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# Investigating the association between regeneration of urban blue spaces and risk of incident chronic health conditions stratified by neighbourhood deprivation: A population-based retrospective study, 2000–2018

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## ABSTRACT

Chronic non-communicable diseases are leading causes of poor health and mortality worldwide, disproportionately affecting people in highly deprived areas. We undertook a population-based, retrospective study of 137,032 residents in Glasgow, Scotland, to investigate the association between proximity to urban blue spaces and incident chronic health conditions during a canal regeneration programme. Hazard ratios (HRs) were estimated using Cox proportional hazards models adjusted for age and sex, with the incidence of a given health condition as the dependent variable. The analyses were stratified by socioeconomic deprivation tertiles. We found that, in areas in the highest deprivation tertile, proximity to blue space was associated with a lower risk of incident cardiovascular disease (HR 0.85, 95% Confidence Interval (CI) 0.76–0.95), hypertension (HR 0.85, 95% CI 0.79–0.92), diabetes (HR 0.88, 95% CI 0.83–0.94), stroke (HR 0.85, 95% CI 0.77–0.94) and obesity (HR 0.90, 95% CI 0.86–0.94), but not chronic pulmonary disease, after adjusting for age and sex covariates. In middle and low deprivation tertiles, living closer to the canal was associated with a higher risk of incident chronic pulmonary disease (middle: HR 1.56, 95% CI 1.24–1.97, low: HR 1.34, 95% CI 1.05–1.73). Moreover, in the middle deprivation tertile, a higher risk of stroke (HR 1.36, 95% CI 1.02–1.81) and obesity (HR 1.14, 95% CI 1.01–1.29) was observed. We conclude that exposure to blue infrastructure could be leveraged to mitigate some of the health inequalities in cities.

## 1. Introduction

Chronic non-communicable diseases, including heart disease and diabetes, are leading causes of poor health, disability, and premature death (aged <70 years) globally (World Health Organisation, 2020a). Non-communicable diseases are responsible for over 70% of all deaths worldwide (World Health Organisation, 2020b), but the expanding burden of these conditions is not equally distributed across societies. Instead, there is a strong socioeconomic gradient in chronic diseases resulting in marked health inequalities (Sommer et al., 2015).

It is a widely held view that urbanisation is a major contributor to the

rising burden of chronic diseases (Patel and Burke, 2009). Over half of the global population lives in urban areas, which is expected to increase to 68% by 2050 (United Nations and Department of Economic and Social Affairs, Population Division, 2018). While there are many recognised advantages of living in urban settings, including its beneficial economic effects, urbanicity is increasingly considered to adversely affect common risk factors for chronic diseases, such as higher body-mass index and cholesterol levels (Goryakin et al., 2017). These challenges to health and wellbeing, linked to urbanisation, have sparked a growing interest in improving the natural and built environment to not only reduce the negative impacts of urbanisation, but also to positively promote good

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health and prevent disease, by reconnecting urban planning and public health (Pinter-Wollman et al., 2018).

A growing body of evidence suggests that natural environments have an important role to play in promoting health in urban areas (Garrett et al., 2019, 2020; World Health Organisation, 2016). Most of the research on the health benefits of urban natural environments has focused on green spaces, which have been linked to physical and psychological health benefits through promoting physical activity, stress alleviation, encouraging social cohesion, and mitigating exposure to environmental hazards (Stadler et al., 2017). More recently, it has emerged that living near urban water environments such as rivers, canals and lakes (“blue spaces”) may also offer important health advantages. Epidemiological studies have found that living closer to urban blue spaces is associated with lower psychological distress (Nutsford et al., 2016), lower all-cause mortality (Tieges et al., 2020) and heat-related mortality (Burkart et al., 2016), and reduced exposure to air pollution (McNabola et al., 2008).

The mechanisms that drive the associations between blue space and health are not well understood. A recent systematic review and meta-analysis on these mechanisms concluded that there was evidence to indicate that blue space may increase physical activity, enhance restoration (e.g., through lowering stress levels) and improve environmental factors (Georgiou et al., 2021). The protective effects of physical activity against chronic diseases such as heart disease, stroke and obesity are well established (e.g., Cleven et al., 2020; Kraus et al., 2019; Kyu et al., 2016). Similarly, psychological stress is a predictor for future disease outcomes including cardiovascular disease and obesity (Turner et al., 2020). It has therefore been speculated that the pathway through physical activity and stress reduction may provide a plausible explanation for the observed associations between blue space and disease risk, though the evidence is relatively mixed. More specifically, a systematic review assessing the association between objectively measured physical activity and parks found that the majority of studies reported no associations or mixed associations (Bancroft et al., 2015). This may be due, in part, to methodological heterogeneity and insufficient accounting for possible effect modifiers such as dog ownership and socioeconomic status (e.g. White et al., 2018). Of note, most of these studies have focused on beach and coastal (i.e. non-inland) waters, rather than urban waters (Gascon et al., 2017). Further research is needed to uncover the relationship between blue spaces and health through mechanisms of physical activity.

Relatively few studies have examined the association between exposure to blue space and risk of chronic health conditions such as obesity, diabetes and cardiovascular disease, and findings have been mixed. A systematic review of quantitative studies of blue spaces and health concluded that the evidence base was limited, with significant heterogeneity observed across studies (Gascon et al., 2017). According to the authors, their results highlighted a clear need for longitudinal studies to deepen understanding of this field. A more recent systematic review and meta-analysis (Smith et al., 2021) found a beneficial association between urban blue spaces and obesity, but no studies focused on diabetes, cardiovascular or respiratory diseases, or other chronic health conditions. Thus, there is a paucity of research on the impact of urban blue spaces on chronic health conditions and how these effects are distributed across levels of socioeconomic deprivation.

We set out to examine the association between urban blue spaces and incident chronic health conditions by socioeconomic neighbourhood status. To this end, we undertook a population-based observational retrospective study over a 19-year period of canal regeneration (2000–2018) from complete closure and dereliction to reopening in North Glasgow in Scotland, United Kingdom, using routine patient-level healthcare data from electronic primary care data sources. Glasgow contains some of the poorest and unhealthiest areas in Scotland, with morbidity and mortality rates among the worst in Western Europe even after accounting for levels of socioeconomic deprivation (the so-called “Glasgow effect”) (Hanlon et al., 2005; Livingston and Lee, 2014).

Moreover, residents in Glasgow’s highest deprivation areas have a lower life expectancy and increased risk of poor health outcomes compared to those living in lower deprivation areas, indicating clear geographical health inequalities in the city (Maantay, 2017). The canal regeneration project in this area (including paths, bridges, mobility infrastructure, sporting and community facilities, and aesthetics) provides a unique opportunity to investigate the association between residing in proximity to urban blue spaces and socioeconomic deprivation on chronic health conditions.

## 2. Methods

The study was reported according to ‘STrengthening the Reporting of OBServational studies in Epidemiology’ (STROBE) guidelines (von Elm et al., 2007).

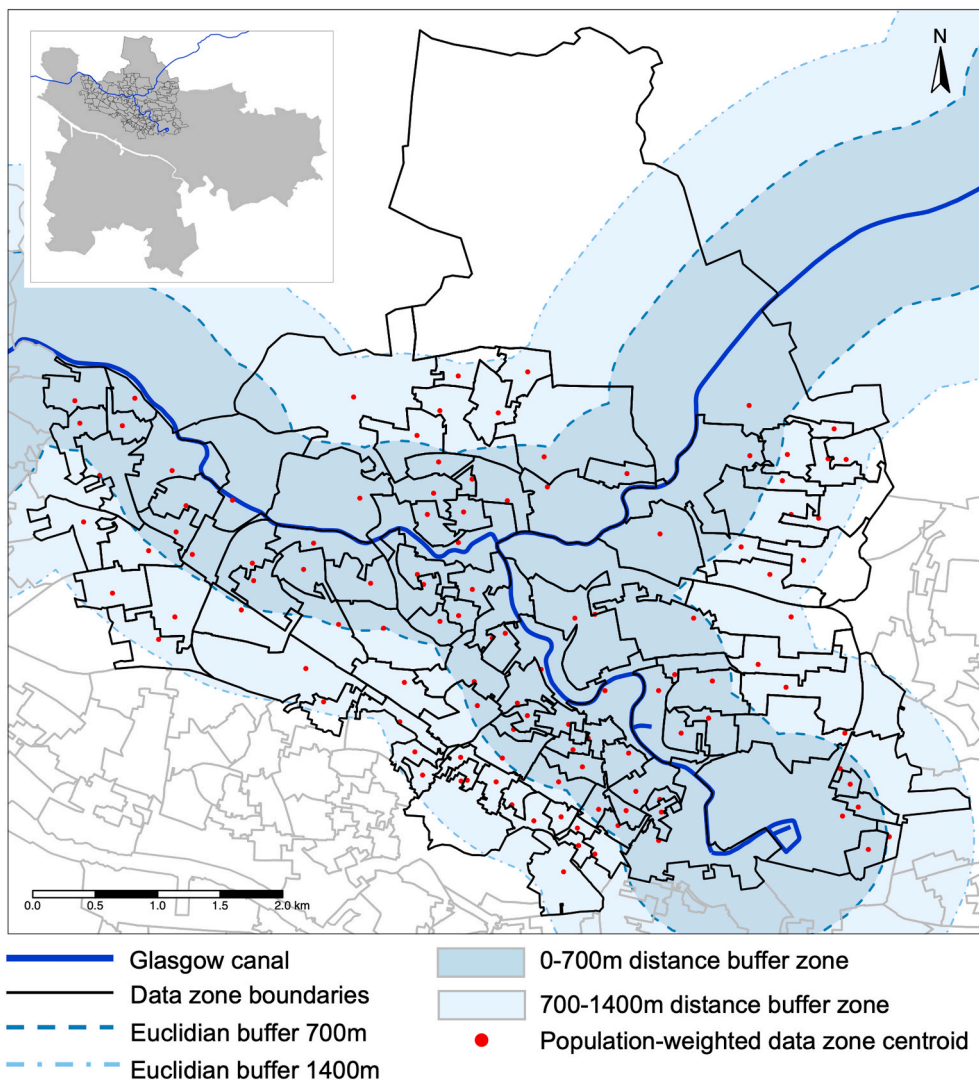
### 2.1. Study setting

Glasgow is the most populous city of Scotland, with a population of 578,710 according to the 2001 UK Census (Office for National Statistics, 2011). The study setting and area is described in detail elsewhere (Tieges et al., 2020). In brief, the study area encompassed the canal network that runs through the North of Glasgow (area 33 km<sup>2</sup>), including the Glasgow Branch of the Forth and Clyde Canal, where most of the regeneration occurred (Fig. 1). At the start of the study period, the soft towpaths along the canal were upgraded (years 2000–2003), providing a traffic free active travel route for walkers, wheelers and cyclists. This was followed by towpath upgrades from soft to hard construction (years 2007–2017). Other key aspects of the canal programme included: locks, footbridges and passage ways to provide vital connections for pedestrians and cyclists between the North of Glasgow and the City Centre, such as the passage under the M8, the Speirs Wharf footbridge and the Stockingfield Bridge; Pinkston water sport, Scotland’s first urban wake park with facilities for professional athletes, alongside community programmes; the ‘Smart Canal’, a pioneering new digital surface flood mitigation system; refurbishment and repurposing of buildings including the Whisky Bond offering studios, offices, coworking and social spaces; and placemaking events such as the annual Glasgow Canal Festival (Fig. 2). The Glasgow city boundary was taken as upper boundary (North), and the M8 motorway which separates North Glasgow from the City Centre as lower boundary (South) (Transport Scotland, 2013).

### 2.2. Data sources

Aggregate-level census data on neighbourhoods (data zones) were obtained. Data zones are the core small area geographical units used in Scotland, with a total of 6,505 data zones created from the 2001 Census (Office for National Statistics, 2011). Data zones are groups of Census output areas, with a population of around 500–1,000 household residents. They nest within local authority boundaries (council areas), and where possible, they have been designed to consider physical boundaries and natural communities and reflect households with similar socioeconomic characteristics. The study area in North Glasgow comprised 149 of the 694 Glasgow data zones. Data zone polygon boundaries and centroid shapefiles were obtained from National Records of Scotland.

National Records of Scotland data were linked to routine general practice (GP) population health data within the National Health Service (NHS) administrative area of Greater Glasgow and Clyde, held within the NHS Scotland Information Services Division Safe Haven. Specifically, the Local Enhanced Service (LES) database from GP surgeries was used. The LES refers to a Scotland-wide scheme aimed at providing a financial incentive to improve clinical and process outcomes in primary care. The criteria for the LES and the data capture templates were generated by the Greater Glasgow and Clyde Health Board which covers all areas included in the study. This LES database captures patient



**Fig. 1.** Glasgow City's 694 data zones according to the 2001 Scotland Census and the Glasgow canal (blue line) comprising (a) the Forth and Clyde canal and (b) the Glasgow branch. The study area is split into two distance buffers: 0–700m (dark blue shaded) and 700–1400m (light blue shaded). These are based on the Euclidian distance from the population-weighted centroids of data zones (red dots) to the nearest portion of the canal. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

information recorded from the Scottish Primary Care Information Resource, a service which provides primary care data for Scotland as a whole (Health Informatics Research Advisory Group, 2015). In the UK NHS, most people are registered with a GP surgery. GPs in the UK hold patients' entire healthcare records and receive correspondence from secondary care providers, including outpatient clinic letters and hospital discharge summaries. Important events and diagnoses on the patient's medical path should therefore be coded into the GP record (Metcalf et al., 2019). Thus, the GP database provides a central, integrated repository with comprehensive data available on patients' medical history.

Data linkage was conducted by NHS Greater Glasgow and Clyde Safe Haven based on the Community Health Index (CHI) number which is a single patient identifier throughout NHS Scotland. We subsequently linked the data zones where a person resided to socioeconomic deprivation status according to Scottish Index of Multiple Deprivation (SIMD) measures (Scottish Government, 2004).

### 2.3. Ethical approval and data security

We obtained study approval from the NHS Greater Glasgow and Clyde Safe Haven team and the Local Privacy Advisory Committee (reference: GSH/19/SS/002); the NHS Greater Glasgow and Clyde Safe Haven operates under delegated ethical approving powers from the West of Scotland Research Ethics Committee. Caldicott approval for re-

use of data was in place. The study adhered to strict information governance and security protocols. Databases were de-identified within the Safe Haven before being securely transferred to a secure workspace in the Aridhia digital research platform (AnalytiXagility). Data access was restricted to three named researchers (ZT, MG and SCZT).

### 2.4. Data variables

#### 2.4.1. Outcome variables: chronic health conditions

The GP LES database provides data on clinical events which refer to any form of diagnosis, measurement, reading, prescription, medication or other clinical finding recorded in the patient's medical history. This includes the dates of these clinical events, events coded as Read Codes (see below) and descriptions for each event as well as the data zone for patients.

Read Codes are a national standard code thesaurus of clinical terms for recording all relevant information from a patient encounter (Information Services Division Scotland, 2020). Read Codes were developed and maintained by the Health and Social Care Information Centre based in Leeds. They are used by GPs throughout the UK NHS. GP practices in Scotland use 5-byte Version 2 Read Codes which are based on International Classification of Diseases (ICD-9-CM) diagnosis and procedure codes from the World Health Organization (World Health Organization, 1978).

We used the algorithm developed by Metcalf et al. (2019) to





**Fig. 2.** Schematic diagram of the timeline of the canal regeneration programme in the North of Glasgow City from complete closure and dereliction to reopening in North Glasgow in Scotland.

determine comorbidity indices from Read Coded administrative databases. Metcalfe et al. generated code lists for both the Charlson Comorbidity Index (CCI) (17 categories) and the Elixhauser Method (31 categories), and they showed that the Elixhauser codes outperformed the CCI codes in predicting hip fracture mortality. Hence, we used the Elixhauser code lists in our study.

We were interested in the following chronic health conditions: chronic pulmonary disease, obesity, diabetes, cardiovascular disease, hypertension and stroke. For the category 'cardiovascular disease', we merged three Elixhauser categories: congestive heart failure, cardiac arrhythmia and valvular disease. Data on stroke were derived from the Elixhauser category 'other neurological disorders', by selecting events with verbal descriptions that matched stroke-related events (Table A.1; Appendix A).

#### 2.4.2. Population sample

From 1,949,017 IDs held in the database during the study period 2000–2018, we excluded IDs of people who died or transferred out of the area in 2000, because we were interested in the health of individuals who lived in the canal region when the canal restoration commenced in 2000. We only included IDs of people aged 20–100y at the start of the study period, because most health conditions of interest are not common in children and teenagers.

#### 2.4.3. Socioeconomic deprivation

Deprivation was measured via the 2004 Scottish Index of Multiple Deprivation (SIMD) which is the Scottish Government's first edition of the SIMD and covers the years 2001–2003 (Scottish Government, 2004). SIMD identifies concentrations of multiple deprivation at the small area (data zone) level across six domains: income, employment, housing, health, education, and geographic access. The SIMD is the recommended measure for monitoring health inequalities (Scottish Government, 2018).

We ranked SIMD scores from highest to lowest for the 694 Glasgow data zones based on the 2001 Census. We expressed SIMD scores as tertiles, with the lowest tertile representing the most deprived areas in Scotland and the highest tertile representing the least deprived areas. Each person in the linked data set was assigned the SIMD tertile of their data zone.

#### 2.4.4. Other variables

Date of birth and death, sex, and age at the start of the study period (01-01-2000) were obtained from the National Records of Scotland (2021).

#### 2.5. Exposure: distance to the canal

The exposure in this study consisted of living near the canal system during a time of regeneration from complete closure and dereliction of canal assets to fully re-opened and navigable waterways. Euclidian (i.e. straight-line) distances were calculated between population-weighted centroids of individuals' data zones to the canal as a proxy for exposure to the canal, using the R package 'sf' (Pebesma, 2018). Data zones were grouped according to this distance in two 700 distance bins: 0–700m (proximal) and 700–1400m (distal) from the canal. The median area of included data zones was 0.13 km<sup>2</sup> (Inter-Quartile Range (IQR) 0.08–0.22 km<sup>2</sup>) and the median Euclidian distance from (non-population-weighted) data zone centroids to the corresponding data zone boundaries was 80 m<sup>2</sup> (IQR 52–123 m<sup>2</sup>).

#### 2.6. Statistical analysis

Analyses were conducted with R Version 3.6.1 (R Core Team, 2019). Categorical study variables were reported as counts and percentages of cases. Continuous variables were described by either mean and standard deviation (SD; for normal data) or medians and IQR non-normal data). Hazard Ratios (HRs) were estimated using Cox proportional hazards regression models, with the incidence of a given health condition as the dependent variable. Incidence was defined as time in months to first recorded clinical event for a given health condition from the start of the study period. Follow-up time was right censored on December 31, 2018. The main predictor was distance to the Glasgow canal: 0–700m and 700–1400m (reference category). We adjusted for the clustering of data (at the data zone level) through frailty modelling of the hazards in the Cox proportional hazards regression models. The HRs and 95% Confidence Intervals (CIs) in the clustering adjusted analyses were comparable to the findings from the main analysis with overlapping CIs. Here we report findings from the analysis without frailty modelling.

Age and sex were included as covariates in the model. The analysis

was stratified by SIMD tertile to explore the role of socioeconomic deprivation as a confounder or effect modifier of the association between distance to the canal and chronic health outcomes. HRs and 95% CIs were reported for each model and graphically represented in forest plots. We selected our final model based on compliance with the proportional hazards assumption using Schoenfeld residuals tests, and comparability of model results for different health conditions, whilst aiming for parsimonious models. Results for the final models are reported. Statistical significance was tested at  $p < 0.05$ .

Sensitivity analyses were performed to check for change in model coefficients according to (1) different starting points for the study period, specifically years 2002 and 2005, and (2) use of different distance bins (0–350m, 350–700m, 700–1050m, and 1050–1400m).

### 3. Results

#### 3.1. Population characteristics

The study sample comprised 137,032 people who lived within 1400m of the canal in North Glasgow during the study period (Fig. 3 and Table 1). The distance bins 0–700m and 700–1400m comprised 71,126 and 65,906 residents aged 20 or over at the start of the study period, respectively. In total, 93,522 (68.2%) of the study sample lived in areas of the highest socioeconomic deprivation tertile, 25,427 people (18.6%) lived in areas of the middle deprivation tertile, and 18,083 people (13.2%) lived in areas of the lowest deprivation tertile. Median age of the study sample was 43.5 years (IQR 31.9–60.2), and 66,530 (48.6%) were women. The population in the three deprivation tertiles were comparable in terms of demographic characteristics (Table 1).

#### 3.2. Association between proximity to urban blue space and incident chronic health conditions

In the population living within 1400m from the canal across the 2000–2018 study period, a total of 10,999 (8.0%) residents had at least one newly recorded chronic health condition during the study period;

this number was 8,477 (9.1%) for areas of the high deprivation tertile, 1,160 (4.5%) for the middle deprivation tertile and 1,362 (7.5%) for the low deprivation tertile. Overall, there were 1,726 (1.3%) newly recorded cases of cardiovascular disease, 4,179 (3.0%) new cases of hypertension, 4,438 (3.2%) new cases of diabetes, 2,152 (1.6%) new cases of stroke, 3,800 (2.8%) new cases of chronic pulmonary disease, and 10,893 (7.9%) new cases of obesity.

First, we tested for modification of the association between proximity to the canal and chronic health conditions by socioeconomic deprivation, using likelihood ratio tests with adjustment for all other variables. This produced  $p$ -values  $< 0.001$  for each of the chronic health conditions, indicating strong statistical evidence of an interaction and therefore that stratification by socioeconomic deprivation tertile was appropriate (Table A.2; Appendix A).

Table 2 and Fig. 4 show the adjusted HR per chronic health condition (cardiovascular disease, hypertension, diabetes, stroke, chronic pulmonary disease, and obesity) as a function of proximity to the canal, stratified by socioeconomic deprivation. In the most deprived areas, living within 700m from the canal was associated with a 15% lower risk of incident cardiovascular disease relative to those living 700–1400m away from the canal (adjusted HR 0.85, 95% CI 0.76–0.95). By contrast, in the middle and low deprivation tertiles, living within 700m from the canal was not associated with a statistically significant change in risk of incident cardiovascular disease compared to living further away.

The findings for hypertension and diabetes showed broadly comparable patterns. In the most deprived areas, people living within 700m from the canal had a 15% lower risk of incident hypertension relative to living 700–1400m away (adjusted HR 0.85, 95% CI 0.79–0.92), and a 12% lower risk of incident diabetes (adjusted HR 0.88, 95% CI 0.83–0.94). Lower risk of new disease among those living proximal to the canal was not found in the middle and low deprivation tertiles.

For stroke, people living in the most deprived areas within 700m from the canal had a 15% lower risk of incident stroke compared to those living 700–1400m away (adjusted HR 0.85, 95% CI 0.77–0.94). By contrast, in the middle deprivation tertile, living within 700m from the canal was associated with a 36% higher risk of stroke (adjusted HR 1.36, 95% CI 1.02–1.81). A similar pattern of results was found for obesity: living  $< 700$ m from the canal was associated with a 10% lower risk of incident obesity in the most deprived areas (adjusted HR 0.90, 95% CI 0.86–0.94), whereas the risk was 14% higher for the middle deprivation tertile (adjusted HR 1.14, 95% CI 1.01–1.29).

Chronic pulmonary disease was the only condition where the risk of incident disease was not lower for people living within 700m from the canal relative to further away, at least in the most deprived areas. However, in the middle and low deprivation tertiles, living closer to the canal was associated with a 56% and 34% higher risk of incident chronic pulmonary disease, respectively (middle: adjusted HR 1.56, 95% CI 1.24–1.97; low: adjusted HR 1.34, 95% CI 1.05–1.73).

Sensitivity analyses using (1) different starting points for the study (years 2002 and 2005) and (2) use of 350m distance bins yielded comparable HRs to those obtained in the original models, with overlapping 95% CIs (see Fig. A.1 and Fig. A.2; Appendix A).

### 4. Discussion

In this population-based, observational retrospective longitudinal study of 137,032 residents using routinely collected healthcare data from a national Scottish primary care database, we investigated the association between proximity to urban blue spaces during a period of extensive regeneration. We found that, in areas of high socioeconomic deprivation, proximity to the Glasgow canal was associated with a lower incident risk of chronic health conditions after adjusting for age and sex covariates. Specifically, compared to people living 700–1400m away from the canal, those living within 700m from the canal had a 15% lower risk of incident cardiovascular disease, a 15% lower risk of incident hypertension, a 15% lower risk of incident stroke, a 12% lower risk

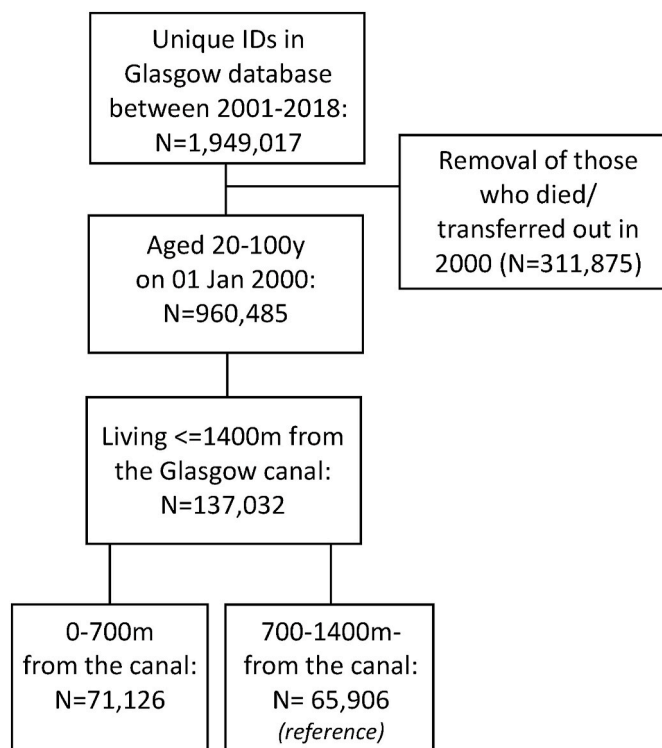


Fig. 3. Study flow diagram.

**Table 1**

Study sample characteristics. N: people included in the analysis (aged ≥ 20 years at the start of the study period). IQR: Inter-Quartile Range. SIMD: Scottish Index of Multiple Deprivation.

	N	Age (Median, IQR)	Sex (% F)	Cardiovascular disease		Hypertension		Diabetes		Stroke		Chronic pulmonary disease		Obesity	
				N	%	N	%	N	%	N	%	N	%	N	%
<b>Distance to canal</b>															
700–1400m	65906	39.8 (28.5–57.2)	48.3%	735	1.1%	1784	2.7%	1888	2.9%	919	1.4%	1451	2.2%	4431	6.7%
0–700m	71126	40.6 (29.0–58.2)	48.8%	991	1.4%	2395	3.4%	2550	3.6%	1233	1.7%	2349	3.3%	6462	9.1%
<b>Total</b>	<b>137032</b>	<b>43.5 (31.9–60.2)</b>	<b>48.6%</b>	<b>1726</b>	<b>1.3%</b>	<b>4179</b>	<b>3.0%</b>	<b>4438</b>	<b>3.2%</b>	<b>2152</b>	<b>1.6%</b>	<b>3800</b>	<b>2.8%</b>	<b>10893</b>	<b>7.9%</b>
<b>SIMD Tertile 1 (most deprived)</b>															
<b>Distance to canal</b>															
700–1400m	41757	43.2 (31.1–61.6)	49.5%	530	1.3%	1263	3.0%	1340	3.2%	673	1.6%	1218	2.9%	3265	7.8%
0–700m	51765	41.2 (29.3–60.0)	48.5%	743	1.4%	1820	3.5%	2003	3.9%	942	1.8%	2013	3.9%	5132	9.9%
<b>Total</b>	<b>93522</b>	<b>42.1 (30.1–60.8)</b>	<b>48.9%</b>	<b>1273</b>	<b>1.4%</b>	<b>3083</b>	<b>3.3%</b>	<b>3343</b>	<b>3.6%</b>	<b>1615</b>	<b>1.7%</b>	<b>3231</b>	<b>3.5%</b>	<b>8397</b>	<b>9.0%</b>
<b>SIMD Tertile 2 (middle deprived)</b>															
<b>Distance to canal</b>															
700–1400m	16891	31.4 (24.5–44.0)	43.5%	85	0.5%	242	1.4%	313	1.9%	87	0.5%	130	0.8%	603	3.6%
0–700m	8536	38.5 (28.0–53.3)	50.0%	91	1.1%	224	2.6%	245	2.9%	105	1.2%	171	2.0%	560	6.6%
<b>Total</b>	<b>25427</b>	<b>33.6 (25.2–47.2)</b>	<b>45.7%</b>	<b>176</b>	<b>0.7%</b>	<b>466</b>	<b>1.8%</b>	<b>558</b>	<b>2.2%</b>	<b>192</b>	<b>0.8%</b>	<b>301</b>	<b>1.2%</b>	<b>1163</b>	<b>4.6%</b>
<b>SIMD Tertile 3 (least deprived)</b>															
<b>Distance to canal</b>															
700–1400m	7258	41.8 (30.5–57.3)	52.4%	120	1.7%	279	3.8%	235	3.2%	159	2.2%	103	1.4%	563	7.8%
0–700m	10825	39.5 (29.0–54.0)	49.4%	157	1.5%	351	3.2%	302	2.8%	186	1.7%	165	1.5%	770	7.1%
<b>Total</b>	<b>18083</b>	<b>40.5 (29.5–55.2)</b>	<b>50.6%</b>	<b>277</b>	<b>1.5%</b>	<b>630</b>	<b>3.5%</b>	<b>537</b>	<b>3.0%</b>	<b>345</b>	<b>1.9%</b>	<b>268</b>	<b>1.5%</b>	<b>1333</b>	<b>7.4%</b>

**Table 2**

Results from Cox proportional hazards regression models adjusted for age and sex (reference: female), stratified by 2004 Scottish Index of Multiple Deprivation (SIMD), for cardiovascular disease, hypertension, diabetes, stroke, chronic pulmonary disease, and obesity. Model results are shown for SIMD Tertile 1 (high deprivation tertile), SIMD Tertile 2 (middle deprivation tertile), and SIMD Tertile 3 (low deprivation tertile) for a distance buffer of 0–700m the canal (reference: 700–1400m). HR: Hazard Ratio; CI: Confidence Interval.

Chronic health condition	Model covariates		HR (95% CI) and p-value		
			SIMD Tertile 1 (Most deprived)	SIMD Tertile 2 (Middle deprived)	SIMD Tertile 3 (Least deprived)
<b>Cardiovascular disease</b>	Distance (m)	< 700m	0.85 (0.76–0.95)**	1.21 (0.89–1.63)	1.07 (0.84–1.36)
	Age		1.07 (1.06–1.07)***	1.09 (1.08–1.10)***	1.08 (1.07–1.09)***
	Sex		1.48 (1.32–1.65)***	1.88 (1.37–2.56)***	2.19 (1.71–2.81)***
<b>Hypertension</b>	Distance (m)	< 700m	0.85 (0.79–0.92)***	1.07 (0.88–1.29)	1.06 (0.90–1.25)
	Age		1.03 (1.03–1.04)***	1.06 (1.05–1.06)***	1.05 (1.05–1.06)***
	Sex		1.04 (0.96–1.12)	1.39 (1.15–1.69)***	1.79 (1.52–2.12)***
<b>Diabetes</b>	Distance (m)	< 700m	0.88 (0.83–0.94)***	0.97 (0.82–1.15)	1.00 (0.84–1.19)
	Age		1.02 (1.02–1.02)***	1.05 (1.04–1.05)***	1.04 (1.03–1.04)***
	Sex		1.27 (1.20–1.34)***	1.49 (1.25–1.77)***	1.78 (1.49–2.13)
<b>Stroke</b>	Distance (m)	< 700m	0.85 (0.77–0.94)**	1.36 (1.02–1.81)*	1.01 (0.81–1.25)
	Age		1.05 (1.04–1.05)***	1.07 (1.06–1.08)***	1.07 (1.06–1.08)***
	Sex		1.08 (0.98–1.19)	1.30 (0.97–1.74)	1.66 (1.33–2.06)***
<b>Chronic pulmonary disease</b>	Distance (m)	< 700m	0.98 (0.91–1.05)	1.56 (1.24–1.97)***	1.34(1.05–1.73)*
	Age		1.03 (1.03–1.03)***	1.06 (1.05–1.07)***	1.05 (1.05–1.06)***
	Sex		0.91 (0.84–0.97)**	0.92 (0.73–1.16)	1.19 (0.93–1.52)
<b>Obesity</b>	Distance (m)	< 700m	0.90 (0.86–0.94)***	1.14 (1.01–1.29)*	1.08 (0.96–1.21)
	Age		1.02 (1.02–1.02)***	1.05 (1.04–1.05)***	1.05 (1.04–1.05)***
	Sex		1.08 (1.03–1.13)**	1.26 (1.12–1.43)***	1.74 (1.55–1.96)***

\*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001.

of incident diabetes, and a 10% lower risk of incident obesity. We did not find a similar pattern of results for chronic pulmonary disease. However, in the middle and low deprivation tertiles, living closer to the canal was associated with a 56% and 34% higher risk of chronic pulmonary disease, respectively. Moreover, in the middle deprivation tertile, a 36% higher risk of stroke and a 14% higher risk of obesity was observed. On the whole, these findings suggest that residential exposure to blue infrastructure was associated with a lower risk for non-communicable diseases in the most deprived areas. They also suggest a higher risk of disease in the middle and/or low deprivation tertiles, though estimates for these effects were less precise. This supports the view that blue spaces could have potential use in mitigating some of the health inequalities in urban communities most at risk.

Previously, it has been shown that living within 500m of the Glasgow canal during its regeneration was associated with a faster decline in mortality rates compared to more distal areas, at the small area level

(Tieges et al., 2020). Our present study using individual-level data supports and extends these findings, by showing that those living in the most deprived areas within 700m around the canal had lower risk of incident disease compared to those living further away.

Our findings are also consistent with previous reports suggesting that the health benefits of blue spaces may be greatest amongst more socioeconomically deprived regions. Specifically, using population area-level data, Wheeler et al. (2012) found better self-reported health with proximity to the coast in England which appeared to strengthen with increasing levels of deprivation. Similar conclusions have been drawn for green spaces; notably, Mitchell and Popham (2008) found that urban populations living in the greenest areas had the lowest levels of health inequality.

It is unclear why our study findings show the largest health benefits for the most deprived neighbourhoods, though stronger associations between green and blue spaces and aspects of health in participants

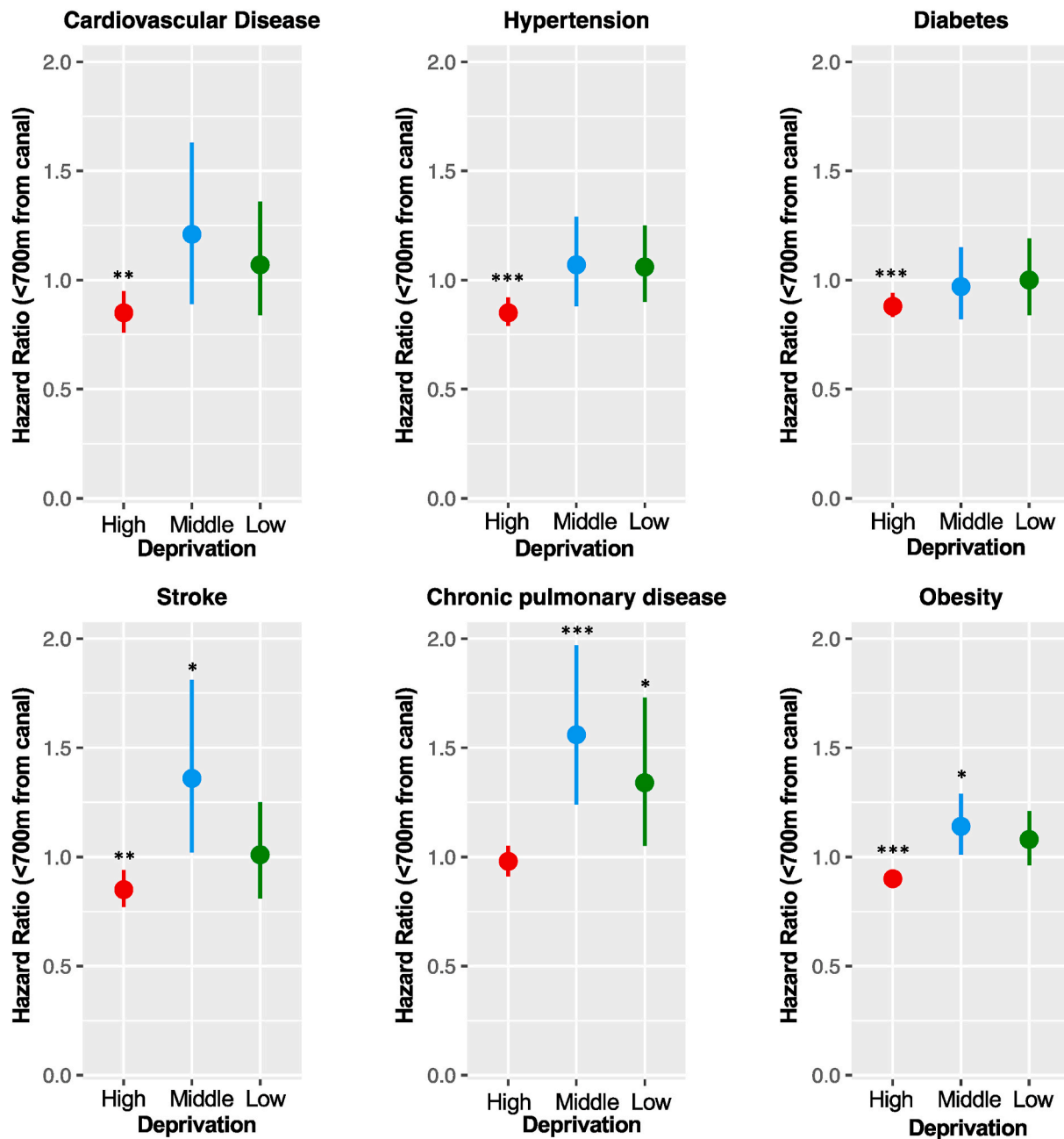


Fig. 4. Results from Cox proportional hazards regression models on the association between distance to the Glasgow canal (<700m vs. 700–1400m) and risk of incident chronic health conditions adjusted for age and sex (reference: female), stratified by 2004 Scottish Index of Multiple Deprivation (SIMD). Hazard ratios (95% CI) are presented for the high deprivation tertile (red), middle deprivation tertile (blue) and low deprivation tertile (green). Statistical significance: \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

living in areas with higher area deprivation have been previously reported (de Keijzer et al., 2019). One possible explanation for this finding is that residents of socioeconomically deprived neighbourhoods generally have worse health outcomes compared to residents of non-deprived neighbourhoods, including poorer physical health, higher risk of mental disorders and higher mortality rate; though these could also be ‘consequences’ of the more fundamental social inequalities that determine people’s health and their opportunities to move (Jokela, 2015). A second explanation may be that people living in the most deprived areas tend to have less blue-green space availability in their neighbourhood (Schule et al., 2019). Interventions to promote health may therefore have a comparatively larger impact in deprived areas, where there is more to gain.

Few studies have examined the impact of living near urban blue

spaces on the risk of chronic health conditions, and findings thus far have been mixed. A recent systematic review and meta-analysis on the association between urban blue spaces and human health reported a small but beneficial association with obesity cross-sectionally (Smith et al., 2021). A longitudinal population study in Finland found that living 500–750m versus <250 m from the nearest urban blue area increased the odds of being overweight (Odds Ratio (OR) 1.24; 95% CI 1.01–1.52), but not obesity. With regards to the association between blue spaces and other chronic health conditions, Smith et al. (2021) identified one paper of routine GP data which reported a beneficial association for prevalence of high blood pressure (OR 0.96; 95% CI 0.94–0.98) and diabetes (OR 0.94, 95% CI 0.91–0.98), but not for other morbidities such as cardiovascular disease, stroke and respiratory conditions (Zock et al., 2018). In another systematic review on blue spaces



and health, Gascon et al. (2017) concluded that the limited studies on obesity (8 studies), and cardiovascular disease (4 studies) and related outcomes provided inconsistent evidence for an association between exposure to blue space and these health outcomes.

Several studies have examined cause-specific mortality from chronic diseases in relation to blue spaces. In a large population-based cohort study of urban residents, Crouse et al. (2018) found reduced risks of mortality in the range of 12–17% associated with living within 250m of blue space compared to living more distally, and these protective effects were found to be highest against deaths from stroke (Cox regression, fully adjusted model: HR 0.83, 95% CI 0.77–0.91) and from respiratory-related causes (HR 0.84, 95% CI 0.78–0.90). Our findings are broadly consistent with regards to lower risk of stroke nearby the canal (adjusted HR 0.85, 95% CI 0.77–0.94), but not chronic pulmonary disease. To put our results further into context, statin drug therapy used for the prevention of heart attacks and strokes has been associated with a 0.71 relative risk of stroke (95% CI, 0.62 to 0.82) and a 0.70 relative risk of composite cardiovascular outcomes (95% CI, 0.63 to 0.78) (Chou et al., 2016); the magnitude of risk reductions in our study appears to be slightly smaller (HR of 0.85 both for stroke and cardiovascular disease) although causality of these associations was not shown.

It is unclear why we did not find a similar association for chronic pulmonary disease, which warrants further investigation. We speculate that the pathways through physical activity offer a plausible explanation for the observed associations between blue space and risk of cardiovascular disease, diabetes, obesity etc. (Cleven et al., 2020) but not chronic pulmonary disease. Physical inactivity is a major risk factor for cardiovascular disease mortality (Patterson et al., 2018), and the American Heart Association has identified sedentary behaviour as a leading preventable cause of death (e.g. Marcus et al., 2006). A recent systematic review of longitudinal studies of physical activity and chronic disease concluded that higher levels of physical activity are likely associated with a lower risk of becoming obese, develop coronary heart disease and diabetes. By contrast, chronic pulmonary disease is linked to other risk factors, primarily smoking but factors such as indoor and outdoor air pollution likely also play a role (e.g. Postma et al., 2015).

Additionally, the association between physical activity and incident hypertension is less consistent (Cleven et al., 2020). Instead, chronic psychosocial stress may play a key role in chronic hypertension, but more studies are needed to confirm this relationship (Liu et al., 2017).

#### 4.1. Strengths and limitations

This is the first population-based cohort study to examine the relationship between urban blue spaces and incidence of non-communicable diseases at the individual level; specifically, we included data from 137,032 individuals who were followed between 2000 and 2018, and we confirmed robustness of our findings through sensitivity analyses. A key strength of our study is the utilisation of an administrative primary care database, which contains comprehensive data on patients' entire medical history, in combination with a novel algorithm to extract relevant information on non-communicable disease diagnoses. The data were held in a controlled and secure Safe Haven to ensure strict data protection. The study was focused on an area of overall high deprivation in Glasgow, and results were stratified by socioeconomic area deprivation, which enabled a discussion around the potential role of blue spaces in tackling health inequality. Our findings add to the small body of evidence on the potential health benefits of urban blue-green spaces and their value for reducing health inequalities.

Several limitations are noted. Due to lack of data availability, we could not account for other health, lifestyle, or environmental factors in our models. There were fewer individuals living in areas of the middle and low deprivation tertiles than in areas of the high deprivation tertile, and wide confidence intervals indicated a relative lack of precision for findings in the middle and low deprivation tertiles. Still, the data are

comprehensive in terms of participant numbers and health events, and the time period covered.

Another study limitation is that health problems for which people did not contact their GP were not considered. We found incidence rates between 1.3% for cardiovascular disease to 7.9% for obesity, which likely represents an underestimate because not all diagnoses were included within each category, and some classifications may have changed over time (as pointed out by Metcalfe et al. (2019)). Moreover, non-attendance at GP practices in Scotland has been found to be most prominent in areas of low socioeconomic status, which may have confounded our study results (Ellis et al., 2017). More generally, obtaining accurate data on presence and onset of disease in the community is challenging and is not always absolute; individuals may not be aware of their health issues at first, and some diseases will be misdiagnosed by health professionals. We were among the first to use the approach proposed by Metcalfe et al. (2019) to extract information on non-communicable diseases from primary care databases, and this method requires further external validation. Some conditions, such as renal and liver disease, had relatively few recorded events, which precluded analyses of these health indices.

We stratified our analyses by widely used aggregate metrics of area-level deprivation, however the degree to which these are representative of individual deprivation status has been questioned (Ingleby et al., 2020). Further, although use of spatially aggregated units (data zones) is common in public health research where exact addresses are unavailable to protect individuals' privacy, a key issue with this approach is the potential for positional errors and exposure misclassification (Healy and Gilliland, 2012). Additionally, the degree of exposure misclassification may differ across deprivation categories compared, however this cannot be checked using the present study data. We used fixed, straight-line distances to estimate residents' proximity to the canal, which will likely have overestimated the provision and accessibility of the canal and surrounding greenness. Also, exposure to the canal at a neighbourhood level does not necessarily reflect exposure for individual residents, whose activity space may include other areas as well. With the appropriate data, we could have incorporated accessibility into our distance measure, although we would still not know whether individuals living closer to blue space used it more than those living further away.

We did not have data for migration and gentrification patterns, which are known to present significant methodological and conceptual challenges (Tulier et al., 2019), and so we were unable to quantify the effect of this factor to check for effect modification. Data on movers within the study area were also not available. Of note, the proportion of residents transferring out of their neighbourhood during the study period was similar for the most and least deprived tertiles (13.4% and 11.7%, respectively), though this does not rule out neighbourhood change linked to socioeconomic status of residents.

Finally, it could be argued that the economic recession in Scotland in 2008–2009, which led to a reduction in healthcare services and might have disproportionately affected areas of high deprivation, could have contributed to our findings. However, this is not what we found, because the number of GP events recorded in the database rose steadily over these years (from 72,895 events in 2007 to 88,862 events in 2011) and this pattern was observed both for the most and least deprived populations.

#### 4.2. Implications for research and policy

The use of the algorithm developed by Metcalfe et al. (2019) for extracting data on chronic health indices from administrative GP databases was a novel aspect of our study. Nevertheless, the new coding approach for GP administrative databases appears to be sufficiently robust and transparent and could be replicated for other exposures; it may help promote more consistent data extraction and reporting of these databases, which provide a rich but underused source of data for public health science in the UK.



Our findings suggest that the canal regeneration programme may have contributed to a beneficial change in the geographically unequal distribution of non-communicable disease risk and therefore towards a reduction in health inequality. If confirmed in future studies, policy-makers should consider these findings when conducting interventions in urban environments involving blue-green spaces. However, caution is warranted because we did not show causality between blue space and improved health outcomes, and confidence intervals were generally wide. Moreover, residual confounding from sociodemographic or geographical factors cannot be ruled out. Nonetheless, our findings suggest that blue urban spaces which promote good health may have an important role to play in reducing socioeconomic health inequalities.

Interestingly, a recent report from the Scottish Public Health Observatory, which works to improve Scotland's overall health and reduce health inequality, highlighted the need to consider improvements in people's immediate environment as one of the ways that health inequalities can be addressed (Public Health Scotland, 2021). Indeed, living in a disadvantaged neighbourhood has been associated with higher incidence of coronary heart disease independent of individual risk (personal income, education, and occupation) (Diez Roux et al., 2001), lending support to the idea that the physical environment of residence could be an important target for improving public health.

#### 4.3. Future research

We showed that routinely collected primary care databases constitute a powerful resource to investigate the health impact of blue infrastructure, and we would encourage use of these valuable and comprehensive resources in research.

Future studies should consider including data on lifestyle factors (e.g., smoking and physical activity), environmental factors (e.g., urban heat island and air quality) and individual-level deprivation measures. Specifically, the role of individual factors (e.g., education, employment and income) as effect modifiers of the association between blue spaces and health should be further explored. This would allow for a more complete picture of the impact of blue spaces on health in synergy with their use for economic development and climate adaptation.

Studies on the health impact of blue spaces should consider incorporating measurement of accessibility using network (i.e. route-based) distance buffers, which may be more appropriate for certain aspects of physical health research (e.g., physical activity) than Euclidian distance buffers (Labib et al., 2020). With regards to the canal regeneration programme, the location and timing of different types of assets such as paths, bridges, and mobility infrastructure could be considered in future studies; such an approach may uncover the influence of specific water infrastructure assets on health outcomes which, ultimately, could inform future development of inland urban waterways. Our findings suggest that living near urban blue spaces has important health benefits, but further research is needed to uncover the mechanisms by which these nature-based urban environments might affect public health.

#### 4.4. Conclusions

This study indicates that living near urban blue space may positively impact on risks of chronic diseases, specifically in areas of high socioeconomic deprivation. We conclude that canal restoration efforts could be leveraged to mitigate urban health inequalities for those most at risk. These potential health and health equity benefits of nature-based urban environments, and their synergistic impact on socioeconomic and climate resilience of cities and the quality of life of citizens, warrant further investigation.

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#### Declaration of competing interest

None.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijheh.2022.113923>.

#### References

- Bancroft, C., Joshi, S., Rundle, A., Hutson, M., Chong, C., Weiss, C.C., Genkinger, J., Neckerman, K., Lovasi, G., 2015. Association of proximity and density of parks and objectively measured physical activity in the United States: a systematic review. *Soc. Sci. Med.* 138, 22–30. <https://doi.org/10.1016/j.socscimed.2015.05.034>.
- Burkart, K., Meier, F., Schneider, A., Breitner, S., Canario, P., Alcoforado, M.J., Scherer, D., Endlicher, W., 2016. Modification of heat-related mortality in an elderly urban population by vegetation (urban green) and proximity to water (urban blue): evidence from Lisbon, Portugal. *Environ. Health Perspect.* 124, 927–934. <https://doi.org/10.1289/ehp.1409529>.
- Chou, R., Dana, T., Blazina, I., Daeges, M., Jeanne, T.L., 2016. Statins for prevention of cardiovascular disease in adults: evidence report and systematic review for the US preventive services task force. *JAMA* 316, 2008–2024. <https://doi.org/10.1001/jama.2015.15629>.
- Cleven, L., Krell-Roesch, J., Nigg, C.R., Woll, A., 2020. The association between physical activity with incident obesity, coronary heart disease, diabetes and hypertension in adults: a systematic review of longitudinal studies published after 2012. *BMC Publ. Health* 20, 726. <https://doi.org/10.1186/s12889-020-08715-4>.
- Crouse, D.L., Balram, A., Hystad, P., Pinault, L., van den Bosch, M., Chen, H., Rainham, D., Thomson, E.M., Close, C.H., van Donkelaar, A., Martin, R.V., Menard, R., Robichaud, A., Villeneuve, P.J., 2018. Associations between living near water and risk of mortality among urban Canadians. *Environ. Health Perspect.* 126, 077008 <https://doi.org/10.1289/EHP3397>.
- de Keijzer, C., Tonne, C., Sabia, S., Basagana, X., Valentin, A., Singh-Manoux, A., Anto, J. M., Alonso, J., Nieuwenhuijsen, M.J., Sunyer, J., Davdand, P., 2019. Green and blue spaces and physical functioning in older adults: longitudinal analyses of the Whitehall II study. *Environ. Int.* 122, 346–356. <https://doi.org/10.1016/j.envint.2018.11.046>.
- Diez Roux, A.V., Merkin, S.S., Arnett, D., Chambless, L., Massing, M., Nieto, F.J., Sorlie, P., Szklo, M., Tyroler, H.A., Watson, R.L., 2001. Neighborhood of residence and incidence of coronary heart disease. *N. Engl. J. Med.* 345, 99–106. <https://doi.org/10.1056/NEJM200107123450205>.
- Ellis, D.A., McQueenie, R., McConnachie, A., Wilson, P., Williamson, A.E., 2017. Demographic and practice factors predicting repeated non-attendance in primary care: a national retrospective cohort analysis. *Lancet Public Health* 2, e551–e559. [https://doi.org/10.1016/S2468-2667\(17\)30217-7](https://doi.org/10.1016/S2468-2667(17)30217-7).
- Garrett, J.K., Clitherow, T.J., White, M.P., Wheeler, B.W., Fleming, L.E., 2019. Coastal proximity and mental health among urban adults in England: the moderating effect of household income. *Health Place* 59, 102200. <https://doi.org/10.1016/j.healthplace.2019.102200>.
- Garrett, J.K., White, M.P., Elliott, L.R., Wheeler, B.W., Fleming, L.E., 2020. Urban nature and physical activity: investigating associations using self-reported and accelerometer data and the role of household income. *Environ. Res.* 190, 109899. <https://doi.org/10.1016/j.envres.2020.109899>.
- Gascon, M., Zijlema, W., Vert, C., White, M.P., Nieuwenhuijsen, M.J., 2017. Outdoor blue spaces, human health and well-being: a systematic review of quantitative studies. *Int. J. Hyg. Environ. Health* 220, 1207–1221. <https://doi.org/10.1016/j.ijheh.2017.08.004>.
- Georgiou, M., Morison, G., Smith, N., Tiegies, Z., Chastin, S., 2021. Mechanisms of impact of blue spaces on human health: a systematic literature review and meta-analysis. *Int. J. Environ. Res. Publ. Health* 18, 2486. <https://doi.org/10.3390/ijerph18052486>.
- Goryakin, Y., Rocco, L., Suhrcke, M., 2017. The contribution of urbanization to non-communicable diseases: evidence from 173 countries from 1980 to 2008. *Econ. Hum. Biol.* 26, 151–163. <https://doi.org/10.1016/j.ehb.2017.03.004>.

- Hanlon, P., Lawder, R.S., Buchanan, D., Redpath, A., Walsh, D., Wood, R., Bain, M., Brewster, D.H., Chalmers, J., 2005. Why is mortality higher in Scotland than in England and Wales? Decreasing influence of socioeconomic deprivation between 1981 and 2001 supports the existence of a 'Scottish Effect'. *J. Public Health* 27, 199–204. <https://doi.org/10.1093/pubmed/fdi002>.
- Health Informatics Research Advisory Group, 2015. A Health and Biomedical Informatics Research Strategy for Scotland. Scottish Government. <https://www.gov.scot/publications/health-biomedical-informatics-research-strategy-scotland/pages/4/>. (Accessed 24 February 2021).
- Healy, M.A., Gilliland, J.A., 2012. Quantifying the magnitude of environmental exposure misclassification when using imprecise address proxies in public health research. *Spat. Spatiotemporal Epidemiol.* 3, 55–67. <https://doi.org/10.1016/j.sste.2012.02.006>.
- Information Services Division Scotland, 2020. Coding and terminology systems. <https://www.isdscotland.org/products-and-services/terminology-services/coding-and-terminology-systems/>. (Accessed 2 February 2021).
- Ingleby, F.C., Belot, A., Atherton, L., Baker, M., Ellis-Brookes, L., Woods, L.M., 2020. Assessment of the concordance between individual-level and area-level measures of socio-economic deprivation in a cancer patient cohort in England and Wales. *BMJ Open* 10, e041714.
- Jokela, M., 2015. Does neighbourhood deprivation cause poor health? Within-individual analysis of movers in a prospective cohort study. *J. Epidemiol. Community Health* 69, 899–904. <https://doi.org/10.1136/jech-2014-204513>.
- Kraus, W.E., Powell, K.E., Haskell, W.L., Janz, K.F., Campbell, W.W., Jakicic, J.M., Troiano, R.P., Sprock, K., Torres, A., Piercy, K.L., Physical Activity Guidelines Advisory Committee, 2019. Physical activity, all-cause and cardiovascular mortality, and cardiovascular disease. *Med. Sci. Sports Exerc.* 51, 1270–1281. <https://doi.org/10.1249/MSS.0000000000001939>.
- Kyu, H.H., Bachman, V.F., Alexander, L.T., Mumford, J.E., Afshin, A., Estep, K., Veerman, J.L., Delwiche, K., Iannarone, M.L., Moyer, M.L., Cercy, K., Vos, T., Murray, C.J., Forouzanfar, M.H., 2016. Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ* 354, i3857. <https://doi.org/10.1136/bmj.i3857>.
- Labib, S.M., Lindley, S., Huck, J.J., 2020. Spatial dimensions of the influence of urban green-blue spaces on human health: a systematic review. *Environ. Res.* 180, 108869. <https://doi.org/10.1016/j.envres.2019.108869>.
- Liu, M.Y., Li, N., Li, W.A., Khan, H., 2017. Association between psychosocial stress and hypertension: a systematic review and meta-analysis. *Neurol. Res.* 39, 573–580. <https://doi.org/10.1080/01616412.2017.1317904>.
- Livingston, M., Lee, D., 2014. "The Glasgow effect?"—the result of the geographical patterning of deprived areas? *Health Place* 29, 1–9. <https://doi.org/10.1016/j.healthplace.2014.05.002>.
- Maantay, J.A., 2017. The collapse of place: derelict land, deprivation and health inequality in Glasgow, Scotland. In: Etingoff, K. (Ed.), *Urban Land Use: Community-Based Planning*. Apple Academic Press, Oakville, Canada, pp. 3–50.
- Marcus, B.H., Williams, D.M., Dubbert, P.M., Sallis, J.F., King, A.C., Yancey, A.K., Franklin, B.A., Buchner, D., Daniels, S.R., Claytor, R.P., American Heart Association Council on Nutrition, Physical Activity, Metabolism; American Heart Association Council on Cardiovascular Disease in the Young; Interdisciplinary Working Group on Quality of Care and Outcomes Research, 2006. Physical activity intervention studies: what we know and what we need to know: a scientific statement from the American heart association council on nutrition, physical activity, and metabolism (subcommittee on physical activity); council on cardiovascular disease in the young; and the interdisciplinary working group on quality of care and outcomes research. *Circulation* 114, 2739–2752. <https://doi.org/10.1161/CIRCULATIONAHA.106.179683>.
- McNabola, A., Broderick, B.M., Gill, L.W., 2008. Reduced exposure to air pollution on the boardwalk in Dublin, Ireland. Measurement and prediction. *Environ. Int.* 34, 86–93. <https://doi.org/10.1016/j.envint.2007.07.006>.
- Metcalfe, D., Masters, J., Delmestri, A., Judge, A., Perry, D., Zogg, C., Gabbe, B., Costa, M., 2019. Coding algorithms for defining Charlson and Elixhauser comorbidities in Read-coded databases. *BMC Med. Res. Methodol.* 19, 115. <https://doi.org/10.1186/s12874-019-0753-5>.
- Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet* 372, 1655–1660. [https://doi.org/10.1016/S0140-6736\(08\)61689-X](https://doi.org/10.1016/S0140-6736(08)61689-X).
- National Records of Scotland, 2021. Statistics and data. <https://www.nrscotland.gov.uk/statistics-and-data>. (Accessed 16 July 2021).
- Nutsford, D., Pearson, A.L., Kingham, S., Reitsma, F., 2016. Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. *Health Place* 39, 70–78. <https://doi.org/10.1016/j.healthplace.2016.03.002>.
- Office for National Statistics, 2011. 2001 Census Aggregate Data. May 2011, UK Data Service.
- Patel, R.B., Burke, T.F., 2009. Urbanization—an emerging humanitarian disaster. *N. Engl. J. Med.* 361, 741–743. <https://doi.org/10.1056/NEJMp0810878>.
- Patterson, R., McNamara, E., Tainio, M., de Sa, T.H., Smith, A.D., Sharp, S.J., Edwards, P., Woodcock, J., Brage, S., Wijndaele, K., 2018. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *Eur. J. Epidemiol.* 33, 811–829. <https://doi.org/10.1007/s10654-018-0380-1>.
- Pebesma, E., 2018. Simple features for R: standardized support for spatial vector data. *R J.* 10, 439–446. <https://doi.org/10.32614/RJ-2018-009>.
- Pinter-Wollman, N., Jelic, A., Wells, N.M., 2018. The impact of the built environment on health behaviours and disease transmission in social systems. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 373. <https://doi.org/10.1098/rstb.2017.0245>.
- Postma, D.S., Bush, A., van den Berge, M., 2015. Risk factors and early origins of chronic obstructive pulmonary disease. *Lancet* 385, 899–909. [https://doi.org/10.1016/S0140-6736\(14\)60446-3](https://doi.org/10.1016/S0140-6736(14)60446-3).
- Public Health Scotland, 2021. Impact of deprivation on health. <http://www.healthscotland.scot/health-inequalities/impact-of-ill-health/impact-of-deprivation-on-health>. (Accessed 20 March 2021).
- R Core Team, 2019. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>. (Accessed 10 February 2020).
- Schule, S.A., Hilz, L.K., Dreger, S., Bolte, G., 2019. Social inequalities in environmental resources of green and blue spaces: a review of evidence in the WHO European region. *Int. J. Environ. Res. Publ. Health* 16. <https://doi.org/10.3390/ijerph16071216>.
- Scottish Government, 2004. The Scottish Index of Multiple Deprivation (SIMD). The Scottish Government. <https://data.gov.uk/>. (Accessed 24 February 2021).
- Scottish Government, 2018. Long-term monitoring of health inequalities: December 2018 report. <https://www.gov.scot/publications/long-term-monitoring-health-inequalities-december-2018-report/pages/4/>. (Accessed 7 November 2020).
- Smith, N., Chastin, S., Tiegies, Z., Webb, S., Georgiou, M., King, A., 2021. A systematic literature review and meta-analysis of quantitative studies on the impact of urban blue space on human health. *Cities* 119.
- Sommer, I., Griebler, U., Mählke, P., Thaler, K., Bouskill, K., Gartlehner, G., Mendis, S., 2015. Socioeconomic inequalities in non-communicable diseases and their risk factors: an overview of systematic reviews. *BMC Publ. Health* 15, 914. <https://doi.org/10.1186/s12889-015-2227-y>.
- Stadler, J., Kabisch, N., Korn, H., 2017. *Nature-based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice*. Springer Open.
- Tiegies, Z., McGregor, D., Georgiou, M., Smith, N., Saunders, J., Millar, R., Morison, G., Chastin, S., 2020. The impact of regeneration and climate adaptations of urban green-blue assets on all-cause mortality: a 17-year longitudinal study. *Int. J. Environ. Res. Publ. Health* 17. <https://doi.org/10.3390/ijerph17124577>.
- Transport Scotland, 2013. Making the most of Scotland's canals. <https://www.transport.gov.scot/media/30484/j269946.pdf>. (Accessed 15 February 2021).
- Tulier, M.E., Reid, C., Mujahid, M.S., Allen, A.M., 2019. "Clear action requires clear thinking": a systematic review of gentrification and health research in the United States. *Health Place* 59, 102173. <https://doi.org/10.1016/j.healthplace.2019.102173>.
- Turner, A.L., Smyth, N., Hall, S.J., Torres, S.J., Hussein, M., Jayasinghe, S.U., Ball, K., Clow, A.J., 2020. Psychological stress reactivity and future health and disease outcomes: a systematic review of prospective evidence. *Psychoneuroendocrinology* 114, 104599. <https://doi.org/10.1016/j.psyneuen.2020.104599>.
- United Nations, Department of Economic and Social Affairs, Population Division, 2018. World Urbanization Prospects: the 2018 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations. <https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf>. (Accessed 19 February 2021).
- von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gotsche, P.C., Vandenbroucke, J.P., Initiative, S., 2007. The Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 370, 1453–1457. [https://doi.org/10.1016/S0140-6736\(07\)61602-X](https://doi.org/10.1016/S0140-6736(07)61602-X).
- Wheeler, B.W., White, M., Stahl-Timmins, W., Depledge, M.H., 2012. Does living by the coast improve health and wellbeing? *Health Place* 18, 1198–1201. <https://doi.org/10.1016/j.healthplace.2012.06.015>.
- White, M.P., Elliott, L.R., Wheeler, B.W., Fleming, L.E., 2018. Neighbourhood greenspace is related to physical activity in England, but only for dog owners. *Landsc. Urban Plan.* 174, 18–23. <https://doi.org/10.1016/j.landurbplan.2018.01.004>.
- World Health Organisation, 2016. Urban Green Spaces and Health: a Review of Evidence. <https://www.euro.who.int/data/assets/pdf/file/0005/321971/Urban-green-spaces-and-health-review-evidence.pdf>. (Accessed 5 November 2020).
- World Health Organisation, 2020a. Noncommunicable diseases. Factsheet. <https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases>. (Accessed 7 March 2021).
- World Health Organisation, 2020b. Noncommunicable diseases. Progress monitor 2020. <https://www.who.int/publications/i/item/ncd-progress-monitor-2020>. (Accessed 15 February 2021).
- World Health Organization, 1978. *International Classification of Diseases: [9th] Ninth Revision*.
- Zock, J.P., Verheij, R., Helbich, M., Volker, B., Spreeuwenberg, P., Strak, M., Janssen, N.A.H., Dijkstra, M., Groenewegen, P., 2018. The impact of social capital, land use, air pollution and noise on individual morbidity in Dutch neighbourhoods. *Environ. Int.* 121, 453–460. <https://doi.org/10.1016/j.envint.2018.09.008>.