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Prevalence Distribution of Chronic Obstructive Pulmonary Disease (COPD) in the City of Osorno (Chile) in 2018, and Its Association with Fine Particulate Matter $PM_{2.5}$ Air Pollution

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Abstract: Outdoor air pollution and biomass smoke exposure are related to the prevalence of chronic obstructive pulmonary disease (COPD). Since Osorno, Chile, is saturated with fine particulate matter ($PM_{2.5}$), the aim of this work is to determine the prevalence distribution of COPD patients in the Primary Health Care (PHC) system in the city of Osorno, and its relationship with $PM_{2.5}$. A cross-sectional descriptive study was carried out on COPD patients enrolled in the six PHC centers (PHCCs) of the city to assess the adjusted prevalence (population over 40 years). Gender- and territory-associated odds ratios (ORs) were also determined. In addition, an urban analysis of the distribution of $PM_{2.5}$ and an exploratory analysis of the spatial behavior of enrolled COPD patients through featured binning were carried out. In 2018, the city of Osorno had 809 enrolled COPD patients in the PHC system (55.1% female), with a 1.3% age-adjusted prevalence (inhabitants over 40 years old), which was 11.7% after underdiagnosis correction. The COPD patients were mainly between 70 and 79 years old (34.3%). The urban area under the administration of the PHCC Rahue Alto (PHCC-RA) had a higher OR (1.98 [1.73–2.26]) compared to the situation of the city. Also, air pollution ($PM_{2.5}$) was the highest in the PHCC-RA area, which could account for the observed prevalence. The number of COPD patients in this area is the highest in the commune, which increases the risk of complications derived from the disease and air pollution. Thus, territories with the highest COPD prevalence have the largest OR, which could complicate patients' condition due to the high levels of outdoor air pollution.

Keywords: outdoor $PM_{2.5}$; chronic obstructive pulmonary disease; Osorno

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1. Introduction

Chronic obstructive pulmonary disease (COPD) is a global public health problem due to its high prevalence, its progressive condition, the deterioration of the patient's quality of life, and its great economic impact [1]. Smoking is the primary risk factor for COPD, but not all smokers develop the disease, as it also depends on genetic susceptibility [2] and other exogenous factors, such as exposure to biomass combustion smoke [3].

In 2015, 3.2 million people died from COPD worldwide [4]. In 2017, the prevalence was estimated at 300 million patients, and it was the cause of 5.7% of all global deaths [5]. Global mortality of COPD is anticipated to increase up to 7.8% of total mortality in 2030 [6], unless urgent actions are taken to reduce underlying risk factors, especially smoking. However, globally, while 1.1 billion people smoke tobacco, about 3 billion people are exposed to biomass-burning smoke [7,8]. In 2010, the global prevalence of COPD was estimated at 11.7% [9]. The Latin American Pulmonary Obstruction Research Project (PLATINO) of the Latin American Thoracic Association estimated that Santiago—the capital of Chile—has a crude prevalence of 16.9%, or 14.5% when adjusted by age (over 40 years), sex, ethnicity, education, pack-years of smoking, exposure to household biomass and coal pollution, occupational exposure to dust, and body mass index [10].

Exposure to outdoor air pollution is also related to the prevalence and incidence of COPD [11,12] and a decrease in respiratory function [13]. In Chile, 31.8% of patients with COPD report having never smoked, so this high prevalence would be associated with exposure to occupational dust or gases, biomass combustion, history of pulmonary tuberculosis, chronic asthma, respiratory infections during childhood, air pollution, and the socioeconomic stratum [14].

Atmospheric pollution is the presence of polluting elements in the air that alter its composition and affect any component of the ecosystem [15]. It is a public health problem worldwide, mainly due to its harmful effects on the respiratory and cardiovascular systems [16]. Among the pollutants, particulate matter (PM) is distinguished into a large fraction ($\leq$10 µm, PM_{10}) and a fine fraction ($\leq$2.5 µm, $PM_{2.5}$), composed of particles small enough that they can penetrate the respiratory tract until reaching the alveoli and the bloodstream [17].

Exposure to air pollutants increases both morbidity and mortality rates, as well as the number of hospital admissions of patients with respiratory and cardiovascular symptoms [16], and is of particular importance due to its harmful effect on patients with chronic respiratory diseases [18]. It is estimated that worldwide, 1.4% of mortality is associated with air pollution [19–21]. According to the World Health Organization (WHO), in 2020, there were 3.2 million deaths attributable to the effects of indoor pollution produced by the combustion of paraffin, biomass, and coal, used for heating and/or cooking, of which 19% were from COPD [22]. In China, incomplete combustion of biomass fuel is responsible for 10–12% of COPD cases in non-smokers [23]. However, the impact of air pollution derived from biomass combustion on COPD has not been directly studied in Chile.

The city of Osorno is located 938 km south of Santiago, the capital of Chile. It is the third-most $PM_{2.5}$-polluted city in Chile, with an annual average of 30 µg/m^3 in 2023, after Coyhaique (Aysén region; 38 µg/m^3) and Padre las Casas (Araucanía region, 33 µg/m^3) (https://sinca.mma.gob.cl/index.php/, accessed on 22 March 2024). Osorno was declared a saturated zone for PM_{10} and $PM_{2.5}$ in 2012 [24]. As of 2016, the Atmospheric Decontamination Plan for the City of Osorno has been in effect [25]. According to the 2017 CENSUS, the commune has 161,460 inhabitants, of which 91.4% are located within the urban radius (city of Osorno). The city has 60,132 homes [26], with an average annual consumption of 13.4 m^3 of firewood per home in 2017 [27].

In this work, we determine the sociodemographic characteristics and prevalence of COPD among the inhabitants of the different administration territories of the Primary Health Care Centers (PHCCs) in the city of Osorno, Los Lagos Region, Chile, in 2018. In addition, we describe the geographical distribution pattern of patients according to the levels of $PM_{2.5}$ in the city. First, we analyzed the territorial distribution of COPD patients enrolled in the six PHCCs from the city and the age-adjusted prevalence distribution (regarding the population over 40 years old). To establish whether living in a particular area in the city of Osorno is a risk factor for COPD, and to compare the magnitude of different territories' risks for that outcome, odds ratio (OR) analysis was also carried out. Then, we mapped the urban distribution of $PM_{2.5}$ during the critical air pollution episodes in the city and discussed how this factor could affect the health of COPD patients and the functioning of the Primary Health Care system.

2. Materials and Methods

2.1. Study Design and Ethical Approval

An analytical, observational, and cross-sectional research was carried out, which incorporated an independent variable ($PM_{2.5}$ pollution) in a quasi-experimental manner. The administration territories of each of the six Primary Health Care Centers (PHCCs) were delimited for the entire city of Osorno (urban Osorno, UOS), being the following: PHCC Marcelo Lopetegui, hereinafter PHCC-ML; PHCC Ovejería, PHCC-OV; PHCC Pampa Alegre, PHCC-PA; PHCC Pedro Jauregui, PHCC-PJ; PHCC Quinto Centenario, PHCC-QC; and PHCC Rahue Alto, PHCC-RA (Figure 1). The territorial information from the Health Department of the Municipality of Osorno (HDMO) was used. Polygons were adjusted using the ArcGIS Desktop 10.5 software (Environmental Systems Research Institute, Inc., ESRI. Redlands, CA, USA, 2020), according to the urban boundary of Osorno obtained from the 2017 census micro-data [28]. This study was approved by the Scientific Ethics Committee of the Valdivia Health Service (ORD N°036, 17 February 2020).

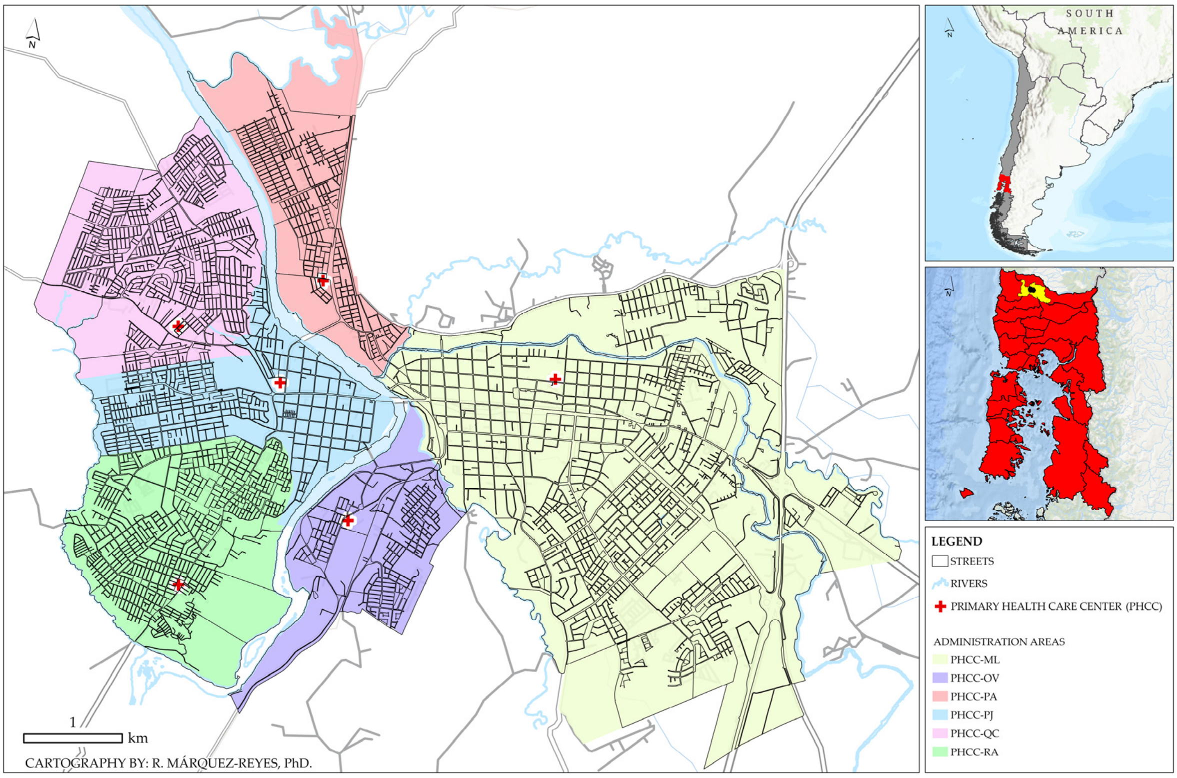

Figure 1. Administration areas of the six Primary Health Care Centers (PHCCs) in the city of Osorno, Los Lagos region, Chile. Colored areas depict the urban territories administered by each PHCC (located at red crosses). Right upper insert, location map of the Los Lagos region (red) in Chile (gray). Middle insert, location of the city of Osorno (black dot) within the commune of the same name (yellow area) in the Los Lagos region (red). PHCC-ML, Primary Health Care Center Marcelo Lopetegui; PHCC-OV, Ovejería; PHCC-PA, Pampa Alegre; PHCC-RA, Rahue Alto; PHCC-PJ, Pedro Jauregui; PHCC-QC, Quinto Centenario. Open arrowhead, magnetic north. Bar, 1 km.

2.2. COPD Patients' Information, Adjusted Prevalence, and Odds Ratio

Secondary databases of COPD patients, obtained from the patient registry of the Adult Respiratory Disease Control Program, were acquired between March and May 2020. The studied population was enrolled in the PHC system in 2018. Consolidated data were submitted to HDMO in June 2019. Thereafter, HDMO staff deleted sensitive data not related to this study, and patients' names were anonymized. The sociodemographic characteristics of users with COPD were identified, including age, sex, educational level, ethnicity, nationality, and address. Adjusted prevalence was determined by the relationship between the number of users with COPD and the population over 40 years old living in the administration area of each PHCC, and at the city level (urban Osorno, UOS). The population structure and composition in the city of Osorno and in each of the six PHC system territories were obtained from the Economic Commission for Latin America and the Caribbean (ECLAC)-REDATAM database (available at https://redatam.org/cdr/descargas/censos/poblacion/CP2017CHL.zip, accessed on 15 March 2024). A contingency table analysis was carried out to determine the odds ratio (OR). The OR was used to establish whether living in a particular area in the city of Osorno (i.e., different PHCC administration territories) is a risk factor for COPD, and to compare the magnitude of different territories for that outcome (see the workflow methodology in Figure S1).

2.3. Territorial Analysis

The users' addresses were standardized at the block level, geolocated using the Google Earth Pro program (Google LLC, Mountainview, CA, USA), and exported as a KMZ file. Employing the kernel density tool from ArcGIS Desktop 10.5 software (ESRI, Redlands, CA, USA, 2020), an exploratory analysis of the spatial behavior of users with COPD (heat maps; patient distribution) was carried out (Figure 2). Also, feature binning was carried out to increase the visualization capability by using ArcGIS Pro 3.1 (ESRI, Redlands, CA, USA, 2023) [29]. Feature binning aggregates large amounts of point features into dynamic polygon bins that vary through scaled levels of detail, and a single bin represents all features within its boundaries at that level of detail [30].

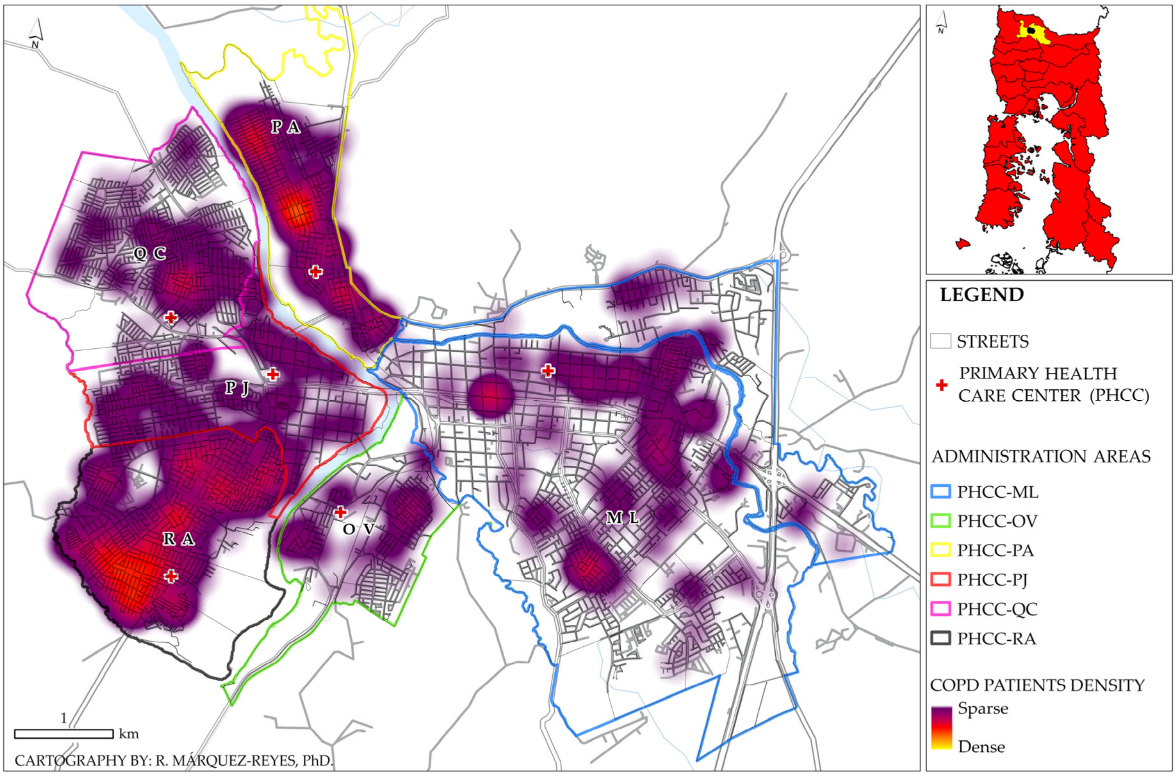

Figure 2. Heat map of COPD patients' distribution in the city of Osorno. Colored scale, from sparse (purple) to dense (yellow). Administration areas of the six Primary Health Care Centers (PHCCs) in the city of Osorno are depicted. PHCC-ML, Primary Health Care Center Marcelo Lopetegui (blue); PHCC-OV, Ovejería (green); PHCC-PA, Pampa Alegre (yellow); PHCC-RA, Rahue Alto (dark grey); PHCC-PJ, Pedro Jauregui (red); PHCC-QC, Quinto Centenario (pink). Upper right insert, location map of the city of Osorno (black) in the Los Lagos region. Open arrowhead, magnetic north. Bar, 1 km.

2.4. *$PM_{2.5}$ Air Pollution Data and Measurements*

The Chilean Ministry of the Environment defines the critical episode management (CEM) period in the commune of Osorno between 1 April and 30 September of each year. During pre-emergency episodes, the $PM_{2.5}$ 24 h average is between 110 and 169 μg/m^3; in emergency episodes, the $PM_{2.5}$ 24 h average is greater than or equal to 170 μg/m^3 [31].

The whole-commune air pollution ($PM_{2.5}$) data from 2019 were obtained from Osorno's Ministry of the Environment air quality monitoring station [31]. Annual daily average $PM_{2.5}$ levels were used. Hourly $PM_{2.5}$ pollution data on verified pre-emergency (24 h average, $PM_{2.5}$ 110–169 μg/m^3; n = 20) and emergency (24 h average, $PM_{2.5} \geq 170$ μg/m^3; n = 7) days were also downloaded. Territorial $PM_{2.5}$ levels were recorded in 142 different points of the commune (Figure 3A) using the portable eSAMPLER Dual Ambient Monitor/Sampler fine particulate matter measurement equipment (MetOne Instruments Inc., Grants Pass, OR, USA), which allows the measurement of particles in real time through the scattering of visible laser light. The measurements were carried out between 18:00 and 23:59 Chilean local time (CLT) on the days defined as a critical air pollution episode (pre-emergency, n = 26; and/or emergency, n = 17) according to the Chilean Ministry of the Environment forecast model. Collected data were analyzed using advanced geostatistical autocorrelative kriging modeling, which generates an estimated surface from a set of scattered points.

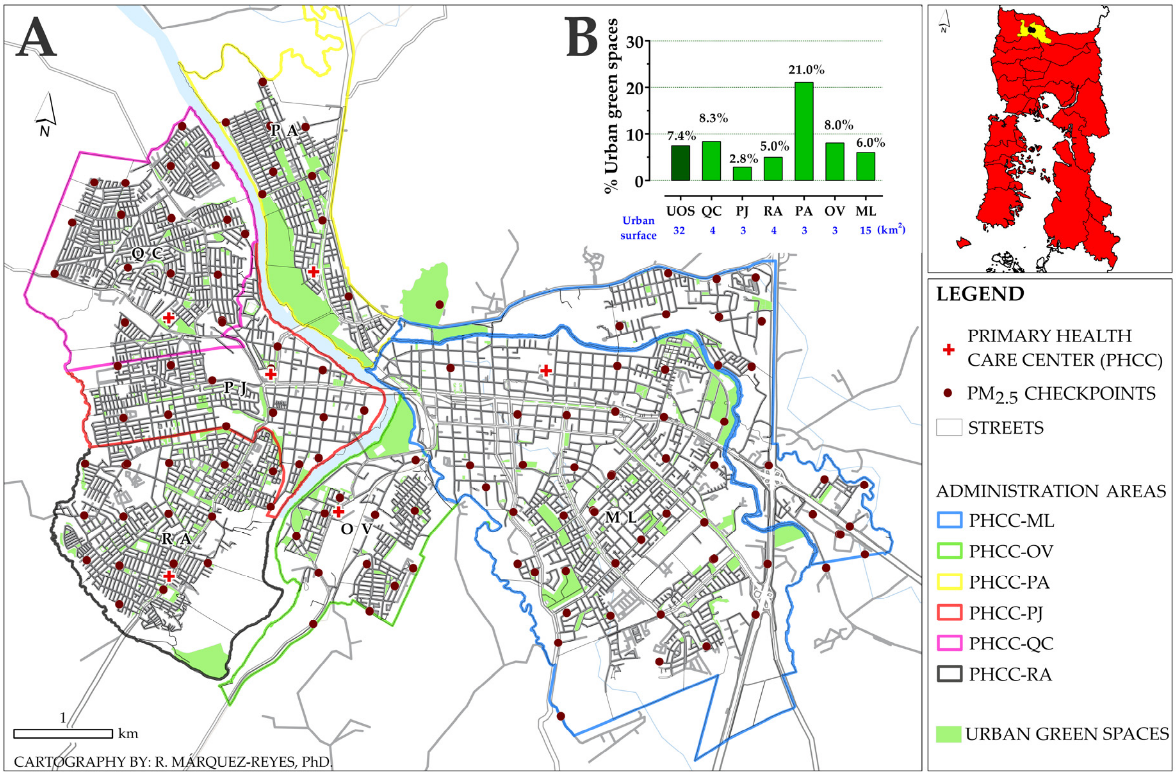

Figure 3. Local air pollution recording and urban green areas in the city of Osorno. (**A**) $PM_{2.5}$ was measured at 142 points (purple dots) on emergency and pre-emergency days in 2019. Open arrowhead, magnetic north. Upper right insert, location map of the city of Osorno (black) in the Los Lagos region. Bar, 1 km. (**B**) Urban green spaces (UGSs) are hatched in light green. PHCC-ML, Primary Health Care Center Marcelo Lopetegui; PHCC-OV, Ovejería; PHCC-PA, Pampa Alegre; PHCC-RA, Rahue Alto; PHCC-PJ, Pedro Jauregui; PHCC-QC, Quinto Centenario.

To obtain the surface of urban green spaces (UGSs; Figure 3B), the communal (municipality) inventory of urban green areas was uploaded, grouped by PHCC administration areas, and obtained by using the geometry calculation tool from ArcGIS Pro 3.1 (ESRI 2023). WGS84 projection and UTM 18 S coordinates were used.

2.5. Statistical Analyses

Analyses were performed and graphs were made using GraphPad Prism® version 6.07 software (GraphPad Software, San Diego, CA, USA). Odds ratios were expressed as ORs and 95% confidence intervals (OR [95% CI]). OR = 1, territory does not affect odds of COPD; OR > 1, territory associated with higher odds of COPD; and, OR < 1, territory associated with lower odds of COPD. Statistical differences were ascertained by Chi-square and considered significant when $p < 0.05$. Whole-city (UOS) and PHCC area averages of $PM_{2.5}$ values are Means ± Standard Error of the Mean (SEM). Statistical differences were ascertained using the two-way Mann–Whitney test and considered significant when $p < 0.05$.

3. Results

3.1. Sociodemographic Data

In 2018, the city of Osorno had 147,666 inhabitants (52.5% females; 2017 Census). The study group was the urban population of Osorno (UOS) over 40 years old, which corresponded to 62,839 inhabitants (42.6% of the total population), with 34,764 (55.3%) females and 28,075 (44.7%) males. The Primary Health Care (PHC) system had 809 users with COPD, with 55.1% (n = 446) females and 44.9% (n = 363) males (Table 1). Regarding territorial distribution among the six PHCCs in the city, it was greatest in the PHCC-RA, with 36.1% of the users and 18.5% of the city's population over 40 years old. The second greatest was PHCC-ML, with 22.7% of users with COPD and 32.1% of the above-mentioned population. Regarding the age of the patients, the ranges of 60–69 years stand out, with 27.5% of the cases, and 70–79 years, with 34.3%. The median age of COPD patients reached 72 years. In terms of the maximum educational level reached, 45.4% of users reported incomplete primary education and 17.3% reported having completed primary education. This proportion was obtained from patients who declared their educational level (416 out of 809). Regarding native people (4.4% Mapuche) and nationality (99.8% Chilean), they are variables with little representation within the sample and their analysis was carried out by incorporating them within the administration territory. A detailed sociodemographic description at the territory level of each Family Health Care Center can be found in Table S1.

Table 1. Sociodemographic characteristics of users with chronic obstructive pulmonary disease (COPD) enrolled in the Primary Health Care (PHC) system from the city of Osorno in 2018.

Variable	Frequency	%
Gender		
Female	446	55.1
Male	363	44.9
Age (Years Old)		
40–49	18	2.2
50–59	97	11.9
60–69	223	27.5
70–79	278	34.3
80 and older	193	23.8
Educational Level [1]		
Without educational teaching	36	8.6
Incomplete primary education	189	45.4
Complete primary education	72	17.3
Incomplete secondary education	38	9.1
Complete secondary education	60	14.4
Incomplete higher education	4	0.9
Complete higher education	17	4.1
Ethnicity		
Mapuche	36	4.4
None	773	95.6

Table 1. *Cont.*

Variable	Frequency	%
Primary Health Care Center (PHCC) [2]		
Marcelo Lopetegui (PHCC-ML)	184	22.7
Ovejería (PHCC-OV)	43	5.3
Pampa Alegre (PHCC-PA)	144	17.8
Rahue Alto (PHCC-RA)	292	36.1
Pedro Jáuregui (PHCC-PJ)	83	10.3
Quinto Centenario (PHCC-QC)	63	7.8
Nationality		
Chilean	807	99.8
Foreigner	2	0.2

[1] Educational level is expressed with respect to the users who reported that variable (n = 416). [2] Expressed as a percentage of the total users with COPD.

3.2. COPD Adjusted Prevalence and Odds Ratio

The urban adjusted prevalence was 13 cases per 1000 inhabitants over 40 years old (1.3%), for both females and males. The highest prevalence was found in the PHCC-RA area, with 26 cases per 1000 inhabitants among females, and 24 per 1000 in males; while the lowest age-adjusted prevalence corresponded to the PHCC-QC area, with 5 and 7 cases per 1000 inhabitants, for females and males, respectively (Table 2). Contingency analysis and odds ratios (ORs) of the COPD condition were analyzed in the different PHCC administration areas (Figure 4). It was observed that the inhabitants of the PHCC-RA territory had a higher OR, being 1.98 [1.73–2.26], compared to the total urban situation (UOS) (Figure 4A). Similarly, both female and male people in PHCC-RA had a higher OR than the communal situation, being 2.03 [1.69–2.44] and 1.91 [1.56–2.34], respectively (Figure 4B,C). Finally, both in the entire city and in the different PHCC administration areas, we did not find significant differences between females and males (Figure 4D).

Table 2. Adjusted prevalence of COPD, according to Primary Health Care Center (PHCC) administration areas and sex, in the city of Osorno in 2018. UOS, urban area of Osorno; PHCC-ML, PHCC Marcelo Lopetegui; PHCC-OV, Ovejería; PHCC-PA, Pampa Alegre; PHCC-RA, Rahue Alto; PHCC-PJ, Pedro Jauregui; PHCC-QC, Quinto Centenario.

Territory	Females			Males		
	COPD Patients	Population over 40 Years Old [1]	Age-Adjusted Prevalence (Per 1000 Inhabitants) [2]	COPD Patients	Population over 40 Years Old [1]	Age-Adjusted Prevalence (Per 1000 Inhabitants) [2]
UOS	446	34,764	13	363	28,075	13
PHCC-ML	105	11,238	9	79	8906	9
PHCC-OV	24	2228	11	19	1835	10
PHCC-PA	77	4537	17	67	3557	19
PHCC-RA	162	6302	26	130	5320	24
PHCC-PJ	49	4170	12	34	3391	10
PHCC-QC	29	6289	5	34	5066	7

[1] According to 2017 Chilean Census. [2] Inhabitants over 40 years old.

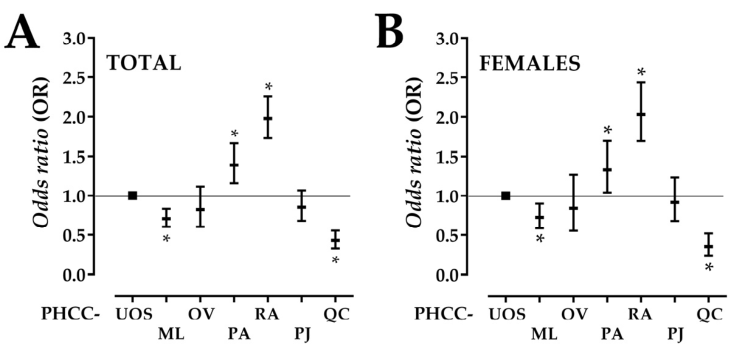

Figure 4. *Cont.*

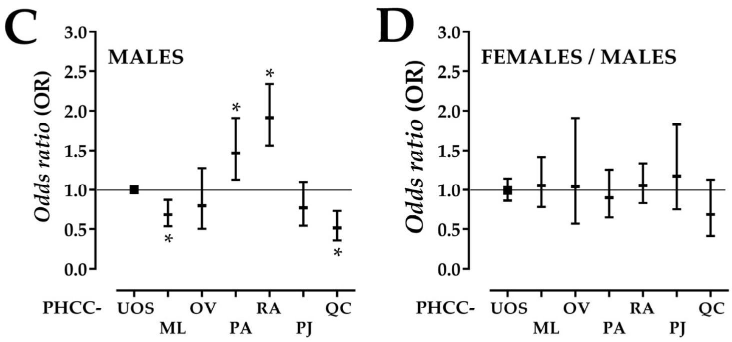

Figure 4. Territorial odds ratios (ORs) in patients with COPD. (**A**) Odds ratios in the entire population (females and males) over 40 years old from the city of Osorno (UOS, closed square), and in the different areas of Primary Health Care Centers (PHCCs); (**B**) in females; (**C**) in males; (**D**) female-to-male ratio. Values, OR ± 95% confidence interval (CI). *, $p < 0.05$, assessed by contingency analysis and the Chi-square test regarding the urban communal situation. UOS, urban area of Osorno; PHCC areas: ML, Marcelo Lopetegui; OV, Ovejería; PA, Pampa Alegre; RA, Rahue Alto; PJ, Pedro Jáuregui; QC, Quinto Centenario.

3.3. $PM_{2.5}$ Outdoor Air Pollution in Osorno

The annual average of outdoor levels of $PM_{2.5}$ measured in 2019 in Osorno reached 33.3 ± 2.2 μg/m^3 (Mean ± SEM, n = 365) with a marked seasonality, mainly associated with biomass combustion [32]. As shown in Figure 5A, there was an increase in $PM_{2.5}$ levels in April, and they remained elevated until September. In consequence, monthly averages were also elevated throughout the entire period of critical episode management (CEM; Figure 5B). So, between autumn and winter (April to September), there was a five-fold increase in $PM_{2.5}$ air pollution compared with summer (January to March) and spring (October to December) (Figure 5B, upper inset). It must be noted that the annual average reached 33.2 ± 2.2 μg/m^3, a value that is significantly lower than the CEM period average (56.4 ± 3.6 μg/m^3; $p < 0.05$, two-tailed Mann–Whitney test).

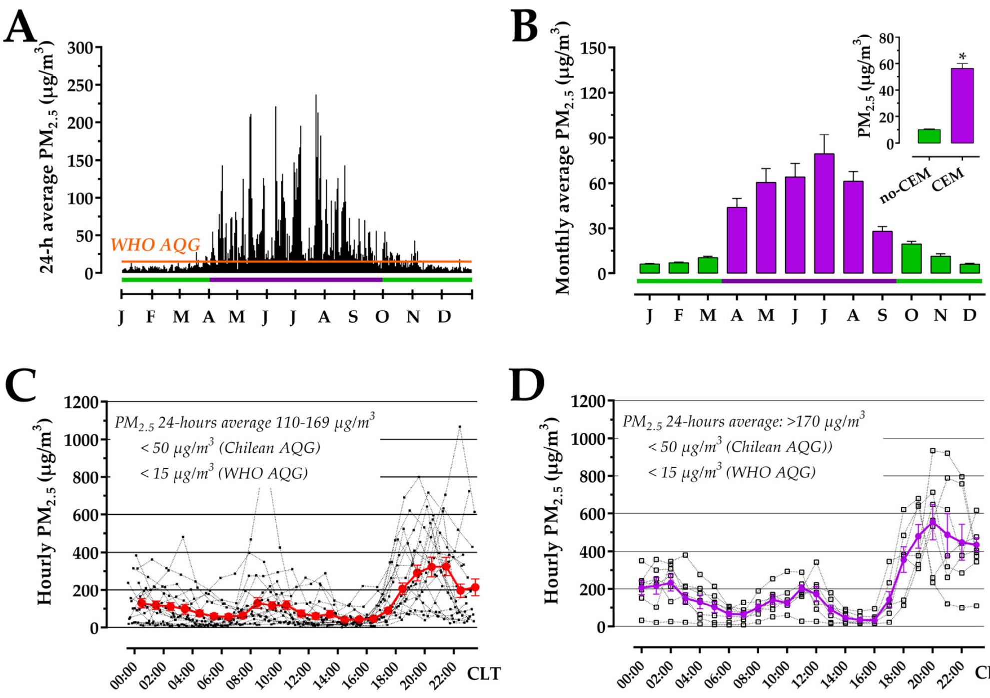

Figure 5. Outdoor air pollution in Osorno in 2019. (**A**) Daily averages of $PM_{2.5}$. Green line below the recording, critical episode management (CEM) period (from 1 April to 30 September); purple line, no-CEM period (from 1 January to 31 March, and from 1 October to 31 December). The orange line

at 15 μg/m^3 depicts the 24 h WHO Air Quality Guideline (AQG). (**B**) Monthly averages of $PM_{2.5}$. Upper insert, $PM_{2.5}$ concentration both in the CEM (green) and no-CEM (purple) periods. Values, Means ± SEMs. * $p < 0.01$, Mann–Whitney test. (**C**) Hourly variation in $PM_{2.5}$ levels on the twenty days of verified pre-emergency. Filled squares with dotted connecting lines depict individual circadian changes; red-filled circles, the Means ± SEMs (n = 20). (**D**) Hourly variation in $PM_{2.5}$ levels on the seven verified emergency days. Open squares with dotted connecting lines depict individual circadian changes; purple-filled circles, Means ± SEM's (n = 7); CLT, Chilean local time.

Daily variations in $PM_{2.5}$ air pollution were also analyzed during pre-emergency and emergency critical episodes in 2019. Figure 5C summarizes the hourly $PM_{2.5}$ changes on 20 verified pre-emergency days. $PM_{2.5}$ reached its maximal values of ca. 320 μg/m^3 in the late evening, between 20:00 and 21:00 CLT. A second peak in $PM_{2.5}$ was observed (ca. 130 μg/m^3) in the morning, between 08:00 and 10:00 CLT. During verified emergency episodes (n = 7, Figure 5D), $PM_{2.5}$ reached its maximal value of ca. 550 μg/m^3 at 20:00 CLT and remained elevated up to 23:00 CLT. A second marked increase in $PM_{2.5}$ was observed (ca. 200 μg/m^3) in the morning, at 11:00 CLT. It must be noted that $PM_{2.5}$ air pollution reached its nadir (ca. 40 μg/m^3) between 14:00 and 16:00 CLT in both pre-emergency and emergency episodes. These data also show that the evening increase in $PM_{2.5}$ reached a rate (from 16:00 to 20:00 CLT) of ca. 70 μg/m^3/h and 125 μg/m^3/h during pre-emergency end emergency episodes, respectively.

3.4. Territorial $PM_{2.5}$ Air Pollution

Between April and September 2019, 26 pre-emergency and 17 emergency episodes were predicted [33]. During those days, $PM_{2.5}$ was measured in different points of the communal urban area (Figure 3), to apply a self-correlative model (kriging) and determine the sectorial communal distribution of $PM_{2.5}$. As shown in Figure 6A, fine PM air pollution is heterogeneously distributed in the commune. The three territories located to the west of the Rahue River, QC, PJ, and RA, remain in the same contamination range ($PM_{2.5}$ > 170 μg/m^3). Figure 6B shows that the average $PM_{2.5}$ values in the recording period are different, being higher in the PHCC-RA area (446.1 ± 58.0 μg/m^3), followed by PHCC-PJ (304.1 ± 66.6 μg/m^3) and then PHCC-QC (274.1 ± 38.5 μg/m^3). The highest result is directly associated with the highest OR of COPD for the inhabitants of the PHCC-RA area, unlike what is observed in the PHCC-OV area, which presents the lowest pollution levels and ORs.

3.5. COPD Patient Distribution in Osorno

Figure 7 shows the aggregated distribution of COPD patients into hexagonal binnings for each urban territory. Patients, both females (Figure 7A) and males (Figure 7B), are mainly concentrated in the PHCC-RA area, a zone that is exposed to the highest levels of $PM_{2.5}$ pollution during pre-emergency and emergency critical episodes (Figure 6A). The greatest average number of patients per binning was in the PHCC-RA area, both for females and males. Also, the maximum aggregation numbers were in the PHCC-RA area, with 13 and 8 patients for females and males, respectively. It is interesting to mention that despite the PHCC-PA area having a maximum aggregation number of 12 and 8 patients for females and males, respectively, the $PM_{2.5}$ levels recorded during the CEM period in 2019 (107.2 ± 35.0 μg/m^3) were lower than in the PHCC-RA area (Figure 6B). This area is the one with the highest percentage of green areas in the city (Figure 3).

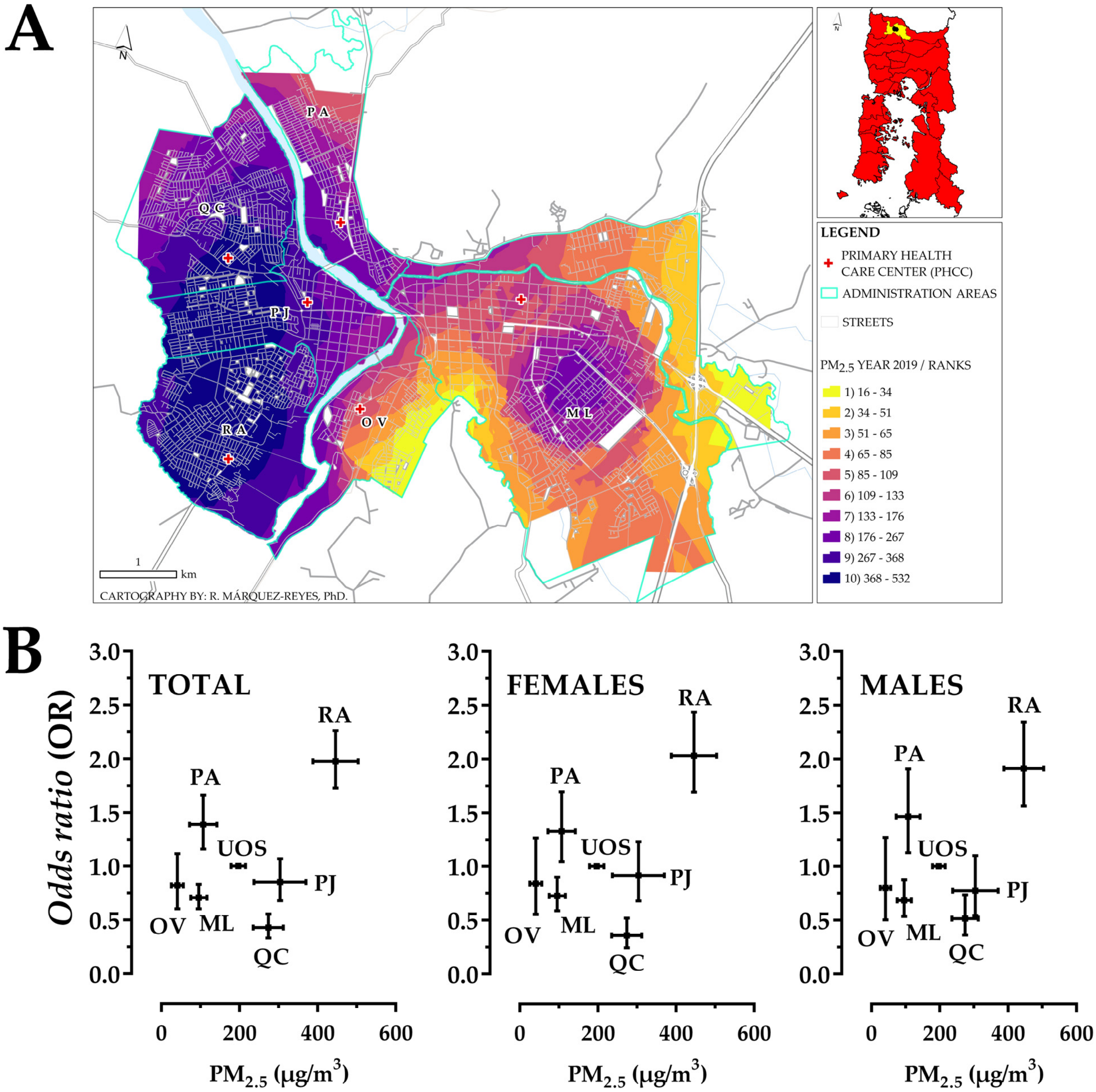

Figure 6. Air pollution distribution in Osorno and territorial ORs of COPD. (**A**) Autocorrelative model of $PM_{2.5}$ pollution in the different management areas of each of the Primary Health Care Centers (PHCCs; red crosses) in the city of Osorno. $PM_{2.5}$ levels are ranked on a color scale. Upper right insert, location map of the city of Osorno (black) in the Los Lagos region. Bar, 1 km. (**B**) Association between average levels of $PM_{2.5}$ pollution and the territorial ORs in the total urban population, females, and males. Abscissae, $PM_{2.5}$ values are Mean ± SEM; ordinate, OR (95% CI). UOS, urban area of Osorno; PHCCs: ML, Marcelo Lopetegui; OV, Ovejería; PA, Pampa Alegre; RA, Rahue Alto; PJ, Pedro Jáuregui; QC, Quinto Centenario.

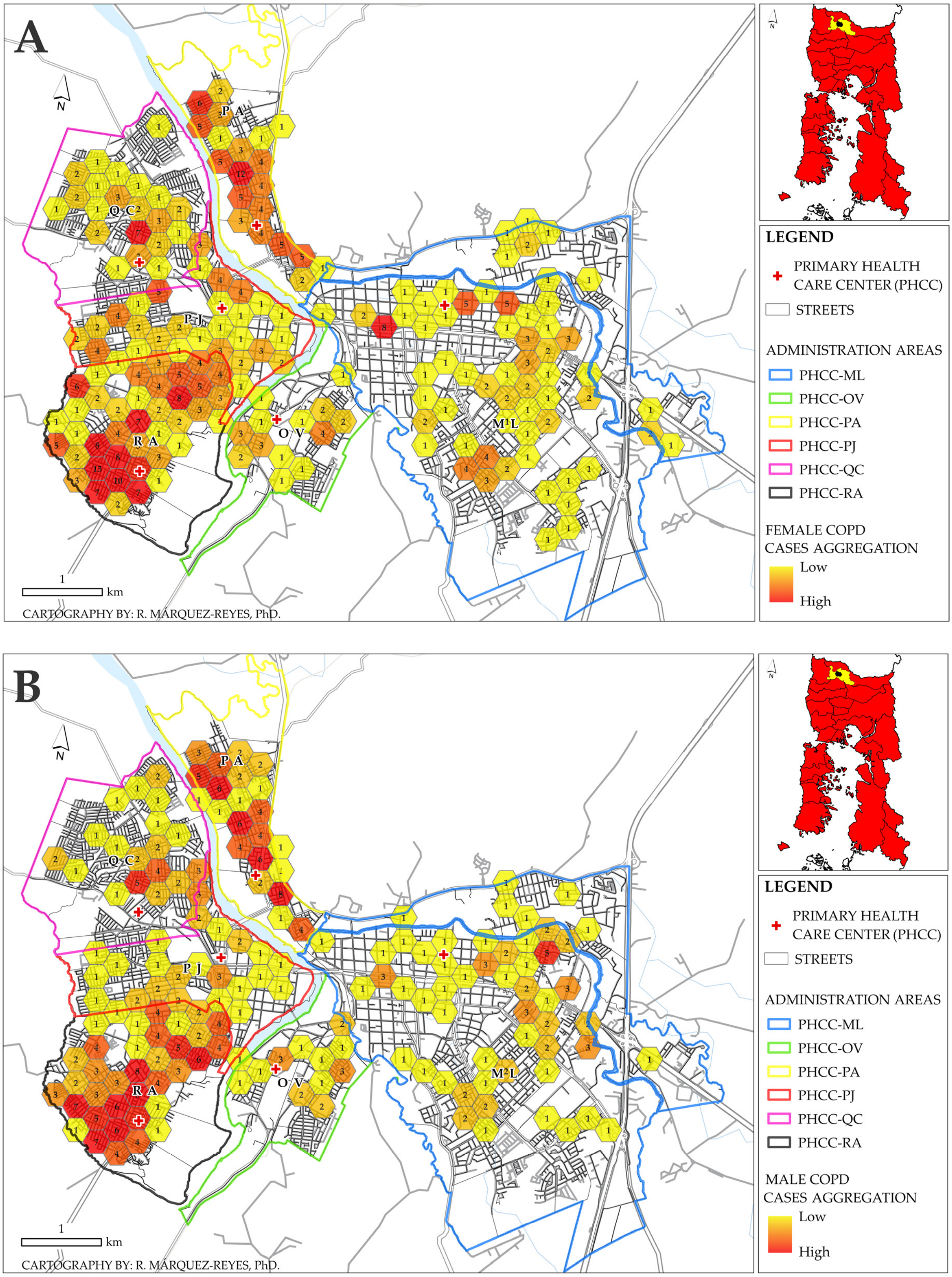

Figure 7. Hexagonal binning aggregation from COPD patients in different management areas of each Primary Health Care Center (PHCC; red crosses) in the city of Osorno. (**A**) Females; (**B**) males. Color scale, low-to-high (yellow-to-red) patient aggregation number per hexagon. PHCCs: ML, Marcelo Lopetegui; OV, Ovejería; PA, Pampa Alegre; RA, Rahue Alto; PJ, Pedro Jáuregui; QC, Quinto Centenario. Upper right insert, location map of the city of Osorno (black) in the Los Lagos region. Bar, 1 km.

4. Discussion

A descriptive observational cross-sectional study that incorporates an independent variable ($PM_{2.5}$ pollution) in a quasi-experimental manner was carried out. The territorial distribution of the COPD patients enrolled in the six Primary Health Care Centers (PHCC) that exist in the city of Osorno was analyzed. The prevalence of chronic obstructive pulmonary disease (COPD) was evaluated both in the urban area of Osorno commune and in the different administration territories in each of the six PHCCs. Additionally, these results were compared with $PM_{2.5}$ air pollution levels.

In this study, we estimate an urban prevalence of 1.3% (13 users/1000 inhabitants) among the population over 40 years old from Osorno. Depending on the different PHCC areas, adjusted prevalence varies between 0.5 and 2.6%. In females, the prevalence ranges between 0.5 and 2.6%, while in males, between 0.7 and 2.4%. The observed prevalence is lower than the one presented in 2005 by the PLATINO study, which estimated a national (Santiago, capital of Chile) prevalence of 16.9% (14.7–19.1%, 95% CI) [10]. On the other hand, the global prevalence of COPD among people aged 30–79 years in 2019 was 10.3% (95% CI 8.2–12.8) [34]. The observed prevalence reported here is ca. 12% of the global value, which could be justified because of COPD underdiagnosis, which varies between 65.8% and 90.6% [35–42]. Since the PLATINO study showed that 89% of individuals found to have COPD according to spirometry results did not have a previous diagnosis in five Latin American cities (including Santiago, Chile) [10], if the observed prevalence is adjusted to this condition, we find a corrected prevalence of 11.7% (4.2% to 23.4%) in females and 11.8% (6.1% to 22.2%) in males over 40 years old (Table S2). After this correction, territorial prevalences do not differ significantly from the national prevalence, except for the one corrected in PHCC-RA, which would reach 22.8%, with 23.4% for females and 22.2% for males. Although four out of the six PHCC territories—i.e., ML, OV, PJ, and QC—have odds ratios less than or equal to that of the entire city, the RA and PA areas are quite different, with ORs 97.6% and 38.9% larger than the OR of the entire city, respectively. This observation is valid for both males and females. In two territories of the city (i.e., PA and QC), the adjusted prevalence in males is higher than in females, as previously described [10]. However, in the OV, RA, and PJ areas, the prevalence in females is higher than in males, meaning that gender differences are not observed at the communal (urban) level. Since in Chile, adult female smoking prevalence is 32.7% [43], the increased COPD prevalence and odds ratios in the females from the RA and PA areas may be attributed to their greater susceptibility to tobacco smoke (whether they are active or second-hand smokers) [44]. On the other hand, this condition can be attributed to pollution from biomass combustion [45,46], which primarily affects women who cook in poorly ventilated environments where concentrations of particulate material in room air are higher than the recommended levels. In Osorno, 94.7% of households use firewood as fuel, and of those, 62.5% use biomass combustion as an energy source for cooking [47]. The population pyramids from Osorno inhabitants (urban area) and from each of the six PHCC areas show a graphical representation of statistics regarding the age and sex of the population (Figure S1). Osorno's population, and that of its administration territories by each PHCC, is moving from a stationary to a constrictive population pyramid, and the RA and PS territories have the highest density of people over 60 years old, the age group to which 85.6% of COPD patients in the city of Osorno belong.

Regarding schooling, 45.4% of users report a maximal educational level of incomplete primary education, like what was published by the PLATINO study [10]. COPD patients in the RA territory are one of the groups with the lowest educational level, with 61.8% of patients with incomplete primary education (with an additional 13.7% without educational teaching), only surpassed by QC patients, with 68.9% (with the addition of 11.1% illiterate) (Table S2). According to 2017 census data (available online at https://redatam.org/es/microdatos, accessed on 15 March 2024), 29.5% of the population (illiterate included) over 40 years old in the city of Osorno have incomplete primary education; this percentage increases to 48.9% when we consider the population over 60 years old. Thus, although only

51.4% of patients with COPD declare their educational level, the results reported here differ from the census characteristics of the city of Osorno. Also, the RA and PA territories have ca. 20% females aged between 15 and 40 years old. These findings are important, given that females with low educational levels showed a faster forced expiratory volume in 1 s (FEV_1) decline than highly educated females, and this effect of low educational level on FEV_1 decline is stronger in younger females [48].

Outdoor $PM_{2.5}$ air pollution in Osorno exceeded both annual (5 $\mu g/m^3$) and 24 h average (15 $\mu g/m^3$) WHO recommendations [49], with a marked seasonality, mainly between April and September. Despite this, monthly variations are not considered in WHO recommendations or Chilean guidelines [50]. The monthly concentration corresponds to the average of the measured 24 h concentration values at the monitoring station, in a calendar month, and is a more accurate indicator of seasonal variations in air pollution. The annual average masks the real pollution levels, given that due to the nature of air pollution in Osorno, the summer and spring months (in Chile, January, February, March, October, November, and December, called the "no-CEM" period in this work) have good air quality since wood combustion decreases considerably due to the increase in ambient temperature. In autumn and winter (i.e., from April to September, called the "CEM" period in this work), the cold environment forces an increase in the demand for energy from biomass combustion (94.7% of households [47]). The CEM period was 5.6 times more polluted than the "no-CEM" period in 2019. In places where air pollution comes from other anthropogenic sources, such as industrialization or vehicular transportation, the annual average may be representative.

With every 10 $\mu g/m^3$ elevation in $PM_{2.5}$, the probability of COPD-related emergency room visits and hospital admissions rose by 1.4–2.5% [51]. The daily oscillations in $PM_{2.5}$ air pollution are also interesting. During pre-emergency and emergency episodes, $PM_{2.5}$ levels vary from ca. 40 $\mu g/m^3$ to 320 $\mu g/m^3$ or 550 $\mu g/m^3$ in 4 h, respectively. COPD patients have worse lung function, lower FEV_1 and oxygen saturation, more severe emphysema, higher blood pressure, and cardiovascular mortality when exposed to higher levels of $PM_{2.5}$ [52]. Furthermore, the adverse effects of air pollution are greater in the elderly [53].

On the other hand, exacerbations of respiratory symptoms in patients with COPD can be triggered by different factors (alone or in combination), such as either bacterial or viral respiratory infections (which may coexist), environmental pollutants, or unknown factors [54]. Short-term (daily) exposure to fine $PM_{2.5}$ (10 $\mu g/m^3$) is associated with increased hospitalizations, emergency room visits, and outpatient visits [55], mainly by inducing the release of pro-inflammatory cytokines, production of chemo-attractive mediators, generation of reactive oxygen species (ROS), and protease activation, leading to airway inflammation, immune dysfunction, and altered airway epithelial structure and microbiome [56]. During pre-emergency and emergency episodes (CEM period), the population located in both PHCC-RA and -PA areas is exposed to pollution levels that greatly exceed the WHO 24 h air quality recommendations [49]. If we add the high density of COPD patients to this, air pollution in this area could have very serious consequences for patients, aggravating their chronic condition, with high risks and consequent high costs of maintaining health. A study about the hidden economic burden of morbidity related to air pollution concludes that the health cost of residents exposed to moderate concentrations of PM_{10} ($\leq$20 $\mu g/m^3$), and who suffer from chronic diseases (asthmatic children and elderly with coronary heart disease), is approximately 42 times higher than that of acute patients (i.e., EUR 8.8 million in acute patients vs. EUR 370 million in chronic patients) [57]. Also, outdoor particulate matter is the second most frequent reason contributing to the disability-adjusted life year (DALY) rates for COPD [58].

Our results allow us to assume that acute exposure to outdoor $PM_{2.5}$ could evoke excessive demand in Primary Health Care Centers, by either increasing COPD exacerbations on the same day [59] or after up to 10 lag days [60]. Fine particulate matter is a major risk factor for COPD [61], and $PM_{2.5}$ increases the incidence and prevalence of COPD during long-term exposure [62,63]. So, elevated outdoor $PM_{2.5}$ pollution could explain, at least in part, the higher prevalence of COPD in some polluted territories, but with this experimental design, it is not possible to know if patients acquired COPD because of prolonged $PM_{2.5}$ exposure or if they came to live in that area with pre-existing COPD.

Despite having both a high prevalence and OR, $PM_{2.5}$ levels in the PHHC-PA area are not among the highest in the commune, which could be attributed to the presence of a large area of urban green spaces. The presence of urban green spaces can reduce $PM_{2.5}$ levels when compared to places with less vegetation cover, providing better air quality [64]. In fact, exposure to residential greenness had a protective effect, being associated with a lower risk of COPD [61]. Beneficial effects of 10% increments in green cover within a 1 km residential buffer on COPD and asthma have been reported [65].

Since for each 5 $\mu g/m^3$ reduction in $PM_{2.5}$, the risk of acquiring COPD decreases by 12% [66], and early mortality could be reduced to 0.52% [52], all interventions to lessen patients' exposure to $PM_{2.5}$ may benefit those with COPD. An important challenge for public health is the generation of more effective health regulations for atmospheric pollution, due to the use of biomass combustion as a means of heating, cooking, and clothes drying, and its potentially harmful effect on the health of COPD or chronic respiratory disease patients.

5. Conclusions

The prevalence distribution of COPD patients in the city of Osorno, Los Lagos, Chile, in 2018 was studied. Since Osorno is the third most polluted city in Chile, urban $PM_{2.5}$ distribution was also assessed.

COPD prevalence in the entire urban commune was like national levels. But there were marked differences between the six Primary Health Care Center (PHCC) administration territories into which the commune is divided, particularly in areas with the greatest socioeconomic vulnerability in the city. Remarkably, the Rahue Alto PHCC area has a prevalence that is double that of the entire city and is also the most polluted area in Osorno, which could have serious consequences for patients, aggravating their chronic condition, with high risks and the consequent high cost of maintaining health.

Through spatial analysis, it was possible to determine the sectors of the city that have the greatest exposure to $PM_{2.5}$, which can affect the health of chronic respiratory disease patients, such as patients with COPD. This would justify the need to establish $PM_{2.5}$ measurement networks, both intra- and extra-domiciliary, to make the problem visible and reduce the risk of exposure to air pollutants, thus promoting a better quality of life.

The results reported here raise the need to correct and promote a change in the current public policies existing at the local level, which are marked by a strong sectoral bias, towards the development of joint actions between state institutions, based on interdisciplinary work between different bodies and departments, such as Health and Environment.

These results would allow us to focus and direct the delivery of financial subsidies, derived from the current Decontamination Plan of the City of Osorno, towards the people immersed in areas with greater health risk because of their exposure to $PM_{2.5}$.

The most important limitations of this study are those derived from the way secondary data were collected, since the precision in their collection is unknown. Furthermore, the temporal sequence of events cannot be known, so it is not known if there are causal relationships (since it cannot be determined if the exposure preceded the disease or vice versa). On the other hand, the presence (or absence) of smoking in the study population, the use of firewood, or another source of heating or cooking (e.g., coal, petroleum products, etc.) is unknown. Therefore, a deeper characterization of patients and their homes is very important.

This work is pioneering in the field and will constitute a baseline for future research on the topic. Also, the use of sensitive geographic data is an invaluable asset for both the people to whom they belong and for the health teams and those responsible for public policies. The multidisciplinary nature of this study is a strength since it places the pathological condition in a specific territory, along with the sociodemographic and geographic variability of each sector, which is considered an important contribution to the population of the city of Osorno, as well as to the health professionals of the Primary Health Care network. Geographic information system (GIS) application is a valuable tool to spatially locate the distribution of patients and their potential exposure to pollutants.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos15040482/s1, Figure S1: Research workflow and results, impact, and projections summary; Figure S2: The population structure and composition in Osorno and each of the six Family Health Care Center (FHCC) territories; Table S1: Sociodemographic characteristics of users with chronic obstructive pulmonary disease (COPD) in Osorno in 2018, according to the Family Health Care Center (FHCC) administration area; Table S2: Corrected prevalence of COPD in Osorno.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Scientific Ethics Committee of the Valdivia Health Service (ORD N°036, 17 February 2020) for studies involving sensitive human data.

Informed Consent Statement: Patient consent was waived because sociodemographic data and addresses were obtained from the Osorno Municipal Health Department (secondary data), who anonymized sensitive data. Other data was obtained from public sources of information.

Data Availability Statement: The sociodemographic data of COPD patients presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions (sensitive information). Publicly available datasets analyzed in this study can be found in https://sinca.mma.gob.cl/index.php/estacion/index/key/A01 (accessed on 27 February 2024), https://estadisticas.ssosorno.cl/poblacion/ (accessed on 27 February 2024), and https://redatam.org/es/microdatos (accessed on 27 February 2024).

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