Ambient air pollution, urban green space and childhood overweight and obesity: a Health Impact Assessment for Barcelona, Spain

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Highlights

- *To our knowledge, no study has evaluated the attributable burden of multiple air pollutants ($PM_{2.5}$ and NO_2) and urban green spaces (NDVI and % GA) on childhood overweight/obesity, and this is the first study that includes both pollutants.*
- Complying the 2021 WHO guidelines for $PM_{2.5}$ it could prevent 1,468 (5.60%) of annual cases of childhood obesity and
- If Barcelona meet the recommendation levels of WHO 2021 for NO_2, 3,094 (4.32%) annual childhood overweight/obesity cases in Barcelona, Spain.

Abstract

Background Recent studies have shown that high levels of air pollution and lack of urban green spaces (UGS) have an impact on childhood overweight/obesity, but, to our knowledge, no study has evaluated the attributable burden of multiple air pollutants ($PM_{2.5}$ and NO_2) and urban green spaces (NDVI and % GA) on childhood overweight/obesity, and this is first study that includes both pollutants. The aim of this study is to estimate the attributable cases of childhood overweight/obesity due to ambient air pollution and UGS in the city of Barcelona, Spain.

Methods We applied a quantitative Health Impact Assessment (HIA) approach. We assessed exposure to air pollution particulate matter of 2.5 micrometres or less in diameter ($PM_{2.5}$) and nitrogen dioxide (NO_2) using a use regression model and two UGS proxies: the normalized difference vegetation index (NDVI), and the percentage of green area (%GA).

Four ideal scenarios were evaluated: compliance 1) with the 2006 (10 μg/m^3 annual mean $PM_{2.5}$, 40 μg/m^3 annual mean NO_2) and 2) 2021 World Health Organization (WHO) guidelines (5 μg/m^3 annual mean $PM_{2.5}$, 10 μg/m^3 annual mean NO_2); and 3) with 0.3111 NDVI; 3) with 25%

GA, from which exposure-response functions were obtained. We estimated the relative risk and population attributable fraction (PAF) for each scenario and exposure, calculated the prevalence of childhood overweight and obesity and estimated the expected number of cases of childhood overweight/obesity in Barcelona attributable to air pollution and UGS for each scenario.

Results If Barcelona's air quality policies were to meet the 2006 WHO AQGs for air pollution (scenario 1), we could prevent 736 (2.81%) annual cases of childhood obesity due to $PM_{2.5}$ and 249 (0.34%) annual cases of childhood overweight/obesity due to NO_2. However, complying 2021 WHO guidelines for $PM_{2.5}$ and NO_2 we could prevent 1,468 (5.60%) and 3,094 (4.32%) of annual cases of childhood obesity and childhood overweight/obesity, respectively. In addition, if Barcelona would increase the 25%GA and reach 0.31 units of NDVI, a total of 3,329 (4.65%) and 5,629 (7.86%) of annual cases of childhood overweight/obesity could be prevented, respectively. The attributable (and preventable) burden of childhood overweight/obesity by quintiles is higher in Q5 (most deprived) than in Q1 (least deprived).

Discussion The results indicate a large attributable burden of overweight/obesity cases attributable to air pollution and a burden of almost twice as many cases attributed to lack of UGS.

Abbreviations

ABS, Basic Health Area; AQGs, Air Quality Guidelines; HIA, Health Impact Assessment; NDVI, Normalized Difference Vegetation Index; NO_2, Nitrogen Dioxide; $PM_{2.5}$, Particular matter 2.5 µm; UGS, Urban Green Spaces.

Keywords: Health Impact Assessment; Urban environment; Urban green spaces; Air pollution; Childhood obesity; Barcelona

Resumen

Antecedentes: Estudios recientes han demostrado que los altos niveles de contaminación atmosférica y la falta de espacios verdes urbanos (UGS) tienen un impacto en el sobrepeso/obesidad infantil, pero hasta donde sabemos, ningún estudio ha evaluado realmente la carga atribuible de estas exposiciones en el sobrepeso/obesidad infantil El objetivo de este estudio es estimar los casos atribuibles de sobrepeso/obesidad infantil debido a la contaminación atmosférica y UGS en la ciudad de Barcelona, España. **Métodos:** Aplicamos un enfoque cuantitativo de evaluación del impacto en la salud (EIS). Evaluamos la exposición a la contaminación atmosférica ($PM_{2.5}$ y NO_2) utilizando un modelo de regresión de uso y dos proxis de espacios verdes: el índice de vegetación de diferencia normalizada (NDVI), y el porcentaje de área verde (%GA) estimado a un nivel de cuadrícula fina (250 m×250 m).

Se evaluaron cuatro escenarios ideales: 1) el cumplimiento de las directrices de la Organización Mundial de la Salud (OMS) de 2006 y 2) de 2021 sobre los niveles de exposición al $PM_{2.5}$ y NO_2; y 3) el cumplimiento del NDVI de 0,3111; 3) el cumplimiento del 25% de GA, del que también obtuvimos funciones de exposición-respuesta. Estimamos el riesgo relativo y la fracción atribuible a la población (FAP) para cada escenario y exposición. Calculamos la prevalencia de sobrepeso y obesidad infantil, y estimamos el número esperado de casos de sobrepeso/obesidad infantil en Barcelona atribuibles a las $PM_{2.5}$ y NO_2 y a los UGS para cada escenario.

Resultados Si las políticas de calidad del aire de Barcelona cumplieran las AQGs de la OMS de 2006 para la contaminación atmosférica (escenario 1), podríamos evitar 736 (2,81%) casos anuales de obesidad infantil debido a las $PM_{2.5}$ y 249 (0,34%) casos anuales de sobrepeso/obesidad infantil debido al NO_2. Sin embargo, cumpliendo las directrices de la OMS de 2021 para las $PM_{2.5}$ y el NO_2 podríamos evitar 1.468 (5,60%) y 3.094 (4,32%) de casos anuales de obesidad infantil, respectivamente. Además, si Barcelona aumentara el 25%GA y alcanzara 0,31 unidades de NDVI, se podrían evitar un total de 3.329 (4,65%) y 5.629 (7,86%) de casos anuales de sobrepeso/obesidad infantil, respectivamente. La carga atribuible (y prevenible) del sobrepeso/obesidad infantil por quintiles es mayor en el Q5 (el más desfavorecido) que en el Q1 (el menos desfavorecido). **Discusión** Los resultados indican una gran carga atribuible de casos de sobrepeso/obesidad atribuibles a la contaminación atmosférica y una carga de casi el doble de casos atribuibles a la falta de espacios verdes.

Palabras Clave: Evaluación del Impacto en Salud; Entorno urbano; Espacios verdes urbanos; Contaminación del aire; Obesidad infantil; Barcelona

1. Introduction

Throughout history, urban environments have become agglomerations of economic growth, innovation, greater access to information, services, and education. This has led to migration from rural areas to cities, which are becoming increasingly numerous. (des Roches et al., 2020; Duranton & Puga, 2020; European Environment Agency, 2010). Nowadays, worldwide cities concentrate 55% of the world's population, and by 2050 it will increase to 70% (United Nations Department of Economic and Social Affairs, 2018). Ongoing processes of urbanization have led cities to become centres of productivity, innovation, and social encounters, providing many benefits and amenities to our everyday life. However, cities have become hotspots for urban air pollution, driven by dense motorized traffic, powered by combustion of fossil fuels and biomass. Air pollution is considered the most important cause of environmental mortality (World Health Organization, 2021) and a determinant of multiple diseases (cardiovascular disease, overweight/obesity, respiratory diseases, cancer and others) (Al-Kindi et al., 2020; Dominski et al., 2021). Moreover, due to competing land use interests, historic green spaces are vanishing in urban environments and urban green spaces (UGS) and access to nature in cities are becoming scarce (United Nations, 2018). UGS are linked to health and wellbeing (Nieuwenhuijsen & Khreis, 2018; WHO, 2017). Epidemiological studies suggest certain influence to increase physical activity (Alberti et al., 2019) and reduced screen time, better sleep quality (Jia et al., 2021; Lachowycz & Jones, 2011) and lower all-cause mortality (Barboza et al., 2021). According to the Sustainable Development Goals (SDGs), urban environments are focused on being inclusive, safe, resilient, and sustainable and this reinforces the notion that the urban environment is a space adapted to all (children and adults) (United Nations Development Programme, 2020).

It is increasingly recognized that increasing levels of air pollution (Bloemsma et al., 2019; de Bont, Díaz, et al., 2021; Malacarne et al., 2021a; Seo et al., 2020) and low levels of UGS (Bloemsma et al., 2019; Bozkurt, 2021; Jia, 2021) can contribute to weight gain, obesity in children and adolescents. Childhood obesity is a worldwide public health concern. Globally, around 18% of children and adolescents are overweight and obese (WHO, 2021), whereas in Barcelona approximately 33% of children are overweight, of which 12% are obese (Generalitat de Catalunya & Institut d'Estadística de Catalunya, 2022; SIDIAP, 2014).

Children with obesity poses a great risk of obesity in adulthood, and is associated with a multitude of chronic diseases, including type 2 diabetes, cardiovascular diseases, cancer, and mental health disorders, which can lead to disability or premature death (Bleich et al., 2018; WHO, 2020). The principal risk factor of childhood obesity is a chronic energy

imbalance cause by a combination of excessive caloric intake (diet) and low energy expenditure (physical activity) (Hill et al., 2012). Even though, this energy imbalance is related to multiple factors such as lifestyle behaviours (Bridget Morrissey et al., 2020; Miller & Lumeng, 2018; Poorolajal et al., 2020) and socioeconomic status (SES) (Dogbe et al., 2021; Moradi et al., 2017). Recently, air pollution and lack of UGS also seem to influence on this energy imbalance (Lam et al., 2021; Malacarne et al., 2021b).
Last year the new World Health Organization (WHO) Air Quality Guidelines (AQG) were published (World Health Organization, 2021). The recommended levels of $PM_{2.5}$ (fine particulate matter of 2.5 micrometres or less in diameter and NO_2 (nitrogen dioxide) are 5 μg/m^3 and 10 μg/m^3 respectively and current levels in Barcelona are much higher ($PM_{2.5}$ 14.9 μg/m^3 annual mean, NO_2 42.4 μg/m^3 annual mean) than the $PM_{2.5}$ and NO_2 annual levels recommendations (Khomenko et al., 2021). In addition, several recent studies have proposed a 25% of green areas within cities (Barboza et al., 2021; Khomenko et al., 2020; Mueller et al., 2017, 2018). however, UGS are scarce in the city and only 10.7% of green area is available in the city of Barcelona. Overall, to our knowledge, no study has evaluated the attributable burden of multiple air pollutants ($PM_{2.5}$ and NO_2) and urban green spaces (NDVI and % GA) on childhood overweight/obesity, and this is the first study that includes both pollutants, neither accounting for possible different socioeconomic groups.

For this, in this study we aimed to estimate the attributable (and preventable) cases of childhood overweight and obesity due to ambient air pollution and the attributable (and preventable) cases due to lack of UGS in the city of Barcelona, Spain.

2. Material and methods

2.1. Quantitative Health Impact Assessment

A quantitative health impact assessment (HIA) framework was used to estimate attributable (and preventable) childhood overweight/obesity cases due to air pollution ($PM_{2.5}$ and NO_2) and UGS [Normalized Difference Vegetation Index (NDVI) and percentage of green area (%GA)] current levels in Barcelona at the area bàsica sanitaria (ABS) level. ABS are the elementary territorial unit where primary health care is provided with direct access to the population across Catalonia (including Barcelona) (Servei Català de la Salut & Generalitat de Catalunya, 2020).

We followed the comparative risk assessment framework by comparing the current situations with the counterfactual ideal situation (i.e., Complying with exposure level recommendations). We obtained risk estimates and exposure response functions (ERFs) from the literature to quantify the associations between exposure levels and childhood overweight/obesity. We calculated population attributable fractions and combining those with underlying childhood overweigh and obesity burdens, we estimated attributable health burdens. Finally attributable cases were also assessed according to their distribution by deprivation index at the ABS level.

2.2. Air pollution and UGS data

The air pollution data for $PM_{2.5}$ and NO_2 were derived from land use regression (LUR) models developed at a grid cell scale of 250 m by 250 m for 2015 as part of the ELAPSE project (Effects of Low-Level Air Pollution: A Study in Europe) (de Hoogh et al., 2018). Briefly, the models were based on airbase routine monitoring data, and incorporated chemical transport model estimates, satellite derived data, plus a range of other predictor variables (i.e., roads, land use, altitude). Annual mean value of $PM_{2.5}$ and NO_2 concentrations were estimated for each 250m grid cell using the ELAPSE raster cells whose centroids fell inside each 250m grid cell (Khomenko et al., 2021). To estimate at ABS level, we estimated the average concentration of all the 250x250 grid cells within each ABS area. The models explain 72% and 59% of the spatial variation in the measured concentration for $PM_{2.5}$ and NO_2, respectively (Strak et al., 2021).

To determine exposure to UGS, we have used two proxies, (Barboza et al., 2021), first, the NDVI which represents as the total amount of surrounding greenness (e.i., street trees, green corridors, and general vegetation in public and private spaces), and second, %GA defined by land use (CORINE). NDVI was obtained from satellite images and each grid was obtained from satellite-based sensor [which it is used for earth and climate measurements, also called, Terra Moderate Resolution Imaging Spectroradiometer (MODIS)] from the vegetation indices obtained from the US Geological Survey generated every 16 days with a resolution of 250m x 250m (Barboza et al., 2021; Jesslyn Brown, 2018). NDVI levels range from -1 to 1, with positive and higher values indicating more greenery. Water bodies has been set to 0. All images were collected in the summer season (April to June 2015) to ensure the greenness' period of the year. Then, to estimate at ABS level, we averaged NDVI values from all the 250mx250m cells that are part of each ABS had been calculated.

The %GA proxy was defined as the actual land coverage of UGS of each ABS (considering a 300m buffer) divided by the size of the total ABS. Data for %GA were obtained using the official land use and land cover maps available in CORINE Land Cover 2012 (European Environment Agency, 2022). The CORINE chosen land use categories were those describing UGS generally accessible to the public (e.i., parks, plazas, public gardens) (Barboza et al., 2021; Husqvarna AB, 2020). To obtain %GA at the ABS level, we followed the same approach as for NDVI, by averaging the %GA values of the 250mx250m cells that were part of each ABS (Barboza et al., 2021; Jia et al., 2021; Siljeg et al., 2020).

2.3. Barcelona child population and overweight and obesity

Childhood population data on ABS level for Barcelona were obtained from Institut d'Estadística de Catalunya (IDESCAT) (Generalitat de Catalunya, 2022; Generalitat de Catalunya & Institut d'Estadística de Catalunya, 2022). Health data of overweight/obesity data was obtained from the Information System for Research in Primary Care (SIDIAP). SIDIAP is a large deidentified electronic health record resource with longitudinal data and covers up to 80% of the total Catalan population from the primary health care. The study population included children from 2 to 17 years of age attending primary care centres in Barcelona (de Bont, Márquez, et al., 2021), registered in SIDIAP and with at least 1 height and weight record (SIDIAP, 2014) and we stratified children into 3 age groups (2-5 years, 6-11 years, and 12-17 years) (de Bont et al., 2020) furthermore, we excluded children aged 0 to 2 years. In the view of the fact that there are many changes from birth through infancy to adulthood (Williams et al., 2012).

We obtained overweight/obesity prevalence calculating the Body Mass Index (BMI; calculated as weight in kilograms divided by height in meters squared) from height and body weight measures, which are routinely measured by paediatricians' health professionals in primary care centres. Then, we calculated age- and sex-specific BMI z-scores using the

WHO growth standard and growth reference and we classified children in in overweight/obesity (for children below 5 years old zBMI > +2SD and ≤ +3SD, and above 5 years between > +1SD and ≤ +2SD) and obesity (for children below 5 years old zBMI > 3SD, and above 5 years zBMI > +2SD) (World Health Organization, 2017). We have estimated the prevalence of childhood overweight/obesity per 100 children for each of the 69 ABS in Barcelona for the three age groups of 2-5 years, 6-11 years, and 12-17 years. If a child had multiple BMI measurements being part of the same age group, the unhealthiest measurement was used (e.i., if a child had two measures of BMI between 2-5 years, and one measure was considered normal weight and the other overweight, we have considered this child as overweight for age group 2-5 years). The established overweight/obesity prevalence rates for the three age groups were used as underlying background rates in the HIA framework.

2.4. Deprivation index

We additionally stratified our impact estimates by deprivation index of the ABS. The deprivation index is an important confounder in the associations between air pollution, UGS, and childhood overweight/obesity. To obtained deprivation levels at the ABS levels, we used the Catalonian deprivation index used in primary health care for the allocation of primary care resources for each ABS (Agència de Qualitat i Avaluació Sanitàries de Catalunya (AQuas), 2016). The deprivation index uses population data on socioeconomic level, educational level, employment, life expectancy, premature mortality rate and avoidable hospitalizations. The values go from 0 (ABS with least deprived) to 100 (ABS most deprived) (Agència de Qualitat i Avaluació Sanitàries de Catalunya (AQuas), 2016). The last update of the index is from 2017. For 3 ABS regions we did not had information of deprivation index.

We have hypothesized that exposures are unevenly distributed across the city and therefore attributable (and preventable) cases as well, that in Q1, least deprived, there will be fewer cases of childhood overweight/obesity and, conversely, in the most deprived quintile (Q5) there will be more cases attributable (and preventable) to exposures.

2.5. Counterfactual scenarios

We estimated the impacts of attributable (and preventable) childhood overweight/obesity achieving 1) WHO recommended levels or air pollution and 2) epidemiological studies recommended levels of urban green for good physical and mental health outcomes.

We created four scenarios (counterfactual exposures) (Table 1).

- Scenario 1: compliance of 10 μg/m^3 annual mean $PM_{2.5}$, 40 μg/m^3 annual mean NO_2 based on the oldest WHO AQGs (World Health Organization, 2006) .
- Scenario 2: Compliance of 5 μg/m^3 annual mean $PM_{2.5}$, 10 μg/m^3 annual mean NO_2 based on newest WHO AQGs (World Health Organization, 2021).

Also, we created two scenarios for UGS, assuming ABS complying with recommended levels of urban green coming from epidemiological studies. The 25% of %GA was estimated as a counterfactual exposure to provide universal access to UGS, it has been used, also, in previous studies (i.e., Barcelona, Vienna, Bradford and other European cities) (Barboza et al., 2021; Khomenko et al., 2020; Mueller et al., 2017, 2018).

- Scenario 3: Compliance with 0.3111 NDVI (Barboza et al., 2021).
- Scenario 4: Compliance with 25% GA ((Khomenko et al., 2020; Mueller et al., 2017, 2018).

2.6. HIA framework

The HIA compromised the following steps (Fig. 1 and table 1): (1) we estimated the current (or current) levels of air pollution and UGS exposure, respectively; (2) we obtained the exposure level differences between the current levels and the counterfactual levels exposures; (3) we selected four exposure response-functions (ERFs), an estimation of a specific magnitude between air pollution, UGS exposures and childhood overweight/obesity. The ERFs for $PM_{2.5}$ (RR: 1.06, [95% CI: 1.02-1.11] per 10 μg/m^3) were obtained from a meta-analysis (Lin et al., 2022) for obesity; for NO_2 from a national large longitudinal study (RR: 1.03 [95% CI: 1.02-1.04] per 21.8 μg/m^3) (de Bont, Díaz, et al., 2021) for overweight/obesity and, for NDVI and for %GA from a cohort study for overweight/obesity (OR 0.86 [95% CI 0.71-1.04] per 0.13 NDVI increase and OR 0.86 [95% CI 0.71-1.03] per 29.5% increase in the total percentage of green space, respectively) (Bloemsma et al., 2019). The ERFs found in the scientific literature are for overweight, including obesity, and, only for obesity. In the case of $PM_{2.5}$, the ERFs refer exclusively to obesity. The other ERFs for the other exposures (NO_2, NDVI and %GA) refer to overweight, which includes obesity; (4) the different ERFs were used to estimate the relative risk (RR) of developing childhood overweight/obesity for each exposure and corresponding scenario by ABS level; (5) we calculated the corresponding population attributable fractions (PAFs) using each exposures RR by each ABS level; (6) we combined total childhood population (2 to 17 years old) and overweight/obesity prevalence by each ABS to obtain total burden (TB) and with the population attributable fractions (PAFs), we calculated childhood overweight/obesity cases attributable (and preventable) to current and to counterfactual air pollution and UGS exposure levels for each ABS; (7) we merged combined PAFs with childhood overweight/obesity prevalence to obtain attributable (and preventable) cases under the current situation and counterfactual scenarios (1, 2, 3 and 4) for each ABS for NO_2, NDVI and %GA. For $PM_{2.5}$, we merged PAFs with childhood obesity prevalence to obtain attributable (and preventable) cases under the current situation and counterfactual scenarios (1 and 2) for each ABS; (8) the expected number of childhood overweight/obesity cases to the different exposure (for scenarios: 2, 3 and 4) were estimated by deprivation index (quintiles) (Bleich et al., 2018; Lam et al., 2021). Deprivation index quintiles were compared in scenarios 2, 3 and 4 for each exposure ($PM_{2.5}$, NO_2, NDVI and %GA), through an analysis of variance (ANOVA) to estimate if there are statistically significant (p-value <0,05) differences between means [current exposures and attributable (and preventable) cases] of each quintile. In cases where the ANOVA analysis resulted in a statistically significant difference between quintiles, a post-hoc Bonferroni test was performed using pairwise comparisons of means. The analyses were performed using R 4.1.2 and QGIS software v3.16.

3. Results

In 2015, a total of 218,976 children between 2 and 17 years of age were living in the 69 ABS in Barcelona, in which 32.70% had overweight/obesity and 11.97% had obesity (71,603 and 26,222 children, respectively) (Generalitat de Catalunya & Institut d'Estadística de Catalunya, 2022) (Table 2 and Fig. 2).

3.1. Scenario 1 and 2: $PM_{2.5}$

$PM_{2.5}$ annual levels were 14.9 μg/m^3 with a minimum and maximum levels of 11.4 μg/m^3 and 16.3 μg/m^3, respectively (Fig. 2 and Fig. A.1). For scenario 1 (Table 3), based on the AQGs from 2006 (World Health Organization, 2006), 736 (95%CI, 253-1303) obesity cases (2.81%) were attributed to the annual current $PM_{2.5}$ levels, in which 69 (CI 95%, 24-122) cases at age 2-5y, 412 (CI 95%, 141-730) cases at age 6-11y and 255 (CI 95%, 88-122) cases at age 12-17y. For scenario 2, based on the most recent WHO AQGs (World Health Organization, 2021), 1468 (95%CI, 508-2570) obesity cases (5.60%) were attributed to the current annual $PM_{2.5}$ levels, in which 137 (CI 95%, 47-240) cases at age 2-5y, 822 (CI 95%, 285-1438) cases at age 6-11y and 509 (CI 95%, 176-892) cases at age 12-17y.

3.2. Scenario 1 and 2: NO_2

NO_2 annual levels were 42.4 μg/m^3 with a minimum and maximum levels of 28.1 μg/m^3 and 56.1 μg/m^3, respectively (Fig. 2 and Fig. A.1). For scenario 1 (Table 3), 249 (95%CI, 161-316) overweight/obesity cases (0.34%) were attributed to the annual current NO_2 levels, in which 29 (19-38) cases at age 2-5y, 125 (CI 95%, 84-166) cases at age 6-11y and 95 (CI 95%, 64-125) cases at age 12-17y. On the other hand, for scenario 2 (Table 3), we estimated 3,094 overweight/obesity cases (4.32%) were attributed to the annual current NO_2 levels, in which 357 (CI 95%, 241-470) cases at age 2-5y, 1,541 (CI 95%, 1040-2030) cases at age 6-11y and 1195 (CI 95%, 807-1574) cases at age 12-17y.

3.3. Scenario 3: NDVI

NDVI annual levels were 0.27 units with a minimum and maximum levels of 0.16 units and 0.68 units, respectively (Fig. 3 and Fig. A.2). For scenario 3 (table 4), the counterfactual of NDVI is 0.311 units (Barboza et al., 2021), we estimated 3,329 (CI 95%, -7617; 584) overweight/obesity cases (4.65%) were attributed to the current NDVI levels, in which 409 (CI 95%, -1061; 90) cases at age 2-5y, 1,688 (CI 95%, -4446; 368) cases at age 6-11y and 1,232 (CI 95%, -3288; 262) cases at age 12-17y.

3.4. Scenario 4: %GA

%GA annual levels were 17.6% with a minimum and maximum levels of 0.03% and 79.81%, respectively (Fig. 3 and Fig. A.2). For scenario 4 (Table 4), based on the different studies the counterfactual level was 25% GA, we estimated 5,629 (CI 95%, -12172; 921) overweight/obesity cases (7.86%), in which, 657 (CI 95%, -1658; 116) cases at age 2-5y, 2835 (CI 95%, -7176; 499) cases at age 6-11y and 2,137 (CI 95%, -5431; 373) cases at age 12-17y.

The childhood overweight/obesity cases attributed to NDVI and %GA should be interpreted with caution as the ERF's RR are not statistically significant, although they show a tendency. That is, the lower interval between 0.71 and 1 (in both cases: 0.71-1.03; 0.71-1.04) includes more numbers than the upper interval (1 to 1.04), suggesting an effect.

3.5. Quintiles differences by current levels and attributable burden

Annual exposure levels for air pollution and UGS are unevenly distributed across deprivation within Barcelona (Table 5). Higher levels of air pollution and UGS were found in Q3 and the lowest in Q1. The prevalence of overweight/obesity was higher in Q5 (38%) than in Q3 (34%), whereas prevalence of obesity was higher Q5 compared with the rest of quintiles (Fig A.1).

Regarding the attributable (and preventable) cases of overweight/obesity due to air pollution, no extreme differences in attributable cases were observed between Q1 and Q5 (p=0.084). However, the least deprived group Q1 [246 (CI 95%, 85-430)] and Q3 [326 (CI 95%, 113-569)] showed statistically significant difference for current $PM_{2.5}$ levels and attributable (and preventable) obesity cases means (Q1 vs. Q3 p=0.024; p=0.037, respectively). For NO_2, both the exposures and attributable (and preventable) annual overweight/obesity [Q1: 586 (CI 95%, 395-773)] and Q3: 679(CI 95%, 459-894)] cases were not statistically different [Q1 vs. Q3 p= 0.53 for exposures and Q1 vs. Q3 p= 0.7] for attributable (and preventable) overweight/obesity cases] and for the rest the p=1.

In reference to UGS, the least deprived ABS the annual mean NDVI levels of 0.28 NDVI while the most deprived ABS have 0.29 NDVI (p-value = 1). Despite this, ABSs in Q1 had 1.3% attributable (and preventable) overweight/obesity cases to NDVI [Q1: -187 (CI 95%, -858;10.3)] and Q5 had 8.71% [Q5: -1149 (CI 95%, -2836;276)]. Although, the posthoc ANOVA Bonferroni procedure did not show statistically significant differences between means (p=1.0). For %GA, the least deprived ABS (Q1) had an annual mean of %GA levels, 16.2% while the most deprived ABS (Q5) had 6.4%. Due to current %GA, Q1 ABSs had 5.1% of attributable (and preventable) overweight/obesity cases and ABS in Q5, 9.6% attributable (and preventable) overweight/obesity cases. Besides this difference, the posthoc ANOVA Bonferroni procedure did not show statistically significant differences between means (p=1.0).

4. Discussion

4.1. Summary

In this HIA we estimated childhood overweight/obesity cases attributable (and preventable) to high levels of air pollution and lack of UGS. We observed that childhood overweight and obesity are serious public health issues in Barcelona, as we have observed very high levels (around 32.7% and 12.0% had overweight and obesity, respectively). Results indicate an attributable (and preventable) burden of 5.60% of childhood overweight/obesity cases of due to $PM_{2.5}$ and 4.32% of childhood obesity cases of due to NO_2. Also, due to lack of UGS in Barcelona, an attributable (and preventable) burden of 4.65% and 7.86% of childhood overweight/obesity (proxies %GA and NDVI, respectively). Although the increase in UGS appears to have a higher attributable (and preventable) burden, it should be interpreted with caution because it was not statistically significant. Also, no significant differences were observed between socioeconomic status and air pollution, but as far as UGS are concerned, the attributable (and preventable) burden seems to be much higher in more deprived areas than in less deprived areas.

4.2. Relevance of results

HIA is a useful methodology to assess the health impacts linked to a precise intervention or a policy proposal under discussion, or also to point out the urgency for action by comparing the current situation (i.e., no action) with a hypothetical situation (i.e., compliance with exposure level recommendations). Air pollution health risk assessments for mortality, cancer, respiratory diseases, and asthma have been done (Al-Kindi et al., 2020; Bhat et al., 2021; Khomenko et al., 2021; Khreis & Nieuwenhuijsen, 2017; Mueller et al., 2017; Pierangeli et al., 2020; Strak et al., 2021) and UGS health risk assessments on mortality mainly and physical activity (Anderson et al., 2021; Barboza et al., 2021; Knobel et al., 2021; Kondo et al., 2020; Santos et al., 2009), but most of these assessments were done for adult populations, and less evidence exists for impacts on children. Except for one, there is a HIA developed in Barcelona, estimating the attributable childhood asthma cases due to air pollution. Comparing our results to this HIA for scenario 1 (WHO AQGs, 2006), estimations of asthma cases due to air pollution are higher than overweight and obesity cases (Pierangeli et al., 2020). Estimations showed that 19% of asthma cases were attributed to $PM_{2.5}$, and 18% asthma cases were attributed to NO_2.

Thus, this HIA reinforces the existing evidence on the burden of the urban environment on childhood overweight/obesity. And it highlights the complexity of 21st century childhood overweight/obesity in developed countries. Currently, childhood overweight/obesity rates are still high in developed countries (Buoncristiano et al., 2021; de Bont et al., 2020; World Health Organization. World Obesity Federation., 2021). The continuous growth of urbanization has lately directed research to take into account the effect of children's physical surroundings (i.e., urban environment) (Congdon, 2019; Huang et al., 2022). Recent literature has observed that increased levels of NO_2 (21.8 μg/m^3) appeared to increase up to a 3% the risk of obesity in children (de Bont, Díaz, et al., 2021) and increased levels of $PM_{2.5}$ (per 10 μg/m^3) was positively associated with a 6% increased risk of childhood overweight/obesity (Lin et al., 2022). In this context, although the mechanisms of air pollution and childhood obesity are not entirely clear, animal, and epidemiological studies suggest that it increases oxidative stress and inflammatory responses in adipose tissue (An et al., 2018), and may influence sleep problems, depression, and anxiety, which are related to weight gain (Parasin et al., 2021).

In fact, children are more vulnerable to air pollution than other population's groups (Mathiarasan & Hüls, 2021) and not only impacts on childhood overweight/obesity but it, also, affects general children's health (i.e., respiratory system, immune status, brain development and cardiometabolic health) (Dominski et al., 2021; Johnson et al., 2021; Tainio et al., 2021) Furthermore, our results showed great differences between air pollution ideal scenarios 1 and 2. Implementing the 2021 recommendations we would prevent 2 times more cases of overweight/obesity compared to the 2006 AQGs. Therefore, the importance of implementing these recommendations is highlighted.

Multiple studies suggest associations between increased UGS [or NDVI] and lower levels of overweight/obesity (Luo et al., 2020), although, some studies have shown no statistical difference association but a tendency for a protective effect of UGS on childhood obesity. (Bloemsma et al., 2019) Our results add more value to the epidemiological evidence because complying with NDVI of 0.311 units, we could prevent 4.65% and assuring 25%GA could prevent 7.86% of childhood overweight/obesity annual cases. So far, UGS may offer opportunities for physical activity associated with a lower risk of obesity (Chen et al., 2022; Jia et al., 2020). In addition, UGS are linked with improved mental health and well-being (which could help to alleviate stress) (Alberti et al., 2019) and involves social interaction among peers associated with lower levels of obesity (Islam et al., 2020; Jansson et al., 2022). It also can reduce noise and air pollution levels (WHO, 2017).

In view of these results, it is clear that there is an urgent need to act to reduce air pollution and to increase UGS in the city and it, will also, help in the mitigation on climate change and co-benefits on population's health. In addition, addressing right policies and actions to reduce air pollution and increase UGS could have a great effect on annual childhood overweight/obesity prevalence but also to preserve and care for children's health.

As we have hypothesized, air pollution and UGS are distributed unevenly across the city. Across European cities exists heterogeneity distribution of air pollution and UGS by socioeconomic levels (Robinson et al., 2018). On the contrary, in North America, the distribution of air pollution and UGS by SES is clearer, there is an association between the most deprived areas and the worst conditions of urban exposures (de Bont, Díaz, et al., 2021; Pierangeli et al., 2020).

In our study, there is a slight trend of higher attributable (and preventable) cases of childhood overweight/obesity with lack of UGS (especially for NDVI) among children living in the most deprived ABS. This might be explained because children are exposed to less levels of UGS and as they generally have worse health outcomes associated because of poverty, psychosocial stress, and worse lifestyle behaviours (de Bont, Díaz, et al., 2021).

4.3. Implications for policy and practice

Ambitious policies are needed in Barcelona to reduce air pollution levels and increase UGS to protect children's health. A combination of policies that reduce motorized traffic volumes and thus air pollution levels (congestion pricing, reduction of parking spaces, low emission zones, superblocks (Mueller et al., 2020), promotion of alternative transport modes such as walking, cycling and public transport) is recommended. Also, tightening up restrictions on gasoline and diesel (combustion) vehicles, and to conduct a public awareness campaign.

The UGS could be increased with the proposals of green corridors plans of the Ajuntament de Barcelona. The green corridors are pacified streets, with more greenery, and allow walking with comfort, convenience, and safety (Ajuntament de Barcelona, 2021). In addition, there are other proposals that should be implemented such as more street trees, small gardens, public pocket parks, general greening of the city (including vertical greening) (Medi Ambient i Serveis Urbans - Hàbitat Urbà. & Ajuntament de Barcelona, 2020; Mueller et al., 2020).

In addition, all these examples and improvement plans of improving air quality and greening the city should be implemented equally in all neighbourhoods of the city. In this way, we will improve the environment and reduce inequalities.

4.4. Strengths and limitations

To our knowledge, no study has evaluated the attributable burden of multiple air pollutants ($PM_{2.5}$ and NO_2) and urban green spaces (NDVI and % GA) on childhood overweight/obesity, and this is the first study that includes both pollutants. Another strength from our HIA is that we considered socioeconomic differences with respect to attributable (and preventable) cases of childhood obesity due to air pollution and UGS. Also, another strength is the high representativeness of the outcome data using SIDIAP data, around 80% of the total child population of Barcelona are included.

However, this HIA has some limitations. Firstly, we have obtained all data at the ABS level, which is a large unit. It won't give us detailed information about exposures and how they are distributed in smaller measure (i.e., census tract has been used in previous HIAs done in Barcelona) giving us more detailed about exposures within the ABS. This means that the data for both the study and the results are not as detailed, so one way to improve this small drawback is that in future studies this factor is taken into account, for better accuracy of the results.

In addition, another limitation related to the air pollution data is that we did not have annual data of $PM_{2.5}$ and NO_2 but only for 2015. For our study period (outcome data from 2008-2018) this shouldn't introduce much bias in estimating the burden of childhood obesity as a recent study showed that $PM_{2.5}$ and NO_2 levels in Spain between 2000-2018 have been almost constant (Vivanco et al., 2021). However, during the pandemic, daily mobility patterns in the metropolitan area of Barcelona changed and the air pollution drastically reduced (Cárcel-Carrasco et al., 2021; Gorrochategui et al., 2022) and could overestimate the today´s burden of childhood obesity.

In reference to the various ERFs used in this HIA to estimate health impacts, on the one hand, a strong point is that the exposure-response function for $PM_{2.5}$ was derived from an internationally, pooled and statistically significant meta-analysis and generalizability of risk estimates is reasonable. In contrast to the $PM_{2.5}$ ERF, for NO_2 and the UGS exposures (proxies: NDVI and %GA), meta-analyses have not yet been performed. For NO_2, the ERF was derived from a large, longitudinal study conducted in Catalonia with statistically significant confidence intervals for childhood overweight/obesity with similar population characteristics to our study population. Therefore, generalizability of NO_2 risk estimates to the Barcelona childhood population was assessed as reasonable. On the other hand, for the UGS exposure proxies, no pooled nor local ERFs are currently available for the Catalan or Spanish childhood population, and thus, we have used an ERF derived from a cohort study of the Dutch childhood population, with a suggested, but not statistically significant effect. Despite being derived from a European childhood population (i.e., Dutch), we acknowledge that the strength of evidence for UGS exposures and childhood overweight and obesity is less strong than the evidence for air pollution exposures and further research on UGS exposure and childhood overweight and obesity is desirable to strengthen the current evidence base.

Moreover, in this HIA, we used WHO established health thresholds for air pollution exposure (scenario 1 and 2) and air pollution counterfactuals are defined by the WHO AQGs of 2006 and 2021. Regarding UGS exposure, WHO recommends to be living within a 300m distance of a green space of at least 0.5 ha (WHO, 2017), however, translating this recommendation into the HIA applied UGS proxies of %GA and NDVI is rather difficult. First research attempts translated this WHO green space access recommendations into the applied 25%GA and 0.311 NDVI proxies (scenario 3 and 4), by reasoning that if 25% of the city area was covered by equally-distributed green space, universal access to green spaces within 300m linear distance from residences would be provided (Khomenko et al., 2020; Mueller et al., 2017, 2018), which subsequently translates into the applied NDVI value of 0.311 (Barboza et al., 2021). We acknowledge that UGS counterfactual scenarios (scenario 3 and 4) imply more uncertainty regarding the provision of health benefits than the air pollution counterfactual scenarios (scenario 1 and 2), however, there is a growing body of literature associating urban green space with numerous health benefits through various mechanisms (Gascon et al., 2016; Muhammad Jabbar et al., 2021), and we believe this health associations to also exist for childhood overweight and obesity prevention. Therefore, we decided to include the UGS scenarios.

providing an overview of possible effects, while acknowledging that the evidence base is thinner for UGS than for air pollution regarding overweight and obesity impacts.

5. Conclusions

In summary, if Barcelona met the 2021 WHO guidelines for $PM_{2.5}$ and NO_2 it could prevent 1,468 (5.60%) and 3,094 (4.32%) of annual cases of childhood obesity and childhood overweight/obesity, respectively. In addition, if Barcelona would increase UGS in terms of %GA and NDVI, it would prevent 3,329 (4.65%) and 5,629 (7.86%) of annual cases of childhood obesity, respectively. The increase of greenspaces would have a more beneficial effect on childhood overweight/obesity in the most disadvantaged child populations of Barcelona. To our knowledge, no study has evaluated the attributable burden of multiple air pollutants ($PM_{2.5}$ and NO_2) and urban green spaces (NDVI and % GA) on childhood overweight/obesity, and this is first study that includes both pollutants, with an environmental health equity perspective.

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8. Tables and figures

Table 1: Air pollution and urban green spaces current and recommended exposures

Exposure Categories	Mean Current Exposure	Exposure Recommendation[a]	Risk estimates (95%CI)	Study population	Study design	Reference
$PM_{2.5}$	14.9 μg/m^3 (11.3-16.3)	*Scenario 1* 10 μg/m^3	1.06 (1.02–1.11) per 10 μg/m^3	Obesity Children 2 to 17 years	Systematic review & meta-analysis	(Lin et al., 2022)
		Scenario 2 5 μg/m^3				
NO_2	42.4 μg/m^3 (28.1-56.1)	*Scenario 1* 40 μg/m^3	1.03 (1.02–1.04) per 21.8 μg/m^3	Overweight & obesity Children 2 to 17 years	Large longitudinal study	(de Bont, Díaz, et al., 2021)
		Scenario 2 10 μg/m^3				
NDVI	0.27 (0.2-0.7)	*Scenario 3* 0.31 NDVI [b]	0.86 (0.71–1.04) per 0.13 NDVI	Overweight & obesity Children 3 to 17 years	Cohort study	(Bloemsma et al., 2019)
%GA	10.7% (0.03- 79.80%)	*Scenario 4* 25% GA [c]	0.86 (0.71–1.03) per 29.5%			

$PM_{2.5}$: particulate matter less than 2.5 μm of diameter; NDVI: Normalized Difference Vegetation Index; %GA: percentage of green spaces; CI: Confidence Interval.

[a] $PM_{2.5}$ and NO_2 exposure recommendation from WHO Air Quality Guidelines (AQGs) 2006 and 2021, respectively.

[b] NDVI: (Barboza et al., 2021)

[c] %GA: (Khomenko et al., 2020; Mueller et al., 2017, 2018)

Exposure Categories	Mean Current Exposure	Exposure Recommendation	Risk estimates (95%CI)	Study population	Study design	Reference
$PM_{2.5}$	14.9 μg/m³ (11.3-16.3)	*Scenario 1* 10 μg/m³	1.06 (1.02–1.11) per 10 μg/m³	Obesity Children 2 to 17 years	Systematic review & meta-analysis	(Lin et al., 2022)
		Scenario 2 5 μg/m³				
NO_2	42.4 μg/m³ (28.1-56.1)	*Scenario 1* 40 μg/m³	1.03 (1.02–1.04) per 21.8 μg/m³	Overweight & obesity Children 2 to 17 years	Large longitudinal study	(de Bont, Díaz, et al., 2021)
		Scenario 2 10 μg/m³				
NDVI	0.27 (0.2-0.7)	*Scenario 3* 0.31 NDVI	0.86 (0.71–1.04) per 0.13 NDVI	Overweight & obesity Children 2 to 17 years	Cohort study	(Bloemsma et al., 2019)
%GA	10.7% (0.03- 79.80%)	*Scenario 4* 25% GA	0.86 (0.71–1.03) per 29.5%			

$PM_{2.5}$: particulate matter less than 2.5 μm of diameter; NDVI: Normalized Difference Vegetation Index; %GA: percentage of green spaces; CI: Confidence Interval.

[a] $PM_{2.5}$ and NO_2 exposure recommendation from WHO Air Quality Guidelines (AQGs) 2006 and 2021, respectively.

[b] NDVI: (Barboza et al., 2021)

[c] %GA: (Khomenko et al., 2020; Mueller et al., 2017, 2018)

Fig. 1: Health Impact Assessment framework: Air pollution, UGS, and childhood overweight/obesity

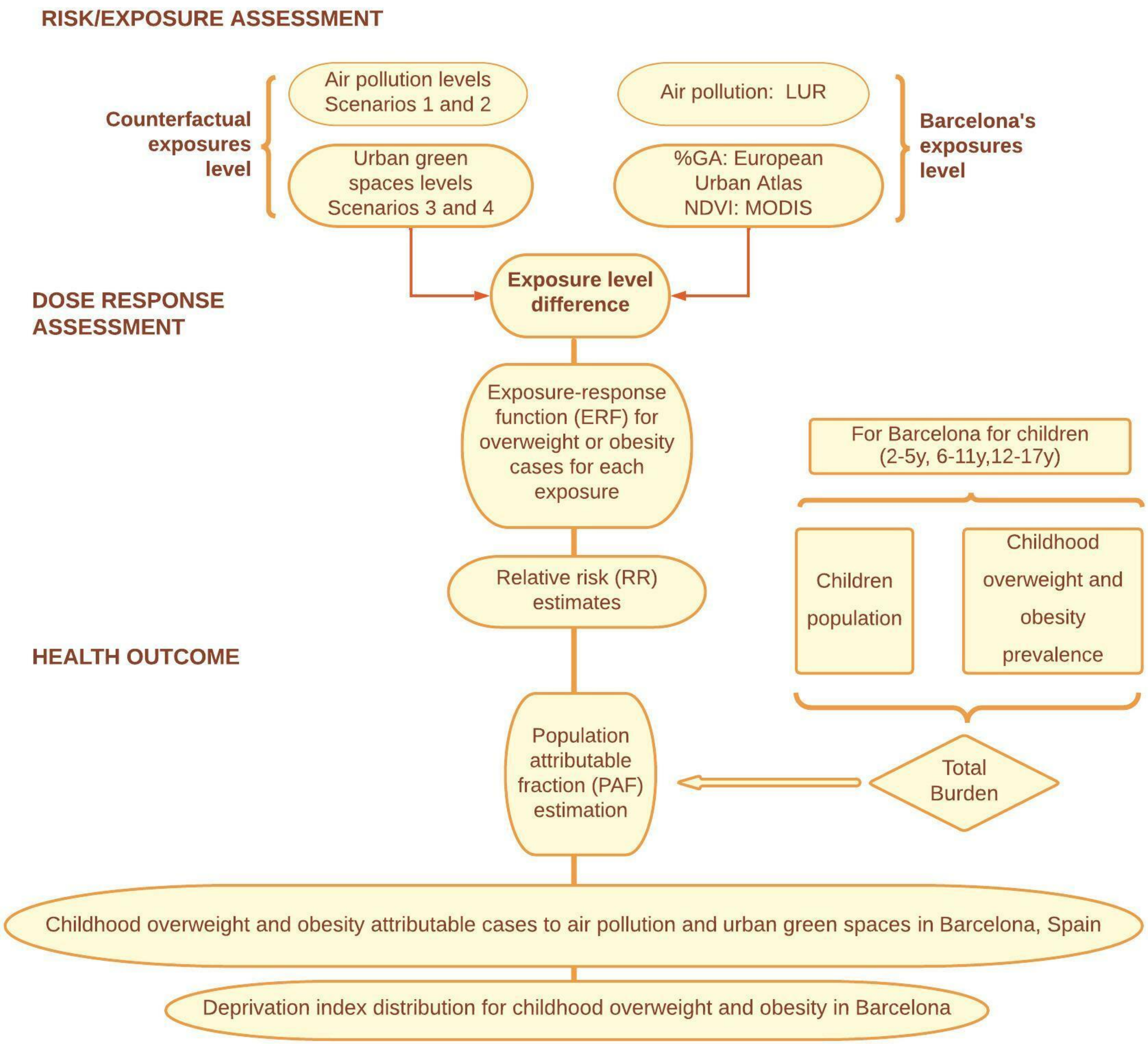


Table 2: Childhood overweight/obesity cases in Barcelona by age groups

Children age range	2-5 years N = 56,531		6-11 years N = 84,227		12-17 years N = 78,218		All children (2-17 years) N = 218,976	
	Cases	**%**	**Cases**	**%**	**Cases**	**%**	**Cases**	**%**
Overweight (including obesity)	8,248	14.6	35,652	42.3	27,704	35.4	71,603	32.7
Obesity	2,440	4.3	14,672	17.4	9,110	11.7	26,222	11.9

Fig. 2: Maps for overweight/obesity and obesity prevalence (quintiles) by ABS in Barcelona, Spain

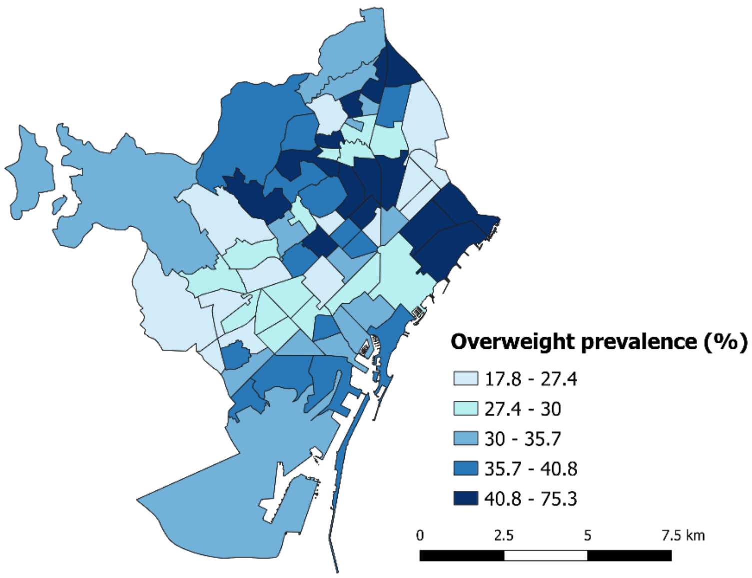


Table 3: Percentage and number of total expected cases attributed to air pollution by age groups and scenarios in Barcelona

Children age range			**2-5 years**		**6-11 years**		**12-17 years**		**All children (2-17 years)**	
			Attributable cases (CI)	**%**	Attributable cases (CI)	**%**	Attributable cases (CI)	**%**	Attributable cases (CI)	**%**
Scenario 1 WHO AQGs 2006	Obesity	**$PM_{2.5}$: 10 µg/m^3**	69 (24; 122)	2.82	412 (141; 730)	2.80	255 (88; 122)	2.79	736 (253; 1303)	2.81
	Overweight (and obesity)	**NO_2: 40 µg/m^3**	29 (19; 38)	0.35	125 (84; 166)	0.35	95 (64; 125)	0.34	249 (161; 316)	0.34
Scenario 2 WHO AQGs 2021	Obesity	**$PM_{2.5}$: 5 µg/m^3**	137 (47; 240)	5.61	822 (285; 1438)	5.60	509 (176; 892)	5.59	1468 (508; 2570)	5.60
	Overweight (and obesity)	**NO_2: 10 µg/m^3**	357 (241; 470)	4.32	1541 (1040; 2030)	4.32	1195 (807; 1574)	4.31	3094 (2081; 4062)	4.32

$PM_{2.5}$: particulate matter less than 2.5 µm of diameter; WHO: World Health Organization; AQGs Air Quality Guidelines; CI: Confidence Interval

Fig. 2: Maps of $PM_{2.5}$ and NO_2 in quintiles of exposure in Barcelona, Spain

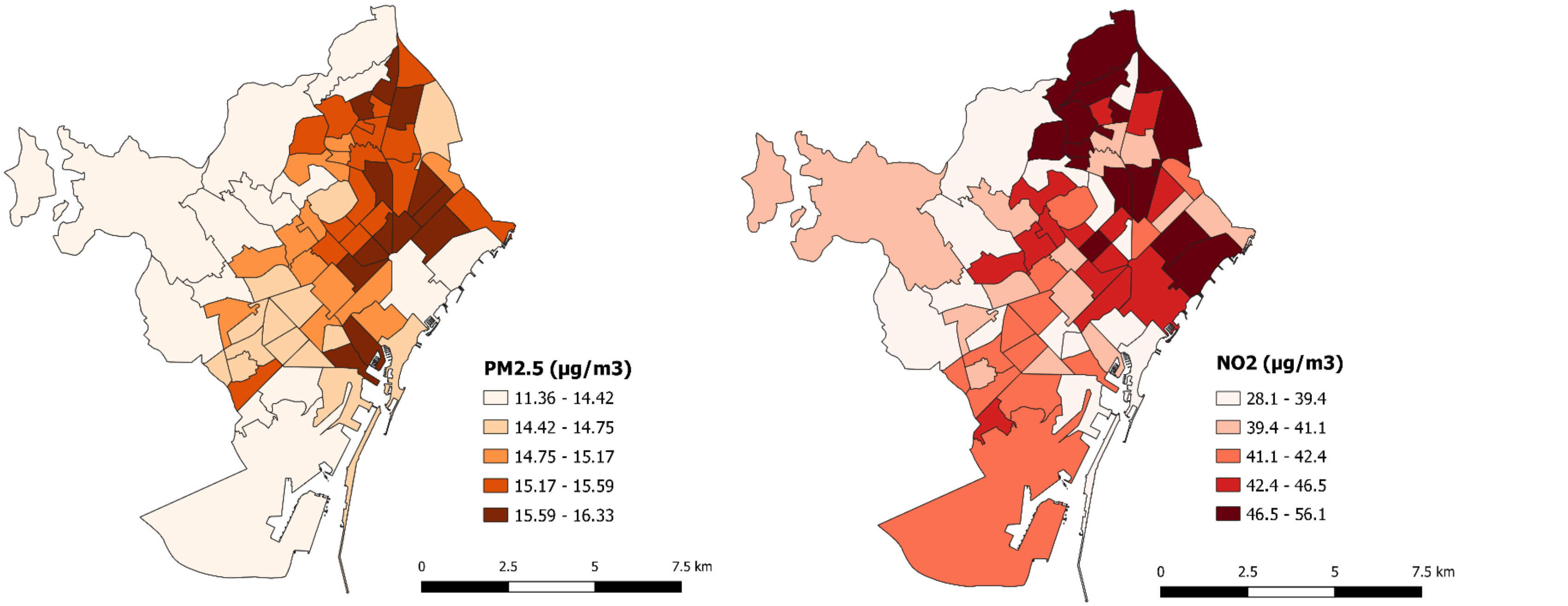


Table 4: Percentage and number of total expected cases attributed to urban green spaces by age groups and scenarios in Barcelona

Age range		**2-5 years**		**6-11 years**		**12-17 years**		**All children (2-17 years)**	
Overweight		Attributable cases (CI)	**%**	Attributable cases (CI)	**%**	Attributable cases (CI)	**%**	Attributable cases (CI)	**%**
Scenario 3 0.311 NDVI	**NDVI**	-409 (-1061; 90)	4.95	-1688 (-4446; 368)	4.73	-1232 (-3288; 262)	4.31	-3329 (-7617; 584)	4.65
Scenario 4 25% GA	**%GA**	-657 (-1658; 116)	7.97	-2835 (-7176; 499)	7.95	-2137 (-5431; 373)	7.71	-5629 (-12172; 921)	7.86

NDVI: Normalized Difference Vegetation Index; %GA: percentage of green spaces; CI: Confidence Interval

Table 4: Percentage and number of total expected cases attributed to urban green spaces by age groups and scenarios in Barcelona

	Children age range		**2-5 years**		**6-11 years**		**12-17 years**		**All children (2-17 years)**	
			Attributable cases (CI)	**%**	Attributable cases (CI)	**%**	Attributable cases (CI)	**%**	Attributable cases (CI)	**%**
Scenario 3 NDVI	Overweight (and obesity)	**NDVI: 0.311 units**	-409 (-1061; 90)	4.95	-1688 (-4446; 368)	4.73	-1232 (-3288; 262)	4.31	-3329 (-7617; 584)	4.65
Scenario 4 %GA		**%GA: 25%**	-657 (-1658; 116)	7.97	-2835 (-7176; 499)	7.95	-2137 (-5431; 373)	7.71	-5629 (-12172; 921)	7.86

NDVI: Normalized Difference Vegetation Index; %GA: percentage of green spaces; CI: Confidence Interval

Fig. 3: Maps of current NDVI and %GA of exposure by ABS in Barcelona, Spain

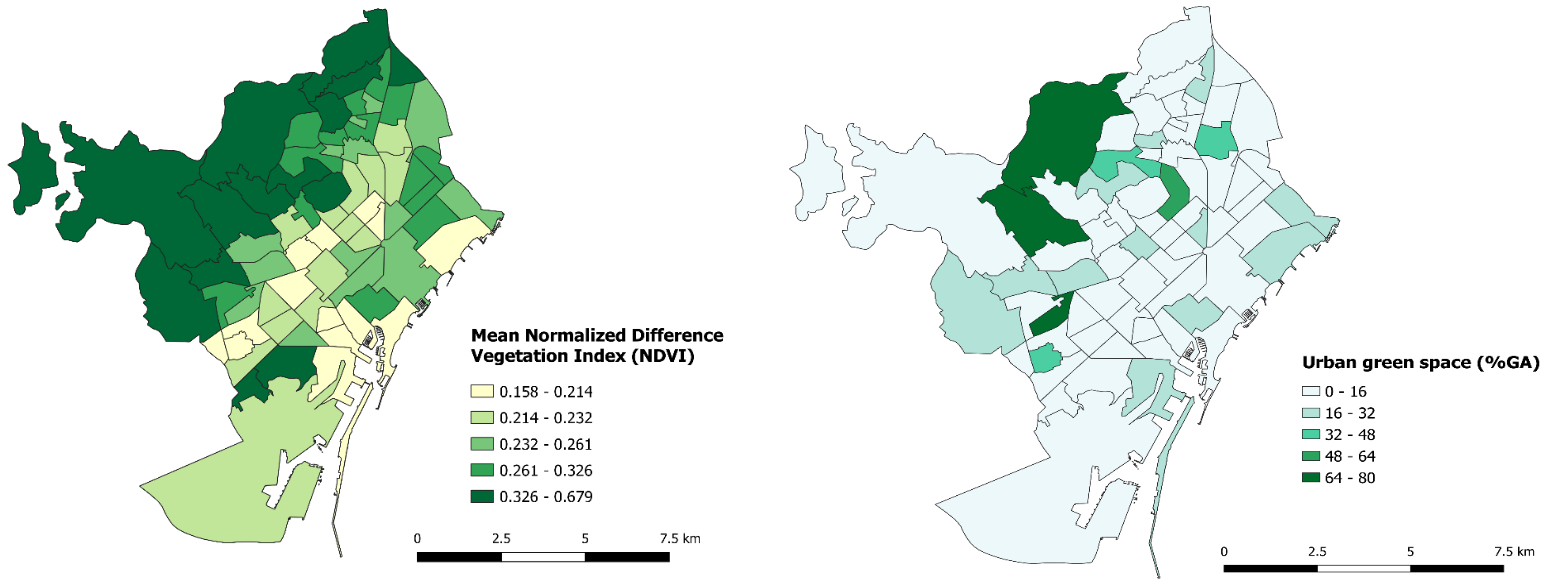


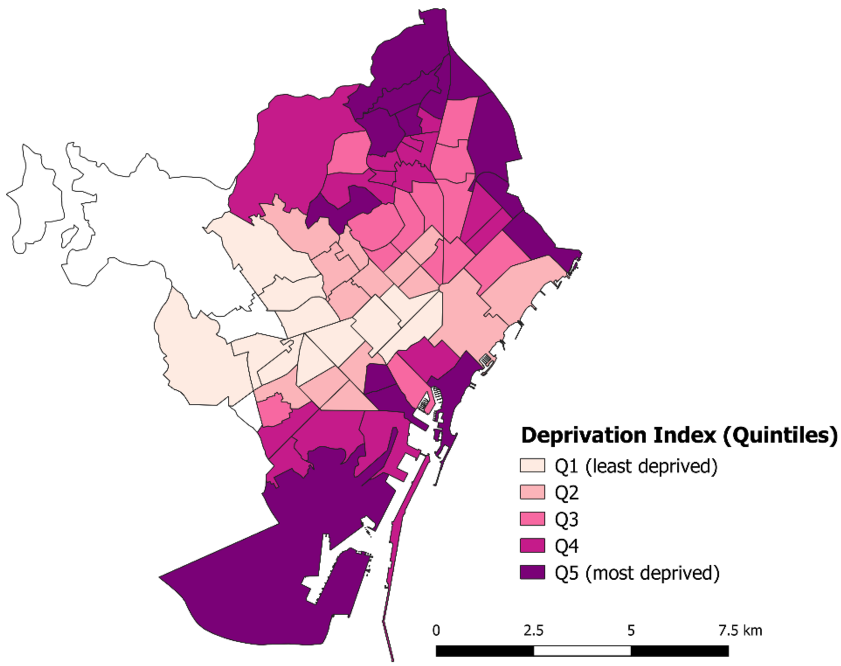
Table 5: Expected number of childhood overweight cases attributed to $PM_{2.5}$, NO_2, NDVI, %GA and deprivation index (in scenario 2, 3 and 4)

Exposure categories	Groups	Mean exposure levels	Standard Deviation (sd)	P-value	Attributable cases	%	LCI	UCI	P-value
$PM_{2.5}$ (µg/m^3) – Obesity									
	Q1 (least deprived)	14.70	0.53	Ref[a]	246	5.5	85	430	Ref[a]
	Q2	15.04	0.42	1.000	255	5.6	88	447	1.000
	Q3	15.51	0.51	**0.024**	326	5.92	113	569	**0.037**
	Q4	14.76	0.86	1.000	285	5.46	99	500	0.822
	Q5 (most deprived)	14.80	0.89	1.000	316	5.6	109	554	0.084
NO_2 (µg/m^3) – Overweight/Obesity									
	Q1 (least deprived)	40.21	4.61	Ref[a]	586	4.02	395	773	Ref[a]
	Q2	42.72	3.54	1.00	561	4.35	379	739	1.0
	Q3	44.17	6.09	0.53	679	4.6	459	894	0.7
	Q4	42.81	5.73	1.00	561	4.28	379	739	1.0
	Q5 (most deprived)	42.79	5.67	1.00	574	4.4	459	894	1.0
NDVI – Overweight/Obesity									
	Q1 (least deprived)	0.28	0.08	Ref[a]	-187	1.3	-858	10.30	Ref[a]
	Q2	0.22	0.02	0.404	-649	5.03	-1578	157	1.00
	Q3	0.25	0.05	1.00	-678	4.6	-1791	149	1.00
	Q4	0.31	0.09	1.00	-35	0.26	-278	-15	1.00
	Q5 (most deprived)	0.29	0.10	1.00	-1149	8.71	-2836	276	0.89
%GA – Overweight/Obesity									
	Q1 (least deprived)	16.23	26.98	Ref[a]	-746	5.1	-1865	113	Ref[a]
	Q2	6.73	14.52	1.00	-1165	9.04	-2643	208	1.00
	Q3	7.46	13.96	1.00	-1365	9.20	-3087	245	1.00
	Q4	15.19	19.94	1.00	-577	4.4	-1405	92	1.00
	Q5 (most deprived)	6.40	9.02	1.00	-1267	9.6	-2820	232	1.00

$PM_{2.5}$: particulate matter less than 2.5 µm of diameter; NO_2: nitrogen dioxide; NDVI: Normalized Difference Vegetation Index; %GA: percentage of green spaces; LCI: Lower Confidence Interval; UCI: Upper Confidence Interval; Q: Quintile

[a] Bonferroni test

Fig. 4: Map for deprivation index in Barcelona, Spain (blank ABS for no data available)

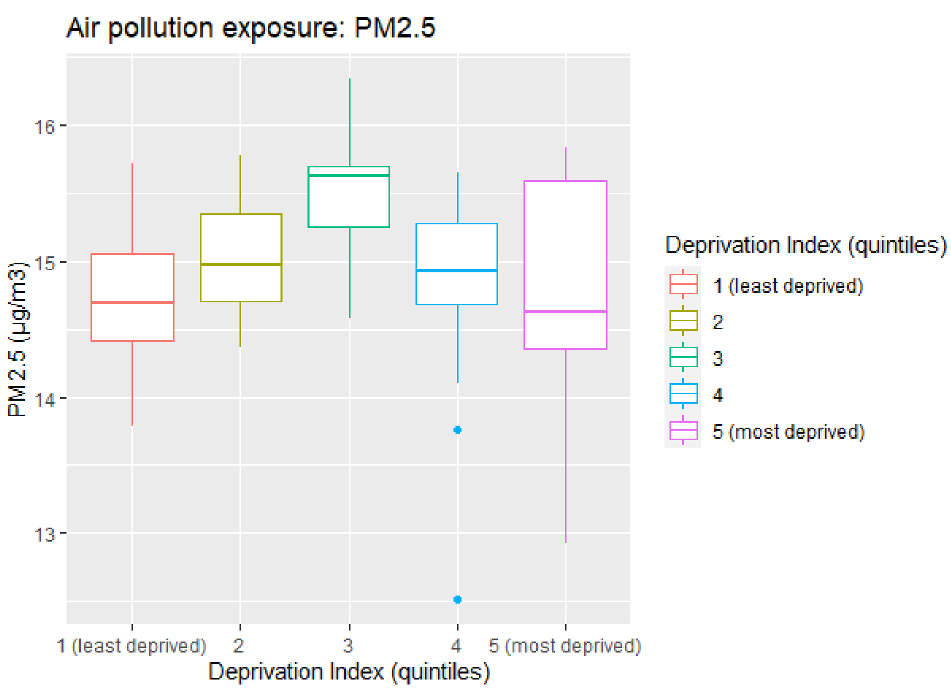


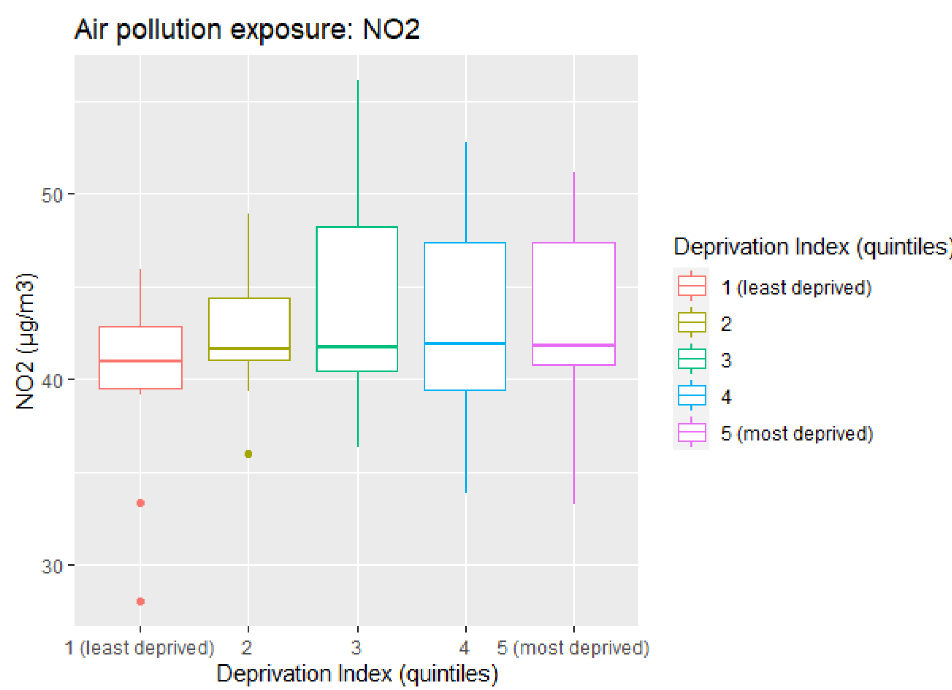
1. Activities carried out by the student

Review of the literature relevant to this Health Impact Assessment, elaboration of the project protocol (introduction, hypotheses, objectives, methods, and chronogram and incorporated "Cambios mayores" UPF TFM committee and oral defense of the protocol; weekly follow-ups and reviews the whole manuscript of the master thesis with advisors, cleaning of data and creation of databases; develop the comparative risk assessment, analysis with RStudio and mapping with QGIS, write a master thesis in paper format (introduction, methodology, results, discussion and conclusions) and discussed findings with advisors. Wrote the master thesis and the scientific article, incorporation of reviews from the UPF committee, oral defense of the master thesis, write a final version and send it to a scientific journal.

Appendices

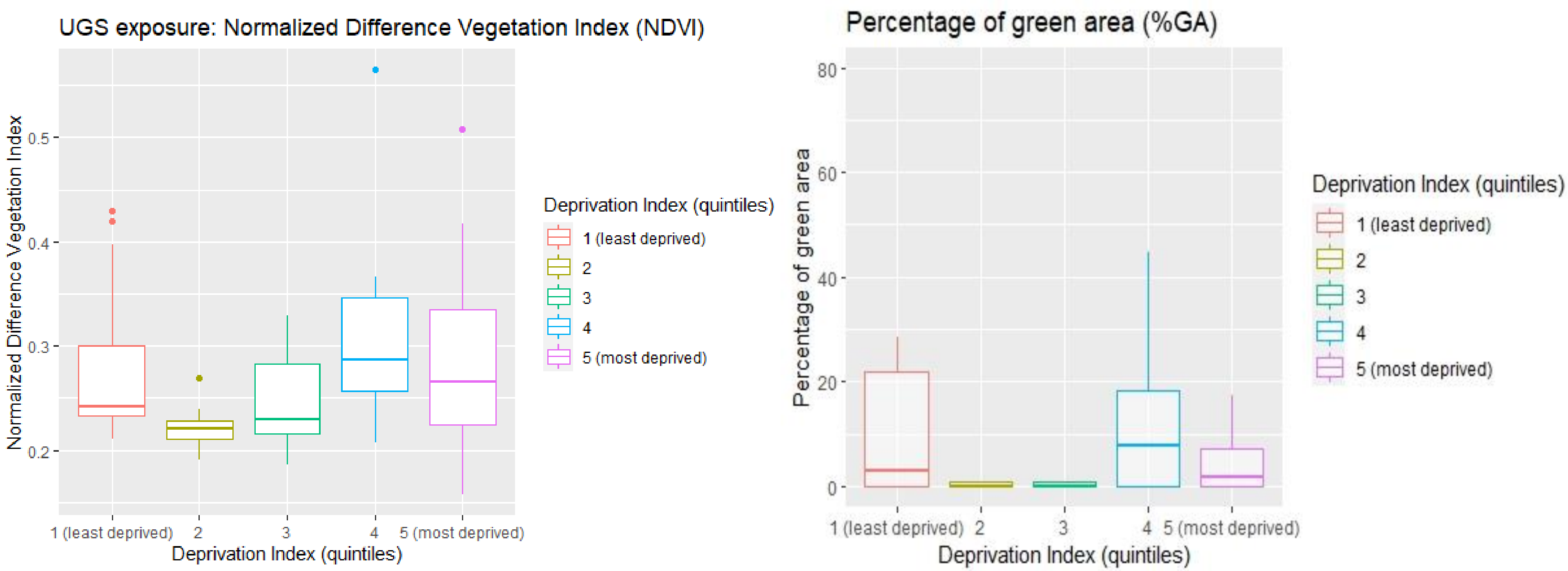
Fig. A.1: Current air pollution levels in Barcelona by deprivation index





In these boxplots are presented current air pollution levels ($PM_{2.5}$ and NO_2, respectively) in Barcelona, Spain by deprivation index in quintiles [Q1 (least deprived), Q2, Q3, Q4 and Q5 (most deprived)].

Fig. A.2: Current UGS levels in Barcelona by deprivation index



In these boxplots are presented current urban green spaces (UGS) levels (two proxies: NDVI and %GA) in Barcelona, Spain by deprivation index in quintiles [Q1 (least deprived), Q2, Q3, Q4 and Q5 (most deprived)].

Table A.1: Childhood overweight/obesity prevalence by deprivation index (quintiles)		
Deprivation index (Quintiles)	**Overweight/obesity (%)**	**Obesity (%)**
Q1 (least deprived)	27	8
Q2	32	11
Q3	34	13
Q4	37	15
Q5 (most deprived)	38	16
Q: Quintile		

Childhood overweight/obesity prevalence by deprivation index (quintiles) in Barcelona, Spain.