**Do green and blue spaces in the residential neighbourhood have an effect on multimorbidity? A comparative, observational study of 48,589 UK Biobank participants**

**Declaration of Conflict of Interest**

The authors declare they have nothing to disclose.

**Abstract**

Introduction

Availability of green and blue space in the urban residential neighbourhood can reduce the risk of poor mental and physical health, however, little is still known about different types of urban green and blue spaces and their differential impact on individuals that have multiple physical and mental chronic health conditions.

Methods

We conducted a cross-sectional study of 48,589 UK Biobank participants to analyse the relationship between exposure to seven types of urban green and blue spaces (parks, street trees, domestic gardens, total green space, inland blue space, proximity to coast and total green and blue space) with five multimorbidity outcomes: simple (2 long-term health conditions (LTCs)), complex (3 LTCs or 4+LTCs), cardio-metabolic, respiratory, and mental multimorbidity. Amount (% in 1500m circular buffers) and proximity (Euclidean distance) of green and blue spaces in the residential neighbourhood were computed individually for each UK Biobank participant using remote sense data from European Urban Atlas. Analyses were adjusted for the Bonferroni correction for multiple testing to reduce the risk of false positive results. Sensitivity analyses were conducted by buffer size (300m and 3000m).

Findings

Individuals that have a higher proportion of inland blue spaces in their residential neighbourhood had lower odds of multimorbidity. For every percent increase in the amount of inland blue space in 3000m buffer, the odds of having complex multimorbidity (3LTCs) decreased by 3% (OR:0·97; 95% CI:0·95-0·98; p-value:0·0002), after applying the Bonferroni correction. In contrast, individuals with higher amount of total green space within a 1500m buffer had higher risk of having 4+ LTCs (OR:1·01; 95% CI:1·00-1·01; p-value:0·00005). Other types of green and blue spaces had no effect on our outcomes.

Conclusion

Urban inland blue spaces, such as rivers and canals, are integral parts of life in UK but they have often been overlooked in observational health research. Future policy should aim to incorporate blue spaces in the design of urban regeneration and public health interventions.

**Key Words**

Blue space, Green Space, Multimorbidity, Mental Health, Cross-sectional Study

**Highlights**

* Few studies have comparatively assessed the impact of different urban green and blue spaces on multimorbidity and chronic health.
* Urban inland blue spaces had a protective effect on complex multimorbidity.
* Total amount of greenery had a negative effect on multimorbidity.
* Parks, street trees, gardens and proximity to coast had no effect on multimorbidity.
* It is not exposure to green but exposure to blue space that reduces the risk of multimorbidity in urban-dwelling middle-aged and older adults.

1. **Introduction**

Prior epidemiological studies have found that exposure to green spaces (green vegetation) can improve mood, reduce stress, and reduce the risk of developing mental and physical health conditions, such as depression, cardio-vascular disease (CVD), and stroke.1,2 Less is known about the influence of blue spaces (water bodies) on health, but some studies show that greater availability of inland blue spaces, like lakes and rivers, and close proximity to coast can improve physical activity and promote good mental health in adults.3–5 Investigations into the relationship between green and blue spaces with health has been made possible partly due to the integration of open-access environmental data into health cohorts, such as land use maps and the Normalised Difference Vegetation Index (NDVI), which can facilitate the modelling of surrounding greenness and availability of water.6 Although the NDVI provides a reliable measure of overall greenness, it often fails to capture the availability, accessibility and quality of urban green and blue spaces, which can be small and fragmented. Newer research suggests that some types of green and blue spaces have a stronger effect on health than others. For example, higher availability of street trees, greater accessibility to public parks, access to serene environments and forests was previously associated with lower risk of depression, CVD and diabetes in middle-aged and older adults.7–10 In comparison, overall greenness, rangeland and agricultural land showed no relationships with these health outcomes.7–10

Different types of green and blue spaces might have a differential impact on health due to their distinctive salutogenic properties and positions in the urban environment.11 Street trees might be beneficial for cardio-vascular disease due to their ability to mitigate harm from air pollution and noise on roads12–14, while blue spaces are more likely to improve mental health because they provide spaces for restoration and socialisation.5,15 Comparative research into the health effects of different urban green and blue spaces, however, is still lacking.11 This could be due to lack of available data and robust environmental modelling in health and well-being research, which can lead to underassessment of the true impact of green and blue spaces on health.11

Multimorbidity, defined as the presence of two or more long-term chronic, mental or physical health conditions (LTCs) within an individual16, can lead to lower quality of life17, cause a decline in physical functioning18, and increase the risk of disability19, mortality20 and healthcare utilisation.21 Certain disease clusters, such as combinations of cardio-metabolic, respiratory, mental health diseases, as well complex multimorbidity (defined as having three or more co-occurring LTCs) can have greater impact on physical functioning, well-being and quality of life.22 Multimorbidity is a growing health problem due to worldwide demographic changes towards ageing populations. Old age is the biggest risk factor for multimorbidity, with the oldest old (85 years+) having the highest prevalence between 80% and 95%.18,23 However, recent observational research has shown that multimorbidity is not merely an inevitable outcome of ageing but a dynamic health state that is shaped by socio-economic, behavioural, and environmental risk factors acquired during the life course.18,23 In the United Kingdom (UK) and other high-income countries (HICs), low socio-economic status (SES)24, low physical activity levels25,26, ethnic minority status18 and greater exposure to air pollution27 were all associated with an increased risk of developing complex, cardio-metabolic, respiratory and mental-physical multimorbidity in middle age.

Individuals at high risk of multimorbidity might benefit from urban green and blue spaces due to their ability to filter pollutants from the air, promote physical activity, and increase socialisation and relaxation.28 However, research about the relationship between green and blue spaces on multimorbidity remains lacking. To address this gap, we studied the relationship between green and blue spaces and multimorbidity in middle-aged and older adults by linking health data from a large, population-based cohort, the UK Biobank, with high resolution environmental data from European Urban Atlas. The integration of data from Urban Atlas allows us to extensively model the residential availability and accessibility of seven different types of green and blue spaces (such as accessibility to a park, availability of street trees, availability of domestic garden space, availability of total greenness, availability of inland water bodies, and the proximity to coast), and comparatively assess their effect on cardio-metabolic, respiratory, mental, simple and complex multimorbidity. The individual integration of green and blue space data from Urban Atlas into the UK Biobank bridges a gap in the literature by substituting aggregate measures of overall greenness with distinct and differentiated calculations of types of urban green and blue spaces. This approach can better inform policy into public health and urban planning, and contributes new methodological and conceptual knowledge into nature-health relationships, which were previously considered unfeasible in large population-based studies due to insufficient exposure measures. As such this is one of the first studies to link Urban Atlas and UK Biobank data to model the effects of specific types of urban green and blue spaces on multimorbidity. 6,29

**2.0 Materials and Methods**

**2.1 Study design and participants**

We conducted a cross-sectional study using baseline data from the UK Biobank, which is a population-based prospective cohort of 502,650 men and women aged 40-69 years. Participation into the cohort is voluntary and baseline information on socio-demographic characteristics, health and lifestyle factors was collected between 2006 and 2010 in 22 assessment centres around the UK.30 Follow-up information on socio-demographic factors and health is available for a sub-section of participants.30 The UK Biobank has been used extensively to study the effects of socio-demographic and lifestyle factors on chronic health.31–33 We chose the UK Biobank due to its large baseline sample size and wealth of information on chronic health, socio-demographic and environmental factors.

**2.2 Green and blue spaces: data source and integration**

Studies increasingly show that an overall measure of greenness, such as the NDVI, is rarely enough to capture urban green spaces, which are often small, fragmented and not always accessible to the public.11 Therefore, we incorporated green and blue space data from European Urban Atlas (UA), which is a high-resolution, open-access, land use dataset that provides objective information on the location and availability of several different types of urban natural environments, such as trees, parks, lakes, rivers and natural greenery, across multiple European Functional Urban Areas (FUA).34 FUAs are statistical unit areas with a population of at least 100,000 people, which include a large metropolitan city and its surrounding commuting zone.34 The overall minimum accuracy for the UA data is 80% and the minimum mapping width is 10m. The UA is collated from SPOT 5 satellite and other Very High Resolution (VHR) imagery for the years 2006, 2012 and 2018 (European Environment Agency, 2012). The UA dataset has good inter-rater reliability with CORINE, UK Land Cover Map and NDVI datasets, and has been widely used in health research to capture urban green spaces.35

We used several different layers of UA data to compute measures of the following types of natural spaces: availability total green space, proximity to public parks, availability of street trees, availability of inland blue spaces, and availability of both green and blue spaces in the residential neighbourhood for individuals in the UK Biobank. Additionally, we used data already available in the UK Biobank to measure availability of domestic garden space and proximity to coast (see table 1 for more details).

**Table 1: Summary of exposures used in our study.**



A detailed description of the UA data integration methods can be found in Appendix I. In brief, the UA data were processed in ArcGIS Pro, which is a tool for geo-spatial analysis and visualisation.36 The six-digit residential location coordinates (northing and easting) of UK Biobank participants were imported as points onto a base layer map. Using the Buffer tool, circular (Euclidean radial distance) buffers around the residential locations of UK Biobank participants were computed. The UA data were imported into shapefiles and converted from vector to raster datasets. The conversion was conducted at a 50m resolution (50mx50m grid cell size) for all 2006 UA layers and at a 10m resolution for the 2012 Street Tree Layer. Although a high spatial resolution would produce more accurate measures, studies have shown that associations with health do not vary greatly between higher and lower resolutions of green space measures.37 We chose to use a 10m resolution for the Street Tree Layer because of the small and fragmented nature of street trees, and because newer research suggests that the health benefits of street trees might be gained only if individuals are able to see at least three street trees from the window of their residential address.38

The percent of the area occupied by the relevant green/ blue space UA raster data within each buffer was calculated using the tool, Zonal Statistics as Table. The distance to urban park was computed using the Near tool, which measured the straight-line distance (in metres) from a participant’s residential address to the edge of the nearest public green space that was captured by the “Urban green space” UA layer data. Participants whose residential address or buffer area fell outside of the boundaries of the UA data layers were excluded from the analyses.

Specifically, availability of total green space was computed as amount (percent (%)) of green space area cover in a 1500m circular buffer. Total green space was measured as the total percent of area cover of UA layers “*Green urban areas*”, “*Agricultural + seminatural + wetland areas*”, and “*Forests*”, which capture a wide range of urban greenery, like parks, as well as natural and agricultural vegetation, like forests, wetlands and fields. 34 (table 1).

Proximity to park was measured as the presence or absence of a public urban green space within a 1500m circular buffer around the residential address of each UK Biobank participant, using the UA layer, “*Green urban areas*”, which captures public areas, such as public parks, gardens, and zoos.34

Availability of street trees was measured as amount (percent (%)) of street tree canopy area cover in a 1500m circular buffer around the residential address of each UK Biobank participant, using 2012 UA layer, “*Street Tree* *layer*”, which captures contiguous patches of trees covering built-up urban areas of at least 500m2.34

Availability of inland blue space was measured as amount (percent (%)) of surface inland water area cover in a 1500m circular buffer around the residential address of each UK Biobank participant, using UA layer “*Water*”, which captures water bodies that are not seas or oceans, such as lakes, rivers and artificial and man-made bodies, like garden ponds (table 1).34

Availability green and blue space was measured as amount (percent (%)) of total green and blue space in 1500m circular buffer around the residential address of each UK Biobank participant. Participants were classed as having amount of green and blue space greater than 0% if they had at least 0.01% green space cover and at least 0.01% blue space cover within the same buffer. Participants who had only green or only blue space within the buffer were classed as having 0% green and blue space (see more on table 1).

Availability of domestic garden space was measured as amount (percent (%)) of domestic garden space area cover in a 1000m circular buffer around the residential address of each UK Biobank participant. Data on domestic garden space was already available for the UK Biobank from linkages with the 2005 Generalised Land Use Dataset (GLUD).39

Data on proximity to coast were obtained from data previously made available for the UK Biobank. Proximity to coast was measured as the straight-line (Euclidean) distance from a participant’s residential address at baseline to their nearest coastline edge.39

**2.3 Sensitivity analyses by spatial scale**

Currently, there is no optimum spatial scale for measuring exposure to green and blue spaces in epidemiological research, but an adequate measure of the surrounding neighbourhood is usually required for accurate exposure assessment.37,40 We conducted our main analyses using exposures captured at 1500m Euclidean radial buffers (circular buffers) around the residential address because this distance is equivalent to a 15-minute walk, which is considered by the World Health Organisation (WHO) as the maximum time anyone should travel to access key health-promoting amenities and resources according to urban theories of healthy living.41 Data on domestic garden space was only available from UK Biobank at 1000m circular buffers.

We conducted sensitivity analyses using circular buffer sizes with Euclidean radii of 300m and 3000m, where data were available (see table 1 for more details). Three-hundred meters is a proxy for the immediate residential neighbourhood and is the maximum-recommended distance anyone should live from an accessible green space, according to the WHO.11 Individuals with multimorbidity might also have limited physical functioning, so including a smaller measure of the residential neighbourhood might be beneficial. Three-thousand meters, on the other hand, is a proxy for the wider residential neighbourhood within which individuals live, socialise and commute to work.11

**2.4 Outcomes**

The outcomes of this study were simple, complex, cardio-metabolic, respiratory, and mental multimorbidity. Simple and complex multimorbidity were measured as disease counts (0 LTCs, 1 LTC, 2 LTCs, 3 LTCs, and 4+ LTCs), where individuals with 2 LTCs had simple multimorbidity, while those with 3 or 4+ LTCs had complex multimorbidity. Individuals with 0LTCs or 1LTC had no multimorbidity. In addition to disease counts, distinct clusters of cardio-metabolic, respiratory, and mental conditions were also included. We used a systematic review on replicable multimorbidity clusters and prior literature on the burden and prevalence of chronic health to derive these multimorbidity clusters for the UK Biobank.23,42 Individuals who had two or more conditions specific to the cluster were coded as having multimorbidity (yes), while individuals who had only one or no conditions specific to the cluster were coded as not having that type of multimorbidity (no).

Data on LTCs was obtained at baseline through a self-reported questionnaires and a nurse-led interviews. The type of LTCs included in this study was guided by a 45-item disease list previously adapted for measuring multimorbidity in the UK Biobank.43 The list only includes mental and physical conditions that are highly prevalent in the British population and have profound, chronic effect on quality of life and functional status (see Appendix II).23

**2.5 Statistical analysis**

To assess the probability of having each multimorbidity outcome relative to the exposure, we applied multinomial logistic regression and adjusted the models for a set of confounders. According to prior literature on the effects of the natural environment on chronic health, socio-demographic factors (such as age, sex, socio-economic status, and ethnicity), physical activity, noise and air pollution are all factors that potentially affect the relationship.14, 8,11 Therefore, we adjusted the models for the following confounders: age, sex (woman or man), annual household income (low: below £18,000; medium: £18,000-£51,999; high: above £52,000), ethnicity (white and other), crime levels (IMD Crime score), area-level deprivation (Townsend Index), physical activity [based on MET min/week: low (< 600 MET), moderate (≥ 600 to 2990 MET), or high (≥3000 MET)], air pollution [particulate matter (PM) 2·5], and noise [16-hour sound level of noise pollution in decibels (dB)]. We chose to include a proxy for crime as well as deprivation due to the urban nature of our population. Crime can be a strong determinant of green space use.44 The IMD Crime score is the only available proxy for area-level crime in UK Biobank, and we chose to use it in the same model with the Townsend Index due to their complimentary nature. The Townsend index measures deprivation related to housing, employment and social mobility45, factors which we consider more relevant for our study than the components of the IMD (income, health, education, living environment), as they are strongly correlated with the exposures and other confounders of our study.

We used a stepwise confounder approach to determine the statistical suitability of each confounder to the model by assessing the degree of change in the effect estimates (odds ratio) with the addition of a set of confounders, results of which can be found in Appendix III.46 In brief, we first computed a univariable model, which showed the odds of having the outcome relative to each exposure metric without adjustment for any confounders. We then added a set of confounders and assessed the degree of change in the odds ratio. Confounders were added in the following sets: Model 1: univariable; Model 2: Model 1 + age, sex, ethnicity, income; Model 3: Model 2 + crime, Townsend Index; Model 4: Model 3 + physical activity; Model 5: Model 4 + air pollution (pm2.5) + noise (results available in Appendix III).

Data on the above confounders was collected from UK Biobank at baseline (year 2006-2012). Age, sex and household income were self-reported at abseline.39 Physical activity was assessed for each participant at baseline using the International Physical Activity Questionnaire (IPAQ). Area-level deprivation, IMD Crime score, air pollution and noise were linked to the residential address of each UK Biobank participant at baseline.39

As we tested multiple exposures, the probability of getting false positive results increased. To account for this, we applied a Bonferroni correction to the analyses, which adjusted the significance level (p-value) of the effect estimates (odds ratios) to account for the probability of getting Type I errors.47 A new significance level (αadjust) of 0·0009 was derived by αunadjust/*n* (or 0·05/58)), whereα unadjust is 0·05 and *n* is the number of tests we conducted. Finally, measures of central tendency for hypothesis testing were applied to assess differences in multimorbidity prevalence by socio-demographic and environmental factors.

**2.6 Participant exclusion and missing data**

A total of 48,589 participants were included in our analytical sample. Figure 1 shows the process of participant exclusion based on data availability. Around 300,000 participants resided within the data boundaries of UA dataset, which included only participants residing in cities and their surrounding commuter zones (a detailed map of residential distribution of UK Biobank participants is included in Appendix II). Out of those 300,000 participants, 83,005 had complete UA exposure data. Over 200,000 participants were excluded because a part of the residential buffer fell outside of the boundary of UA. A further 34,416 participants were excluded because they had missing covariate and proximity to coast data.

A flowchart of a number of patients

Description automatically generated

Figure 1: Flowchart of participant inclusion based on data availability.

**3.0 Results**

The prevalence of the five types of multimorbidity are presented in Figure 2. The prevalence of simple multimorbidity (2 LTCs) was 17%, while the prevalence of complex multimorbidity (3 LTCs or 4+ LTCs) was 11%. Cardio-metabolic multimorbidity had a prevalence of 6%, while respiratory and mental multimorbidity had a prevalence of <1%. Generally, those who had simple (2 LTCs), complex (3 LTCs and 4+ LTCs), cardio-metabolic and respiratory multimorbidity were older (table 2). Participants with mental multimorbidity were very slightly younger than those without mental multimorbidity. A larger proportion of men had cardio-metabolic multimorbidity (8·6% vs 3·3% for women), but a slightly higher proportion of women had mental multimorbidity (0·7% vs 0·5% for men). Overall, a higher proportion of low-income individuals had multimorbidity (table 2). Individuals with any type of multimorbidity, on average, lived in areas with higher crime and deprivation levels. Individuals with 2 LTCs and 3 LTCs also had slightly lower amount of blue space in 1500m, and 3000m buffers around the residential address compared to individuals with 0 or 1 LTC.

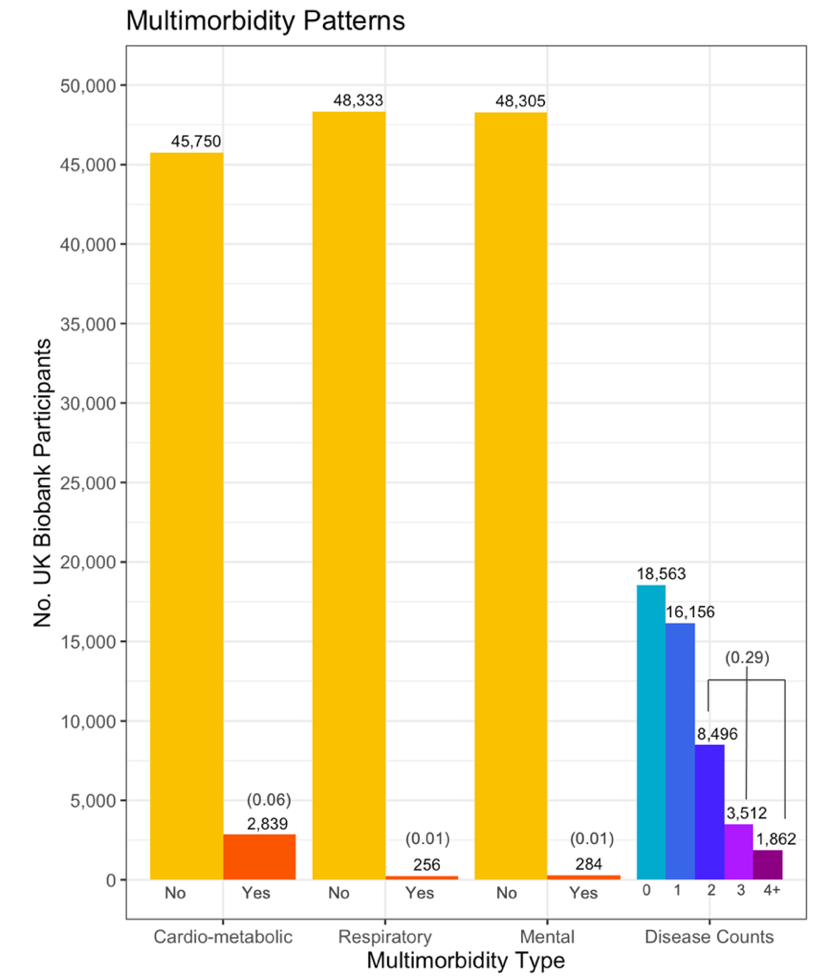


Figure 2: Prevalence of multimorbidity by type in UK Biobank analytical sample.

Table 2: Characteristic of analytical sample by multimorbidity type

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Multimorbidity Type | | | | | | | | | | |
|  | **Cardio-metabolic** | | **Respiratory** | | **Mental** | | **Disease Counts** | | | | |
|  | **No** | **Yes** | **No** | **Yes** | **No** | **Yes** | **0 (LTCs)** | **1(LTC)** | **2(LTCs)** | **3(LTCs)** | **4+(LTCs)** |
| Age (years) in years, mean (SD) | 55·5\* (±8·16) | 60·8\* (±6·49) | 55·8\* (±8·17) | 59·1\*  (±7·21) | 55·8\*  (±8·17) | 54·5\* (±8·02) | 53·3**‡** (±8·02) | 56·0 **‡** (±7·99) | 58·2**‡** (±7·65) | 59·5**‡** (±7·24) | 60·3**‡** (±6·92) |
| Sex |  |  |  |  |  |  |  |  |  |  |  |
| Female | 24,461**†** (96·7%) | 838 **†** (3·3%) | 25,167 (99·5%) | 132 (0·5%) | 25,133**†** (99·3%) | 166**†** (0·7%) | 9,720 (38·4%) | 8,491 (33·6%) | 4,329 (17·1%) | 1,790 (7·1%) | 969 (3·8%) |
| Male | 21,289**†** (91·4%) | 2,001**†** (8·6%) | 23,166 (99·5%) | 124 (0·5%) | 23,172**†** (99·5%) | 118**†** (0·5%) | 8,843 (38·0%) | 7,665 (32·9%) | 4,167 (17·9%) | 1,722 (7·4%) | 893 (3·8%) |
| Ethnicity |  |  |  |  |  |  |  |  |  |  |  |
| White | 40,508 (94·6%) | 2,304 (5·4%) | 42,575**†** (99·4%) | 237**†** (0·6%) | 42,545**†** (99·4%) | 267 **†** (0·6%) | 16,341 (38·2%) | 14,209 (33·2%) | 7,481 (17·5%) | 3,127 (7·3%) | 1,654 (3·9%) |
| Other | 52,42 (90·7%) | 535 (9·3%) | 5,758**†** (99·7%) | 19**†** (0·3%) | 5,760 **†** (99·7%) | 17**†** (0·3%) | 2,222 (38·5%) | 1,947 (33·7%) | 1,015 (17·6%) | 385 (6·7%) | 208 (3·6%) |
| Annual household income before tax (£) |  |  |  |  |  |  |  |  |  |  |  |
| Low (< £18,000) | 8,007**†** (88·8%) | 1,010**†** (11·2%) | 8,913**†** (98·8%) | 104**†** (1·2%) | 8,889**†** (98·6%) | 128**†** (1·4%) | 2,355**†** (26·1%) | 2,828**†** (31·4%) | 1,984 **†** (22·0%) | 1,062**†** (11·8%) | 788 **†** (8·7%) |
| Medium (£18,000 to £51,999) | 21,776**†** (94·4%) | 1,299**†** (5·6%) | 22,969**†** (99·5%) | 106**†** (0·5%) | 22,966**†** (99·5%) | 109**†** (0·5%) | 8,628**†** (37·4%) | 7,834**†** (34·0%) | 4,146 **†** (18·0%) | 1,659**†** (7·2%) | 808**†** (3·5%) |
| High (Greater than £52,000) | 15,967**†** (96·8%) | 530**†** (3·2%) | 16,451**†** (99·7%) | 46**†** (0·3%) | 16,450**†** (99·7%) | 47**†** (0·3%) | 7,580 **†** (45·9%) | 5,494 **†** (33·3%) | 2,366 **†** (14·3%) | 791**†** (4·8%) | 266**†** (1·6%) |
| Crime (IMD score), mean (SD) | 0·14\* (±0·625) | 0·24\* (±0·66) | 0·148\* (±0·627) | 0·317\* (±0·648) | 0·149 (±0·627) | 0·21 (±0·65) | 0·14 **‡** (±0·63) | 0·14 **‡** (±0·62) | 0·16 **‡** (±0·63) | 0·17**‡** (±0·63) | 0·22 **‡** (±0·64) |
| Deprivation (Townsend Index), mean (SD) | -0·32\* (±3·24) | 0·302\* (±3·46) | -0·293\* (±3·26) | 0·717\* (±3·48) | -0·29\* (±3·25) | 0·60\* (±3·65) | -0·335**‡** (±3·21) | -0·34**‡** (±3·27) | -0·22**‡** (±3·27) | -0·18 **‡** (±3·28) | 0·14 **‡** (±3·49) |
| Physical Activity (MET min/week) |  |  |  |  |  |  |  |  |  |  |  |
| Low (< 600 MET min/week) | 8,035**†** (91·7%) | 729**†** (8·3%) | 8,681**†** (99·1%) | 83**†** (0·9%) | 8,686**†** (99·1%) | 78**†** (0·9%) | 2,851**†** (32·5%) | 2,868 **†** (32·7%) | 1,656**†** (18·9%) | 843**†** (9·6%) | 546**†** (6·2%) |
| Moderate (≥ 600 to 2990 MET min/week) | 24,426**†** (94·6%) | 1,393**†** (5·4%) | 25,722**†** (99·6%) | 97**†** (0·4%) | 25,680**†** (99·5%) | 139**†** (0·5%) | 10,030**†** (38·8%) | 8,690**†** (33·7%) | 4,460 **†** (17·3%) | 1,738 **†** (6·7%) | 901**†** (3·5%) |
| High (≥3000 MET min/week) | 13,289**†** (94·9%) | 717**†** (5·1%) | 13,930**†** (99·5%) | 76**†** (0·5%) | 13,939**†** (99·5%) | 67**†** (0·5%) | 5,682 (40·6%) | 4,598 **†** (32·8%) | 2,380 **†** (17·0%) | 931**†** (6·6%) | 415 **†** (3·0%) |
| Annual average air quality for 2010 (PM2·5 µg/m3), mean (SD) | 10·2\*  (±1·07) | 10·3\* (±1·10) | 10·2 (±1·07) | 10·4 (±1·15) | 10·2  (±1·07) | 10·3 (±1·06) | 10·2 (±1·09) | 10·2 (±1·07) | 10·2 (±1·05) | 10·2 (±1·06) | 10·2 (±1·08) |
| Noise (day & evening 2009 - LAeq,16hr in Db), mean (SD) | 54·1 (±4·68) | 54·2 (±4·97) | 54·1 (±4·70) | 54·3 (±4·78) | 54·1\*  (±4·70) | 53·8\* (±4·88) | 54·1 (±4·71) | 54·1 (±4·66) | 54·0 (±4·65) | 54·1 (±4·76) | 54·2 (±4·96) |
| Total Green Space (%) - 300m, mean (SD) | 11·7\* (±16·5) | 11·8\* (±15·8) | 11·7 (±16·5) | 11·1 (±15·9) | 11·7 (±16·5) | 11·6 (±16·1) | 11·4**‡** (±16·4) | 11·7**‡** (±16·4) | 11·8**‡** (±16·4) | 12·0 **‡** (±16·6) | 13·1**‡** (±17·4) |
| Total Green Space (%) - 1500m, mean (SD) | 22·6 (±19·1) | 22·5 (±19·0) | 22·6 (±19·1) | 22·8 (±18·5) | 22·6 (±19·1) | 23·4 (±21·1) | 22·2**‡** (±19·0) | 22·6**‡** (±19·0) | 22·7**‡** (±19·0) | 23·3**‡** (±19·9) | 24·5**‡** (±19·8) |
| Total Green Space (%) - 3000m, mean (SD) | 27·2 (±20·3) | 27·1 (±20·3) | 27·1 (±20·3) | 27·4 (±21·0) | 27·1 (±20·3) | 27·4 (±21·6) | 26·7**‡** (±20·2) | 27·2**‡** (±20·2) | 27·2**‡** (±20·2) | 28·0**‡** (±21·0) | 29·3**‡** (±21·1) |
| Park (presence within 300m) |  |  |  |  |  |  |  |  |  |  |  |
| Yes | 23,941**†** (93·9%) | 1,560**†** (6·1%) | 25,366 (99·5%) | 135 (0·5%) | 25,347 (99·4%) | 130 (0·6%) | 9,712 (38·1%) | 8,471 (33·2%) | 4,431  (17·4%) | 1,857  (7·3%) | 1,030 (4·0%) |
| No | 21,810**†** (94·5%) | 1,279**†** (5·5%) | 22,967 (99·5%) | 121 (0·5%) | 22,958 (99·4%) | 154 (0·6%) | 8,851 (38·3%) | 7,685 (33·3%) | 4,065 (17·6%) | 1,655 (7·2%) | 832 (3·6%) |
| Park (presence within 1500m) |  |  |  |  |  |  |  |  |  |  |  |
| Yes | 44,978**†** (94·1%) | 2,808**†** (5·9%) | 47,534 (99·5%) | 252 (0·5%) | 47,506 (99·4%) | 280 (0·6%) | 18,270 (38·2%) | 15,879 (33·2%) | 8,354 (17·5%) | 3,441 (7·2%) | 1,842 (3·9%) |
| No | 772**†** (96·1%) | 31**†** (3·9%) | 799 (99·5%) | 4 (0·5%) | 799 (99·5%) | 4 (0·5%) | 293 (36·5%) | 277 (34·5%) | 142 (17·7%) | 71 (8·8%) | 20 (2·5%) |
| Domestic Garden Space (%) - 1000m, mean (SD) | 27·6 (±11·3) | 27·0 (±11·3) | 27·6 (±11·3) | 25·9 (±11·3) | 27·6 (±11·3) | 26·3 (±11·0) | 27·5 (±11·2) | 27·7 (±11·4) | 27·7 (±11·2) | 27·4 (±11·4) | 26·9 (±11·3) |
| Tree Canopy Cover (%) - 300m, mean (SD) | 22·9\* (±18·4) | 21·8\* (±17·8) | 22·9\* (±18·4) | 19·5\* (±16·3) | 22·9 (±18·4) | 22·1 (±19·0) | 22·5**‡** (±18·2) | 23·2**‡** (±18·6) | 22·9**‡** (±18·4) | 22·5**‡** (±18·3) | 23·3**‡** (±18·7) |
| Tree Canopy Cover (%) - 1500m, mean (SD) | 21·2\* (±13·7) | 20·3\* (±13·5) | 21·1 (±13·7) | 19·6 (±13·0) | 21·1 (±13·7) | 20·4 (±14·1) | 20·9 (13·6) | 21·3 (±13·8) | 21·2 (±13·6) | 20·7 (±13·6) | 22·5± |
| Blue Space (%) - 300m, mean (SD) | 0·54 (±3·34) | 0·53 (±3·13) | 0·54 (±3·33) | 0·58 (±3·09) | 0·54 (±3·33) | 0·27 (±2·09) | 0·59 (±3·53) | 0·52 (±3·31) | 0·531 (±3·19) | 0·45 (±2·80) | 0·43 (±2·91) |
| Blue Space (%) - 1500m, mean (SD) | 1·31 (±2·87) | 1·20 (±2·90) | 1·30 (±2·88) | 0·99 (±2·27) | 1·31 (±2·88) | 0·89 (±2·02) | 1·37 **‡** (±2·96) | 1·31**‡** (±2·86) | 1·24**‡** (±2·80) | 1·17**‡** (±2·73) | 1·15**‡** (±2·77) |
| Blue Space (%) - 3000m, mean (SD) | 1·55 (±2·34) | 1·46 (±2·47) | 1·54 (±2·35) | 1·39 (±1·92) | 1·54 (±2·35) | 1·39 (±1·92) | 1·61**‡** (±2·38) | 1·54**‡** (±2·35) | 1·49**‡** (±2·29) | 1·41**‡** (±2·35) | 1·40**‡** (±2·24) |
| Distance to coast (miles), mean (SD) | 45·4 (±12·8) | 45·8 (±13·1) | 45·4 (±12·8) | 45·4 (±12·4) | 45·4 (±12·8) | 45·6 (±13·4) | 45·4 **‡** (±12·8) | 45·4 **‡** (±12·8) | 45·3 **‡** (±12·6) | 45·3**‡** (±12·8) | 46·6**‡** (±13·2) |
| Green & Blue Space (%) - 300m, mean (SD) | 1·30 (±7·00) | 1·25 (±6·78) | 1·30\* (±6·98) | 1·84\* (±7·96) | 1·30 (±6·97) | 1·58 (±9·37) | 1·32 (±6·99) | 1·26 (±6·86) | 1·34 (±7·12) | 1·28 (±7·09) | 1·31 (±7·26) |
| Green & Blue Space (%) - 1500m, mean (SD) | 12·6 (±18·9) | 12·5 (±18·9) | 12·6 (±18·9) | 12·2 (±18·9) | 12·6 (±18·9) | 12·2 (±19·8) | 12·7 (±18·7) | 12·4 (±18·7) | 12·5 (±18·9) | 12·8 (±19·8) | 13·7 (±20·2) |
| Green & Blue Space (%) - 3000m, mean (SD) | 23·0 ± (±22·0) | 23·3 (±22·0) | 23·0 (±22·0) | 23·2 (±22·2) | 23·0 (±22·0) | 22·7 (±22·9) | 23·0**‡** (±21·8) | 22·8**‡** (±21·9) | 22·8**‡** (±22·0) | 23·3 **‡** (±22·9) | 25·0**‡** (±23·2) |

\* Mann-Whitney U test p-value < 0·05. **†** Chi-squared test p-value < 0·05. **‡** Kruskal-Wallis H test p-value < 0·05

Table 3: Results of main and sensitivity analyses for the associations between exposure to green and blue spaces with multimorbidity

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Main Analyses | | | | | | | | | | | | | | | | | | | | | | |
| Disease Counts (simple and complex multimorbidity) | | | | | | | | | | | | | | | **Multimorbidity Clusters** | | | | | | | | |
|  | 1 LTC (vs 0 LTCs) | | | 2 LTCs (vs 0 LTCs) | | | 3 LTCs (vs 0 LTCs) | | | | 4+ LTCs (vs 0 LTCs) | | | Cardio-metabolic (yes vs no)| | | | Respiratory  (yes vs no) | | | | Mental  (yes vs no) | | | |
| OR 95% CI p-value | | | OR  95% CI | | p-value | OR  95% CI | | | p-value | OR  95% CI | | p-value | OR  95% CI | | p-value | OR  95% CI | | p-value | OR | 95% CI | p-value |
| Total Green Space (%) - 1500m | 1·00 (1·00 -1·00) >0·05 | | | 1·00 | (1·00 -1·00) | >0·05 | **1·00** | **(1·00 - 1·01)** | **0·01** | | **1·01§** | **(1·00 -1·01)** | **0·00005** | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (1·00-1·01) | >0·05 |
| Park (presence within 1500m) - yes | 0·92 (0·77-1·09) >0·05 | | | 0·92 | (0·75 -1·14) | >0·05 | **0·76** | **(0·58 - 1·00)** | **0·05** | | 1·46 | (0·91-2·33) | >0·05 | 1·40 | (0·98-2·09) | >0·05 |  | | | | | |
| Domestic Garden Space (%) - 1000m | 1·00 | (1·00 -1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (0·98-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 |
| Tree Canopy Cover (%) - 1500m | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 |
| Blue Space (%) - 1500m | 0·99 | (0·99-1·00) | >0·05 | **0·99** | **(0·98-1·00)** | **0·0032** | **0·98** | **(0·96-0·99)** | **0·0016** | | **0·98** | **(0·96-1·00)** | **0·014** | 0·99 | (0·97-1·00) | >0·05 | **0·94** | **(0·89-1·00)** | **0·05** | **0·92** | **(0·86-0·97)** | **0·006** |
| Distance to coast (m) | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 |
| Green & Blue Space (%) - 1500m | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·00) | >0·05 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sensitivity Analyses | | | | | | | | | | | | | | | | | | | | | | | |
|  | **Disease Counts (simple and complex multimorbidity)** | | | | | | | | | | | |  | **Multimorbidity Clusters** | | | | | | | | | |
|  | 1 LTC (vs 0 LTCs) | | | 2 LTCs (vs 0 LTCs) | | | 3 LTCs (vs 0 LTCs) | | | | 4+ LTCs (vs 0 LTCs) | | | Cardio-metabolic (yes vs no) | | | Respiratory  (yes vs no) | | | Mental  (yes vs no) | | | |
| Fully Adjusted Model‖ | | | | | | | | | | | | | Fully Adjusted Model‖ | | | Fully Adjusted Model‖ | | | Fully Adjusted Model‖ | | | |
| OR | 95% CI | p-value | OR  95% CI | | p-value | OR  95% CI | | | p-value | OR  95% CI | | p-value | OR  95% CI | | p-value | OR  95% CI | | p-value | OR | 95% CI | | p-value |
| Total Green Space (%) - 300m | **1·00** | **(1·00 -1·00)** | **0·05** | **1·00** | **(1·00 -1·00)** | **0·05** | 1·00 | (1·00 -1·00) | 0·17 | | 1·01 | (1·00 -1·01) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·01) | | >0·05 |
| Total Green Space (%) - 3000m | 1·00 | (1·00 -1·00) | >0·05 | **1·00** | **(1·00 -1·00)** | **0·03** | **1·00** | **(1·00 -1·01)** | **0·003** | | **1·00§** | **(1·00 -1·01)** | **0·00001** | **1·00** | **(1·00-1·00)** | **0·002** | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | |
| Park (presence within 300m) - yes | 1·02 | (0·96 -1·06) | >0·05 | 1·00 | (0·95 -1·06) | >0·05 | 1·02 | (0·95-1·10) | >0·05 | | 1·09 | (0·99-1·21) | >0·05 | 1·07 | (0·99-1·16) | >0·05 | 0·95 | (0·75-1·21) | >0·05 | 0·90 | (0·70-1·15) | | >0·05 |
| Tree Canopy Cover (%) - 300m | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·01) | | >0·05 |
| Blue Space (%) - 300m | 1·00 | (0·99-1·00) | >0·05 | 1·00 | (0·99-1·00) | >0·05 | 0·99 | (0·98-1·00) | >0·05 | | 0·99 | (0·97-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·01 | (0·96-1·04) | >0·05 | 0·96 | (0·89-1·01) | | >0·05 |
| Blue Space (%) - 3000m | 0·99 | (0·98-1·00) | >0·05 | **0·98** | **(0·97-0·99)** | **0·003** | **0·97§** | **(0·95-0·98)** | **0·0002** | | **0·97** | **(0·95-0·99)** | **0·008** | 0·98 | (0·97-1·00) | >0·05 | 0·95 | (0·89-1·01) | >0·05 | **0·94** | **(0·88-0·99)** | | **0·04** |
| Green&Blue Space (%) - 300m | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·01) | >0·05 | | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·01 | (0·99-1·02) | >0·05 | 1·01 | (0·99-1·02) | | >0·05 |
| Green & Blue Space (%) - 3000m | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | | 1·00 | (1·00-1·01) | >0·05 | 1·00 | (1·00-1·00) | >0·05 | 1·00 | (0·99-1·01) | >0·05 | 1·00 | (0·99-1·00) | | >0·05 |

**§Significant by Bonferroni adjustment (p-value < 0·0009)**

**|Models adjusted for: age, sex, annual household income, ethnicity, crime levels, area-level deprivation, physical activity, air pollution, and noise**

In main analyses, no significant associations were observed between any of the five multimorbidity outcomes with amount of street trees, amount of green and blue space, and amount of domestic garden space after adjustment for confounders (exposure-outcome odds ratios in table 3). It was not possible to assess the relationship between presence of park with respiratory and mental multimorbidity because over 99% of participants had a park within 1500m of their residential address (table 2). Higher amount of total green space was associated with slightly higher odds of having complex multimorbidity (4+ LTCs), and the association remained significant after applying the Bonferroni correction (OR:1·01; 95%CI:1·00-1·01; p-value:0·00005). Higher amount of blue space in 1500m buffer was associated with lower odds of having simple, complex (3 LTCs and 4+ LTCs), respiratory and mental multimorbidity before adjustment for multiple testing. However, after applying the Bonferroni correction, the associations became non-significant (table 3).

In sensitivity analyses, higher amount of blue space in 3000m buffer was associated with lower odds of simple, complex (3 LTCs and 4+ LTCs) and mental multimorbidity before adjustment for multiple testing (table 3). After applying the Bonferroni correction, only the association between higher amount of blue space in 3000m buffer with 3 LTCs remained significant. Specifically, for a 1% increase in the amount of inland blue space within a 3000m buffer around the residential address, the odds of having 3 LTCs decreased by 3% (OR: 0·97; 95%CI: 0·95-0·98; p-value: 0·0002) (table 3). Effect estimates for the confounders in the fully adjusted models can be found in Appendix III.

**4.0 Discussion and Conclusion**

**4.1 Relationship between inland blue spaces and multimorbidity**

Although extensive research has highlighted the health-promoting properties of green spaces, comparatively little is known about the role of blue spaces in these relationships. By using an innovative integration of Urban Atlas data with the UK Biobank, our study was able to uniquely compare exposure to different types of urban green and blue spaces. This approach revealed that higher amounts of inland blue space within 1500m and 3000m buffers around residential addresses were associated with lower odds of mental and complex multimorbidity (3 LTCs) at the 0.05 significance level. Notably, the protective associations for blue spaces remained robust after adjustment for multiple testing, with a 1% increase in blue space within 3000m buffer linked to a 3% reduction in the odds of complex multimorbidity (OR: 0.97; 95% CI: 0.95–0.98; p=0.0002). By contrast, total green space within a 1500m buffer showed weak associations with higher odds of multimorbidity (four or more LTCs) after the Bonferroni correction (OR: 1.01; 95% CI: 1.00–1.01; p=0.00005). Other natural features, such as parks, street trees, domestic gardens, and proximity to the coast, had no significant effects. These findings underscore the utility of linked datasets for advancing our understanding of how diverse natural spaces influence health and highlight inland blue spaces as a potential priority for urban planning and public health interventions.

Our findings contribute to an emerging area of research on the roles of non-coastal blue spaces on chronic health in older adults, which remains largely understudied in the literature.48,49 There could be several reasons why inland blue spaces showed a positive effect on multimorbidity in our study. First, it could be due to improved well-being. Although there is still very little research on the mediating factors in the relationship between inland blue spaces and multimorbidity, prior studies suggest that natural and public open spaces improve well-being in older adults by increasing social cohesion and reduce loneliness.50,51 Individuals with multimorbidity might have poor well-being due to isolation, disability and reduced physical functioning. However, blue spaces can mitigate some of these factors by reducing stress and providing opportunities for socialisation and group physical activities. Another potential reason for our findings might be the improvements in mental health that are driven by exposure to inland blue spaces. Evidence from British populations strongly suggests that blue spaces are more beneficial for mental health rather than physical health, possibly due to their calming and restorative properties.15,52–54 Although we found that greater availability of inland blue space is associated with lower odds of complex multimorbidity, this relationship may be influenced by individuals with co-occurring mental health conditions. Our findings revealed that inland blue spaces, rather than coastal areas, were associated with a positive impact on multimorbidity. This contrasts with previous research suggesting that living near or visiting the coast is generally linked to better physical and mental health among UK adults. 55 One reason for this might be due to individual preferences and the location of urban water bodies. UK Biobank participants predominantly live in cities built on rivers that stretch across the city centres. This could imply that the associations between amount of inland blue space and multimorbidity observed in our study might be specific only to urban populations that have frequent, incidental and convenient encounters with inland blue spaces during day-to-day life. Individuals with multimorbidity might also have limited mobility, which can make travelling and accessing the coast difficult.

It is not entirely clear why we observed significant associations with exposure to blue space but not exposure to both green and blue space, or exposure to street trees and domestic gardens, as all of these natural spaces have been hypothesised to promote health through similar pathways.14 Prior research in the UK Biobank and other HIC populations has shown that street trees and domestic gardens reduced the risk of poor mental health and cardio-vascular disease mortality.56,57 Domestic gardens might be particularly beneficial to older adults with multimorbidity because of their easy access and immediate proximity to the home. The health benefits of domestic gardens in older adults have been previously noted, and include improved mental health and lower risk of having CVD, and diabetes.58–60 The absence of similar relationships in our study may be explained by the residential characteristics of our predominantly urban sample. Participants were more likely to live in apartments, inner-city terraced properties, or assisted living homes, which often feature small, decorative, or communal front gardens that are not easily accessible or usable for individuals with limited physical functioning. Additionally, preferences and perceptions of safety could contribute to the non-significant findings for green spaces.44 Qualitative studies on European urban dwellers indicate that inland water bodies, even those located within public parks, are generally preferred over green spaces for recreation and socialisation. .61,62

**4.2 Implications for research, policy and practice**

This study has several implications for research and policy. First, this foundational knowledge should be used to guide life course research into the roles of blue spaces on the development of multimorbidity. Multimorbidity is a chronic health state that is shaped by certain behavioural and economic factors that occur during critical timepoints in an individual’s early and mid-life.26,63 Future research should employ a longitudinal approach to assess the mediating effects of other socio-behavioural and environmental factors, such as exposure to air pollution and physical activity at a young age. Assessing the ways exposure to nature from conception and throughout early and mid-life shapes these trajectories can help our understanding of the different underlying causal mechanisms and guide the design of appropriate interventions. Research should also focus on examining individual perceptions and use of such spaces, as those might be determining factors in the relationship.

Second, this study has implications for urban policy and planning. Currently, cities are faced with the challenge of the triple burden of non-communicable diseases, ageing and climate change.64 WHO’s sustainable cities framework and the Millenium Sustainable Development Goals (SDGs) emphasise on the need of diverse natural urban spaces that are equitable, safe and accessible for those who need them most.64 Traditionally, sustainable cities initiatives have focused on greenery as a way to improve health and mitigate the effects of climate change65, possibly due to lack of explicit policy guidelines on safe and sustainable blue spaces.66 Our study contributes to an emerging literature that highlights the need for more evidence-based policy guidelines on urban blue space. Urban policy on blue space should focus on several things. First, a diverse range of stakeholders, including women, individuals of ethnic minorities and individuals of low socio-economic status, should be included in decision-making. Three decades ago, inner-city canal and river regeneration across major UK cities resulted in improved pedestrian accessibility and larger investment into post-industrial and derelict areas.67–70 However, the rise of gentrification displaced marginalised communities. Individuals of high socio-economic status now spend more time near urban waterways than individuals of low socio-economic status, even if they live further away from such spaces.71,72 Ensuring the voices of those who benefit most from natural spaces are heard and accounted for is the first step to building healthy and resilient cities.73 Second, policy on blue spaces should focus on providing co-benefits to health and well-being.74 Increasing the availability of inland blue spaces in cities is resource intensive, so urban water bodies should be designed in ways that increase social well-being, improve air and noise quality, and mitigate some of the effects of climate change, such as lowering temperatures and reducing flood risk.74

**4.3 Strengths, limitations and conclusions**

This study has multiple strengths. First, it is one of the first studies to assess the relationship between exposure to green and blue spaces with multimorbidity. Previously, green-blue space research has focused on assessing individual health conditions, an approach that failed to address the true impact natural space on the burden of non-communicable diseases. We also conducted in-depth assessment into multimorbidity by identifying highly prevalent multimorbidity clusters, which expanded the scope of our research to focus on studying the effect of green and blue spaces on disease combinations that have the greatest impact on individual quality of life and healthcare use. Previously, multimorbidity has been measured solely as disease counts, an approach that can miss prevalent and highly lethal disease combinations.3,7 Through a systematic review of multimorbidity clusters, we assessed whether green and blue spaces have varying impacts on different disease combinations. These findings provide valuable insights for future research and public health policy, enabling the design of targeted interventions and treatments for individuals with specific multimorbidity profiles.

Another strength of our study is the novel modelling of green and blue space data from Urban Atlas, which enabled us to comparatively study the effects of different types of green and blue spaces in a large population sample. Modelling individual exposure data and integrating it to the residential location of UK Biobank participants created a rich resource for data analysis that overcomes challenges commonly associated with large-scale nature-health studies, such as the use of aggregate exposure data (data linked at LSOA level). The UK Biobank is a multi-purpose cohort, originally established to study the effects of different lifestyle and environmental factors on human health. As it was not established with the sole purpose of studying the effects of the natural environment on health, information on participants’ green and blue space exposure is vague (measures of overall greenness, like NDVI). By using Urban Atlas data, however, we were also able to model and distinguish between specific types of green and blue spaces and identify novel relationships with inland blue spaces that might have been previously missed due to lack of differentiated green and blue space data.1,6,7,75 This approach enables us to contribute findings to a growing literature on the health benefits of rivers, lakes and canals, and provide clearer directions for future evidence-based research that can inform policy and practice.11,76,77 Additionally, the use of Urban Atlas data to model green and blue spaces for the UK Biobank facilitates future analyses of exposure change over time. Although our study was cross-sectional, the UK Biobank cohort is growing through continuous follow-up data collection and re-assessments. As Urban Atlas data was also collected periodically (for the years 2006, 2012 and 2018), it can allow measures of change of availability and accessibility of green and blue spaces over time. This can help future research understand the different causal pathways contributing to the health effect blue spaces. Finally, we ensured that our analyses were robust by taking into consideration the effect of testing multiple hypotheses and adjusting for that with the Bonferroni correction, which reduced the probability of getting false positive results.

Although our study has plentiful strengths, it is not without its limitations. While we comparatively analysed relationships with different types of green and blue spaces, we did not measure use, accessibility, or quality of surrounding natural spaces. Newer research suggests that measuring availability of blue spaces is not enough to understand the underlying mechanisms behind nature-health relationships, and that other factors like use, perceptions of safety and cleanliness are likely to influence the health benefits individuals gain from their natural spaces.78,79 Assessing use and perceived quality of the natural environment, however, imposes methodological challenges for population-level health analyses due to large sample sizes. Currently, very few population-based UK cohorts contain information on perceptions and use of the natural environment. Furthermore, our analyses did not account for duration of residence at current address. Multimorbidity is a health state that develops slowly over time, which means exposure to green and blue spaces might be beneficial only at critical timepoints during an individual’s life. The UK Biobank currently contains information on duration at current residential address, which could be used in the future to study the impact of exposure duration on health.

Additionally, inaccuracies in our green and blue space exposure measures might have been introduced due to computational resolution. We used a 50m spatial resolution for all UA green and blue space measures except street trees, which could have led to an underestimation of the total availability of green and blue spaces in the neighbourhood, especially in smaller buffer sizes like 300m. Measures of inland blue spaces might have been particularly affected by this because urban areas often contain small, narrow and fragmented water bodies, such as canals, garden ponds and lakes.

Another limitation of the exposure measurement approach might be choice to use circular buffers rather than road network buffers and travel time. While the circular buffer approach is well-suited for large-scale data analysis, it does not account for the physical accessibility of green and blue spaces, which may play a key role in their relationship with health outcomes.80 To estimate walkable neighbourhoods, we used a 1500m buffer, reflecting the average distance adults can walk in 15 minutes.41 However, we recognise that individuals with multimorbidity, particularly those with respiratory conditions, may face significant mobility challenges, making it difficult to walk such distances. This limitation raises important questions about whether our approach adequately accounts for physical accessibility and highlights potential causality issues in modelling access to green and blue spaces. The UK Biobank cohort includes average walking speed data for a subset of participants, which could have been integrated as a proxy for physical functioning. However, walking speed alone does not fully capture the complexity of mobility limitations, which might be driven by mental and social factors as well as physical symptoms.82 To address these concerns, we conducted sensitivity analyses using a smaller 300m buffer to approximate access for individuals with limited physical functioning. These analyses revealed no significant differences in results, suggesting that the overall associations between green and blue spaces and health outcomes were robust to buffer size adjustments. Nonetheless, future research should aim to adopt more sophisticated methods for modelling accessibility. For instance, integrating measures such as road-network distances or travel times could offer a more accurate representation of the everyday challenges faced by individuals with multimorbidity. Such refinements have the potential to enhance our understanding of how physical and social accessibility contribute to health outcomes.

Additionally, our study may be further limited by the exclusion of participants with incomplete or missing exposure data.. A large source of missing exposure data was driven by the decision to exclude participants whose buffers fell outside of the data boundary of the UA. This approach was considered robust in ensuring accurate exposure measures, but missing exposure data could have been derived for those participants by overlaying the UA with larger green and blue space datasets, such as the CORINE and NDVI. Ultimately, we decided against this approach because it could compromise the accuracy of measures due to resolution and timing differences.

Another limitation of this study might be handling of missing data. UK Biobank participants with missing environment, confounder and outcome data were excluded from the analyses. Multiple imputations could have been conducted to derive some of the missing values, but that approach was deemed inappropriate because it was not possible to obtain and model all the socio-demographic and clinical variables that predict and influence the causes of the missing data. Finally, our results may not be generalisable to the entire British population because the UK Biobank sample might suffer from healthy volunteer bias. This was particularly expressed in our multimorbidity prevalence analyses, which showed that the prevalence of respiratory and mental multimorbidity in UK Biobank was much lower compared to that of other HIC populations.22 The UK Biobank, however, was chosen for its large sample size and availability of environment and covariate data which facilitated the execution of the analyses, which can be used as foundational knowledge for future causal research.

In conclusion, our cross-sectional assessment of the relationships between different urban green and blue space exposures with simple, complex, cardio-metabolic, respiratory, and mental multimorbidity showed that higher amount of inland water body space reduced the odds of complex multimorbidity even after adjustment for multiple testing. This research provides foundational knowledge on the impact of urban blue spaces on chronic health in middle-aged and older adults, which could guide public health practice and urban regeneration interventions.

**Ethics approval**

Researchers do not require a separate ethics approval to use UK Biobank data and are covered under the UK Biobank ethics approval by the [North West Multi-centre Research Ethics Committee (MREC)](https://www.hra.nhs.uk/about-us/committees-and-services/res-and-recs/search-research-ethics-committees/north-west-haydock/) as a Research Tissue Bank. This project was approved by the UK Biobank’s Access Management System (AMS), application no. 73700, and grants access to restricted UK Biobank Fields 22701 and 22703 (*home location – east coordinate* and *home location – north coordinate*).

**Declaration of interests**

We declare no competing interests.

**Data availability**

Data fields derived from this study and all other data underlying this article are owned by UK Biobank and can be accessed with an approved project application from the UK Biobank’s Access Management System (AMS). Raw environment data from Urban Atlas is open access and available from European Environment Agency.

**Supplementary material**

Provided as Appendix.

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