, yoga studios, and fitness facilities all contribute meaningfully to health predictions. This suggests that neighborhoods with comprehensive wellness options tend to have better health outcomes. In other words, health appears to be influenced not only by treatment services but also by opportunities for health promotion and disease prevention.

We also looked at how different healthcare services tend to group together across London neighborhoods. Using a statistical technique called PCA, we found that healthcare services naturally form two main clusters in the city. Figure 16 shows how these services organize themselves into different patterns.

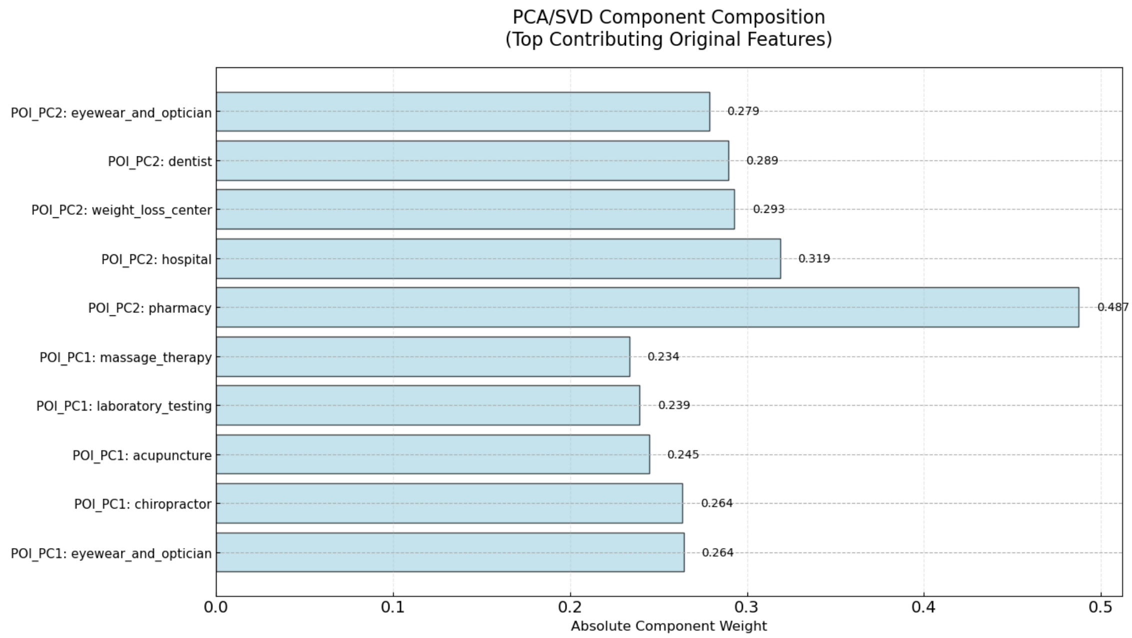

Figure 16: Top Contribution features by clustering

The first cluster includes traditional medical services. Pharmacies appear to be the most important service in this group, followed by hospitals, weight loss centers, dental services, and opticians. This pattern suggests that pharmacies often serve as anchors for other medical services. When a neighborhood has good pharmacy access, it tends to attract other healthcare facilities as well. This creates comprehensive medical hubs that offer residents multiple services in one area.

The second cluster focuses on alternative and preventive care services. This group includes services like chiropractic care, acupuncture, laboratory testing, and massage therapy. These services seem to operate independently from traditional medical infrastructure and form their own networks across the city.

This clustering pattern provides important insights for healthcare planning. Pharmacies work best when combined with other services rather than standing alone, suggesting that coordinated healthcare networks are more effective than isolated facilities. London neighborhoods tend to excel in either traditional medical care or preventive services, but rarely both. Areas strong in basic medical facilities often lack alternative care options, while neighborhoods with good preventive services may have fewer core medical facilities. For optimal health outcomes, neighborhoods would benefit from balanced provision across both service dimensions.

6.4 Policy Recommendations for Integrated Urban Health Planning

Based on the spatial patterns, we propose several policy recommendations that could help address health inequalities across London. These suggestions connect directly to our key findings and focus on three main areas: coordinated planning, green space quality improvements, and healthcare service development.

6.4.1 Integrated Planning and Cross-Departmental Coordination

According to our combined effects analysis in Section 5.1, neighborhoods benefit most when green space quality and healthcare accessibility work together rather than separately. This suggests that planning authorities might achieve better health outcomes by coordinating environmental and healthcare investments.

Planning departments could consider developing assessment frameworks that evaluate new developments based on their combined green space and healthcare impacts. This approach could help ensure that green space improvements and healthcare facility planning support each other rather than competing for resources.

Local authorities might establish working groups that include planners, health professionals, and community representatives. These groups could develop neighborhood assessments that consider how new developments contribute to both green space networks and healthcare access, helping planning decisions address overall health impacts.

6.4.2 Green Space Quality and Connectivity Enhancement

Following the green space analysis in Section 3.2, we found that quality and connectivity measures appear to influence health outcomes significantly. The spatial patterns show that Southwest and Northwest London have higher quality green spaces, while East London shows both poor green space quality and worse health outcomes.

Rather than focusing only on increasing green space area, planning authorities could prioritize creating connected green networks within 500-meter walking distances. This approach might be particularly beneficial in areas like East London where both green space quality and health outcomes need improvement.

Local authorities could develop quality assessment frameworks that evaluate connectivity and accessibility alongside coverage measures. Investment decisions might prioritize improving connections between existing green spaces through corridors and better pedestrian routes.

Based on the spatial patterns in Section 3.2, targeted interventions could focus on areas with adequate green space coverage but poor quality scores. These areas represent opportunities to improve health outcomes without requiring extensive land acquisition.

6.4.3 Healthcare Service Coordination and Accessibility

According to the healthcare facility analysis in Section 5.3, pharmacy accessibility emerges as particularly important for neighborhood health outcomes. The distribution patterns show that while London has substantial healthcare infrastructure overall, access varies significantly across neighborhoods.

Healthcare planning could prioritize pharmacy accessibility as a foundation of neighborhood health infrastructure. Areas with low healthcare service diversity might receive priority for new facilities, particularly community pharmacies and diagnostic services.

The findings also suggest that healthcare services tend to cluster spatially. This creates opportunities for coordinated facility planning that takes advantage of how different services naturally group together.

Based on the service distribution patterns in Section 3.3 , health authorities could develop accessibility standards that ensure minimum levels of both traditional medical services and preventive care services within walking distance. This might be particularly important for the approximately 1,200 areas that currently have access to only one or two service categories.

The comprehensive wellness ecosystems, including health food stores and fitness facilities, contribute to neighborhood health. This suggests that health promotion services could be better integrated into healthcare planning strategies.

6.4.4 Implementation and Monitoring

Implementing these recommendations could benefit from monitoring systems that track both environmental and healthcare accessibility improvements over time. Local authorities might establish baseline measurements using the analytical approach developed in this study to monitor progress and identify emerging gaps.

Regular spatial analysis could help inform resource allocation decisions, ensuring that interventions target areas with the greatest potential for health improvement. The predictive capabilities demonstrated in our model might provide a foundation for evidence-based investment priorities.

Community engagement could be important for implementation, helping ensure that green space improvements and healthcare service developments reflect local needs and preferences. The quality dimensions of green space, including safety and usability, would likely require ongoing community input to ensure that investments translate into actual usage and health benefits.

7 Limitations and Future Work

This study has several important limitations that should be considered when interpreting the findings. The cross-sectional design means causal direction cannot be established, and the patterns represent associations rather than causes. Unobserved factors such as housing quality, migration patterns, and labor market conditions may influence both health outcomes and local amenities.

Exposure measurement presents challenges because residents move through the city for work and education, meaning home-based measures may not capture actual daily exposure patterns (Kwan, 2012). Area-level inference also carries risks of ecological fallacy when individual outcomes are attributed to group averages (Piantadosi et al., 1988).

Data limitations include potential measurement error in green space and healthcare facility indicators. Simple counts cannot capture service quality, opening hours, or affordability. Dimensionality reduction techniques help manage multicollinearity but reduce transparency in interpreting results.

Effects are unlikely to be linear, and returns may diminish once neighborhoods reach basic thresholds. Residents can benefit from facilities in adjacent areas, but physical barriers can limit access even when distances are short. Different boundary systems or scales could shift the observed relationships.

Future research should address these limitations through longitudinal designs, refined accessibility measurements incorporating travel times and service quality, and broader environmental exposures including air pollution and walkability. Examining mechanisms through mediation analysis and testing heterogeneity across different population groups would strengthen understanding of these relationships

8 Conclusion

This dissertation examined how green space quality and healthcare service provision jointly explain spatial variation in health deprivation across London neighborhoods. The integrated approach revealed that environmental and healthcare factors work together rather than independently, with combined models explaining substantially more variance than single-factor approaches.

Key findings demonstrate that within green spaces, quality and accessibility measures are more important than total area, while pharmacy access and core medical services are the strongest healthcare predictors. The evidence suggests that neighborhoods strong in both domains experience the lowest health deprivation, supporting the need for coordinated urban planning approaches. While these findings should be interpreted as associations rather than causal relationships, they align with the understanding that urban health is shaped by interconnected systems. The results provide evidence for integrated planning policies that coordinate green infrastructure development with healthcare service provision to maximize population health benefits across London's diverse neighborhoods.

References

Asthana, S. & A. J. S. Gibson (2008). "Health care equity, health equity and resource allocation: towards a normative approach to achieving the core principles of the NHS". In: *Radical Statistics* 96.0, pp. 6–26. ISSN: 0268-6376.

Basu, S., S. A. Berkowitz, R. L. Phillips, A. Bitton, B. E. Landon & R. S. Phillips (2019). "Association of Primary Care Physician Supply With Population Mortality in the United States, 2005–2015". In: *JAMA Internal Medicine* 179.4, pp. 506–514. DOI: 10.1001/jamainternmed.2018.7624.

Chen, K., T. Zhang, F. Liu, Y. Zhang & Y. Song (2021). "How Does Urban Green Space Impact Residents' Mental Health: A Literature Review of Mediators". In: *International Journal of Environmental Research and Public Health* 18.22, p. 11746. DOI: 10.3390/ijerph182211746. URL: https://doi.org/10.3390/ijerph182211746.

Dadvand, P. & M. J. Nieuwenhuijsen (2018). "Green Space and Health". In: *Effects of Urban Green Infrastructure on Human Health and Well-Being*. Ed. by M. H. Browning & A. Rigolon. Springer, pp. 123–145. DOI: 10.1007/978-3-319-74983-9_20. URL: https://link.springer.com/chapter/10.1007/978-3-319-74983-9_20.

Dzhambov, A. M. & D. D. Dimitrova (2014). "Urban green spaces' effectiveness as a psychological buffer for the negative health impact of noise pollution: A systematic review". In: *Noise & Health* 16.70, pp. 157–165. DOI: 10.4103/1463-1741.134916.

Exeter, D. J., J. Zhao, S. Crengle, A. Lee & M. Browne (2017). "The New Zealand Indices of Multiple Deprivation (IMD): A new suite of indicators for social and health research in Aotearoa, New Zealand". In: *PLOS ONE* 12.8, e0181260. DOI: 10.1371/journal.pone.0181260. URL: https://doi.org/10.1371/journal.pone.0181260.

Feng, X. & T. Astell-Burt (2018). "Residential green space quantity and quality and symptoms of psychological distress: a 15-year longitudinal study of 3897 women in postpartum". In: *BMC Psychiatry* 18.1, p. 348. DOI: 10.1186/s12888-018-1926-1. URL: https://doi.org/10.1186/s12888-018-1926-1.

Guagliardo, M. F. (2004). "Spatial accessibility of primary care: concepts, methods and challenges". In: *International Journal of Health Geographics* 3.3, pp. 1–13. DOI: 10.1186/1476-072X-3-3. URL: https://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-3-3.

Kontopantelis, E., M. A. M. Mamas, H. van Marwijk, A. M. Ryan, I. E. Buchan, D. M. Ashcroft & T. Doran (2018). "Geographical epidemiology of health and overall deprivation in England, its changes and persistence from 2004 to 2015: a longitudinal spatial population study". In: *Journal of Epidemiology & Community Health* 72.2. E-pub ahead of print 20 Dec 2017, pp. 140–147. DOI: 10.1136/jech-2017-209999. URL: https://doi.org/10.1136/jech-2017-209999.

Kwan, M.-P. (2012). "The Uncertain Geographic Context Problem". In: *Annals of the Association of American Geographers* 102.5, pp. 958–968. DOI: 10.1080/00045608.2012.687349.

Luo, W. & F. Wang (2003). "Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region". In: *Environment and Planning B: Planning and Design* 30.6, pp. 865–884. DOI: 10.1068/b29120.

Mitchell, R. & F. Popham (2008). "Effect of exposure to natural environment on health inequalities: an observational population study". In: *The Lancet* 372.9650, pp. 1655–1660. DOI: 10.1016/S0140-6736(08)61689-X.

Mueller, N., D. Rojas-Rueda, X. Basagaña, M. Cirach, T. Cole-Hunter, P. Dadvand, D. Donaire-Gonzalez, M. Foraster, M. Gascón, D. Martinez, C. Tonne, M. Triguero-Mas, A. Valentín & M. Nieuwenhuijsen (2017). "Urban and Transport Planning Related Exposures and Mortality: A Health Impact Assessment for Cities". In: *Environmental Health Perspectives* 125.1, pp. 89–96. DOI: 10.1289/EHP220. URL: https://doi.org/10.1289/EHP220.

Ngan, T. T., R. Wang, C. Tate, M. Green, R. Mitchell, R. F. Hunter & C. O'Neill (2025). "Inequality in green space distribution and its association with preventable deaths across urban neighbourhoods in the UK, stratified by Index of Multiple Deprivation". In: *Journal of Epidemiology and Community Health* 79.2, pp. 102–109. DOI: 10.1136/jech-2024-222485. URL: https://doi.org/10.1136/jech-2024-222485.

Nguyen, P. Y., T. Astell-Burt, H. Rahimi-Ardabili & X. Feng (2021). "Green Space Quality and Health: A Systematic Review". In: *International Journal of Environmental Research and Public Health* 18.21, p. 11028. DOI: 10.3390/ijerph182111028. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8582763/.

Nicodemo, C., B. McCormick, R. Wittenberg & F. D. R. Hobbs (2021). "Are more GPs associated with a reduction in emergency hospital admissions? A quantitative study on GP referral in

England". In: *British Journal of General Practice* 71.705, e287–e295. DOI: 10.3399/BJGP.2020.0737.

Nussbaum, C., E. Massou, R. Fisher, M. Morciano, R. Harmer & J. Ford (2021). "Inequalities in the distribution of the general practice workforce in England: a practice-level longitudinal analysis". In: *BJGP Open* 5.5, BJGPO.2021.0066. DOI: 10.3399/BJGPO.2021.0066. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8596307/.

Pan, C., X. Qi, S. Cheng, Y. Chen, C. Li, H. Zhang, J. Zhang, Z. Zhang, X. Yang, P. Meng, Y. Yao, Y. Wen, Y. Jia & F. Zhang (2024). "The Comprehensive Effect of Socioeconomic Deprivation on Smoking Behavior: an Observational and Genome-Wide by Environment Interaction Analyses in UK Biobank". In: *International Journal of Mental Health and Addiction* 22, pp. 344–360. DOI: 10.1007/s11469-022-00876-0. URL: https://doi.org/10.1007/s11469-022-00876-0.

Piantadosi, S., D. P. Byar & S. B. Green (1988). "The Ecological Fallacy". In: *American Journal of Epidemiology* 127.5, pp. 893–904. DOI: 10.1093/oxfordjournals.aje.a114892.

Rigolon, A., M. H. E. M. Browning, O. McAnirlin & H. V. Yoon (2021). "Green Space and Health Equity: A Systematic Review on the Potential of Green Space to Reduce Health Disparities". In: *International Journal of Environmental Research and Public Health* 18.5, p. 2563. DOI: 10.3390/ijerph18052563. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7967323/.

Salgado, M., J. Madureira, A. S. Mendes, A. Torres, J. P. Teixeira & M. D. Oliveira (2020). "Environmental determinants of population health in urban settings. A systematic review". In: *BMC Public Health* 20.1, p. 853. DOI: 10.1186/s12889-020-08905-0. URL: https://doi.org/10.1186/s12889-020-08905-0.

Starfield, B., L. Shi & J. Macinko (2005). "Contribution of primary care to health systems and health". In: *The Milbank Quarterly* 83.3, pp. 457–502. DOI: 10.1111/j.1468-0009.2005.00409.x.

Todd, A., A. Copeland, A. Husband, A. Kasim & C. Bambra (2014). "The positive pharmacy care law: an area-level analysis of the relationship between community pharmacy distribution, urbanity and social deprivation in England". In: *BMJ Open* 4.8, e005764. DOI: 10.1136/bmjopen-2014-005764.

— (2015). "Access all areas? An area-level analysis of accessibility to general practice and community pharmacy services in England by urbanity and social deprivation". In: *BMJ Open* 5.5, e007328. DOI: 10.1136/bmjopen-2014-007328.

Tsui, J., J. A. Hirsch, F. J. Bayer, J. W. Quinn, J. Cahill, D. Siscovick & G. S. Lovasi (2020). "Patterns in Geographic Access to Health Care Facilities Across Neighborhoods in the United States Based on Data From the National Establishment Time-Series Between 2000 and 2014". In: *JAMA Network Open* 3.5, e205105. DOI: 10.1001/jamanetworkopen.2020.5105. URL: https://pubmed.ncbi.nlm.nih.gov/32412637/.

Vargas Adorno, B., R. H. M. Pereira & S. Amaral (2025). "Combining spatial clustering and spatial regression models to understand distributional inequities in access to urban green spaces". In: *Landscape and Urban Planning*. Advance online publication / Preprint. URL: https://www.urbandemographics.org/publication/2025_lup_access_green_areas/.

Zhang, L., P. Y. Tan, D. R. Y. Gan & R. Samsudin (2022). "Assessment of mediators in the associations between urban green spaces and self-reported health". In: *Landscape and Urban Planning* 226, p. 104503. DOI: 10.1016/j.landurbplan.2022.104503. URL: https://doi.org/10.1016/j.landurbplan.2022.104503.

Zied Abozied, E., L. A. Munford, A. Copeland, A. Kasim, A. Husband, C. Bambra & A. Todd (2025). "The Positive Pharmacy Care Law revisited: an area-level analysis of the relationship between community pharmacy distribution, urbanicity and deprivation in England". In: *BMJ Open* 15.5, e095540. DOI: 10.1136/bmjopen-2024-095540. URL: https://pubmed.ncbi.nlm.nih.gov/40350197/.