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Analysing the Evidence of the Effects of Climate Change, Air Pollutants, and Occupational Factors in the Appearance of Cataracts

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Abstract: Cataracts are ocular conditions characterized by the opacification of the natural lens within the eye, which develops gradually over time and can affect one or both eyes. This condition commonly results from age-related changes in the lens, but can also arise from various factors. Cataract surgeries are expensive, particularly in states such as Spain, where they receive full support from the Spanish social welfare system. Despite a significant body of research on cataracts, few studies address the social and environmental factors triggering their development or consider the spatiotemporal evolution of their impacts. We analysed the incidence of cataracts in a southern region of Spain, differentiating between senile cataracts (those over 60 years old) and early cataracts (those between 15 and 59 years old). Twenty-one socio-economic, climate, and air pollution variables were statistically analysed using bivariate correlation, cluster analysis, and Geographic Information Systems. Eleven years of observation show a decadal increase in annually averaged maximum temperature and a decrease in annual precipitation, partially explaining the rising incidence of operable cataracts in the following year ($r = 0.77$ and -0.84, respectively; $p < 0.05$). Furthermore, early cataracts responded spatially to % agricultural employment ($r = 0.85$; $p < 0.05$) and moderately to maximum temperatures, insolation, and various constituents.

Keywords: senile cataracts; early cataracts; regional geographical analysis; climate change; air pollutants

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Citation: Echevarría-Lucas, L.; Senciales-González, J.M.; Rodrigo-Comino, J. Analysing the Evidence of the Effects of Climate Change, Air Pollutants, and Occupational Factors in the Appearance of Cataracts. *Environments* **2024**, *11*, 87. https://doi.org/10.3390/environments11050087

Academic Editors: Sergio Ulgiati and Peter Brimblecombe

Received: 22 December 2023
Revised: 16 April 2024
Accepted: 17 April 2024
Published: 24 April 2024

1. Introduction

One of the agreements reached by the scientific community is that climate change poses a significant threat with negative consequences for human health [1]. While measures are in place to mitigate its effects, the likelihood of suffering damage from the various variables affected by climate change increases with the exposure and vulnerability of a population [2,3]. Numerous variables are highly dependent on different climate change scenarios and are being studied from various perspectives, particularly in light of increasingly frequent extreme weather phenomena, such as heatwaves [4]; storms [5]; floods [6]; increased ultraviolet radiation [7]; air, soil, and water pollution [8]; droughts [9]; reduced water resources [10]; coastal phenomena [11]; endangered habitats [12]; food alterations [13]; zoonoses [14]; and food-borne and vector-borne diseases [15]. It is important to highlight the impacts of climate change on the prevalence of common diseases, which may be exacerbated, leading to an increase in their incidence beyond typical levels [3].

It is necessary to discern to what extent the incidence of these diseases corresponds to the typical frequency in the population and to what extent they are results associated with climate change and air pollution. Thus, there has been a significant impact on health systems and social support structures, which tend to be overwhelmed [16]. Specifically, in Spain, infectious, dermatological, nephrological, psychiatric, rheumatological, autoimmune, endocrine, gynaecological, and haematological diseases have experienced a consistent increase in mortality in recent years, surpassing the average mortality rate of the population and the trends of other pathologies with high associated mortality, which tend to stabilize or even decrease. Similar increasing trends are observed in endocrine, allergy-related, and ophthalmological morbidity, which are the three specialties most in demand by the population [17].

Several investigations have confirmed a potential relationship between eye health and climate change, including: (i) allergies and eye irritation related to rising temperatures and changes in precipitation patterns, pollen production, longer allergy seasons, and higher levels of air pollutants [18,19]; (ii) dry eye syndrome due to humidity levels, especially in arid or drought-prone regions [20,21]; (iii) ocular infections influenced by temperature and precipitation, which can affect the distribution and survival of disease-carrying vectors like mosquitoes and ticks [22,23]; and (iv) increased UV radiation resulting from the depletion of the ozone layer, which is related, as explained below, to the development of cataracts in certain age groups [24].

It is important to note that these effects may vary depending on geographical location and individual susceptibility [25]. While proper eye protection, regular eye examinations, and maintaining overall health and hygiene can help mitigate some of these risks, it is hypothesized that addressing climate change and air pollution could also contribute to reducing eye health issues. One of the most common eye diseases is cataracts, defined as an opacity within the crystalline lens of the eye. It typically occurs in older individuals and can lead to high dependency, potentially resulting in blindness, making it a societal concern [26].

Numerous factors can explain the occurrence of cataracts, including electromagnetic radiation (X-rays, ultraviolet, IR, and sun exposure in general) [24,27–29]; dehydration; intentional or accidental consumption of toxic substances (drugs; alcohol; tobacco; pollution; and certain medications such as corticosteroids, tetracycline, statin, or erythromycin) [30–32]; genetic hereditary and aging factors [33]; myopia, diet; malnutrition; age-related oxidative stress; tryptophan deficiency [34,35]; ocular trauma [36]; inflammatory, degenerative, and reactive diseases such as allergies, glaucoma, and uveitis [26]; and metabolic problems such as hypercholesterolemia, hypertension, hypocalcaemia, hypothyroidism, diabetes, or galactosemia [37].

Among these factors, solar radiation, especially ultraviolet radiation, is considered responsible for the development of early cataracts, typically in the population over 40 years old [38]. The risk of developing cataracts increases significantly in both men and women above the age of 60, although it is observed to a greater extent in women after menopause [26,37]. Additionally, prolonged exposure to infrared rays can also lead to the development of discoid posterior subcapsular opacities and true exfoliation of the anterior capsule (exfoliation syndrome), which is commonly observed in workers in the glass industries [39]. Furthermore, analyses of urban pollutants have revealed an association between cataract occurrence and exposure to NO_2, PM_{10} (suspended solid particles of less than 10 microns), and $PM_{2.5}$ (suspended solid particles of less than 2.5 microns), while ozone exposure was found to have a negative association [40]. We also hypothesize that there is a social component affecting cataracts in humans. For instance, individuals with a higher level of education are generally more aware of cataract pathology, but may not be as informed about protective measures [41], suggesting that higher education is not necessarily associated with a lower incidence of cataracts. Therefore, individual protective measures, such as using UV-filtering sunglasses and UV-absorbing hydrogel polymers, may prove useful in reducing the incidence of cataracts [42,43], thereby mitigating some of the harmful effects of climate change. Studies on climate change and health predict an increase in temperatures and a decrease in precipitation in various regions, with the Mediterranean region being among the most affected [1]. The decrease in cloudiness and precipitation, especially those linked to vertically developing clouds, favours the incidence of ultraviolet rays, while the increase in temperatures favours the incidence of infrared rays.

The occurrence of presenile cataracts is also increasing worldwide, with significant associations documented with smoking, hypercholesterolemia, fuel oil exposure, and low socioeconomic status [44]). Subcapsular posterior cataracts have also been associated with atopy, steroid intake, and diabetes mellitus, especially in young patients; however, nuclear cataracts have been mostly linked to high myopia and sun exposure [45].

Considering the above, this current study is based on the hypothesis that there are temporal and spatial relationships between cataract incidence, both crude (annual) and cumulative (eleven-yearly), and the influence of climate, air pollutants, and occupational and socioeconomic factors. We aim to differentiate these effects while focusing on two distinct population groups: (i) individuals aged 15 to 59 years old and (ii) those aged 60 years old and over. Furthermore, we intend to differentiate these groups based on sex assigned at birth. The primary objectives of this research are to investigate whether specific relationships exist between the spatial–temporal changes in cataract incidence and the impact of various factors. These factors include climate variables (average annual temperature, annually averaged daily maximum temperature, annual maximum absolute temperature, average annual insolation, sum of annual rainfall, and average annual relative humidity), air pollutants or constituents (total annual CO_2 emissions, total annual CO emissions, total annual CH_4 emissions, total annual N_2O emissions, total annual PM_{10} emissions, total annual $PM_{2.5}$ emissions, and total pollutants emissions), and occupational factors (annual percentage of employment in the agriculture sector, annual percentage of employment in the industry sector, annual percentage of employment in the construction sector, and annual percentage of employment in the services sector).

We will analyse these factors in relation to age groups and sex assigned at birth at the municipal level. Additionally, we will take into consideration income levels per capita and per household, as well as the altitude above sea level of the municipal capital. To achieve these objectives, we chose an experimental area located in southern Spain, specifically the Axarquía county in the province of Malaga, Andalusia. Therefore, the objectives of this research are as follows: (i) to determine the extent of the correlation between the changes in the number and annual incidence of early and senile cataracts and climatic, air pollution, and occupational and socioeconomic factors; and (ii) to assess the extent of the correlation between the spatial distribution of the number and cumulative incidence of early and senile cataracts and climatic, air pollution, and occupational and socioeconomic factors.

2. Materials and Methods

2.1. Study Area

The population studied in this research was drawn from a public hospital in a coastal county in southern Spain known as Axarquía, located in the province of Málaga. This region comprises 23 municipalities and has a total population of 160,757 inhabitants as per the census data from the National Statistics Institute (INE) in 2021 (see Figure 1). The internal differences between the municipalities in this shire are substantial, in terms of both elevation (reaching heights of up to 2065 m above sea level) and population size. For example, the county seat, Vélez-Málaga, has a population of 82,967 inhabitants, while the least populated municipality has only 173 residents. The evolution of the population between 2010 and 2021 is detailed in Tables S1 and S2 in the Supplementary Material.

2.2. Cataract Dataset and Demographic Analysis

Firstly, segregated information was extracted from the Clinical Station platform (intranet) of the Andalusian Health Service, with strict adherence to the Spanish Data Protection Law. This information pertained to the annual incidence of cataracts (following surgical intervention) from 2011 to 2021 in the Eastern Health Management Area of Malaga–Axarquía. Data included details on sex assigned at birth and age groups, specifically distinguishing individuals aged 60 and over and those between 15 and 59 years old. Information at the municipal level was obtained exclusively for the second age group. It is important to note that these variables were organized numerically in the database, ensuring that no personal details about the individuals within the groups could be discerned. It is assumed that, on average, no more than one year passed between the emergence of operable cataracts (defined as visual acuity < 0.4) and their intervention by the Ophthalmology Service of the Hospital, with the usual interval being approximately four months. The Decree of 4 January 2007—Official Report of the Andalusian Regional Government No. 3 of 2007 established a maximum intervention period of 120 days from the time cataract surgery is considered advisable, the criterion being a visual acuity < 0.4/1. Subsequently, data were extracted from the Spanish National Statistics Institute, "INE" (www.ine.es (accessed on 10 February 2023)); these data encompassed the total population, population segmented by age and sex assigned at birth, and employment sectors (agricultural, industrial, construction, or services) for each year within the studied time frame. Additionally, information on gross and household income levels was collected from the same source, although, in this instance, data were available for only one year, which was 2019.

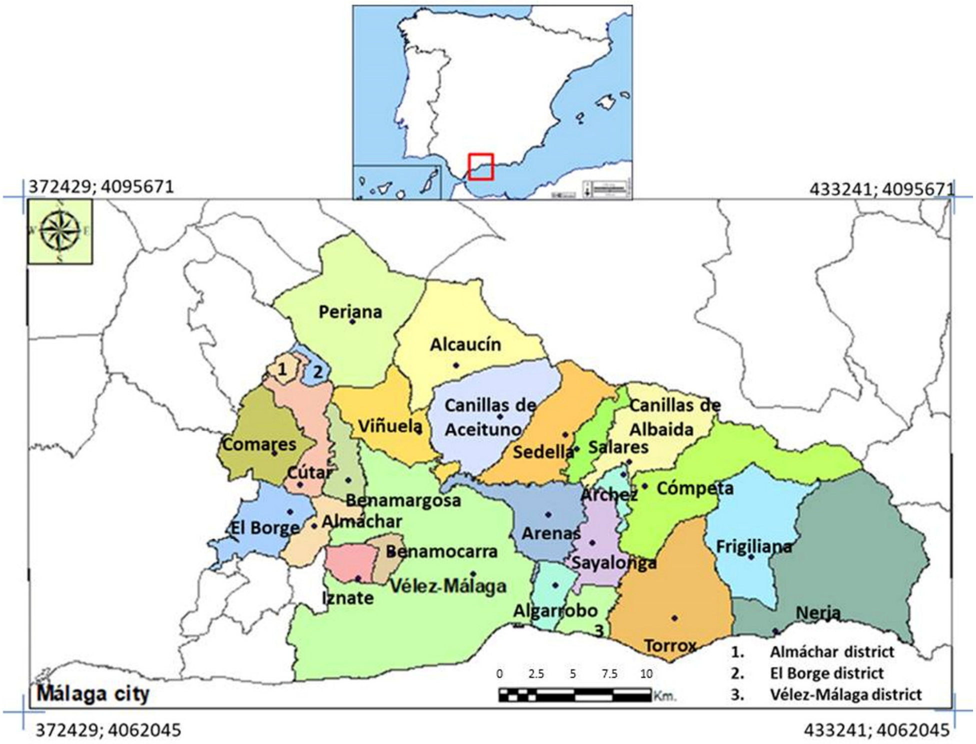

Figure 1. Localisation of municipalities in the Malaga East-Axarquía hospital health area.

The specific incidence of cataracts in people <60 years old was analysed on the one hand, and in people $\geq$60 years old on the other, evaluating the total number of people of each group and sex who developed cataracts each year. The specific incidence rate was then weighted each year with the European standardized population (https://ec.europa.eu/eurostat (accessed on 19 December 2023)) through the use of the direct method of standardization (Equation (1)):

$$\frac{\text{Total of cataracts}(\text{age group, year, sex}) * \text{Total European Standardized Population (age group, year, sex)}}{\text{Total population}(\text{age group, year, sex}) * \text{Total European Standardized Population} \ (= 100,000 \text{ inhab})} \tag{1}$$

For the accumulated standardized incidence at the end of the period, the cases of each year were added up so that, for example, a person aged 55 years old who underwent cataract surgery in 2012, despite the fact that in 2017 they would already be 60 years old, was not included in the group of people with cataracts $\geq$60 years old. The final accumulated standardized incidence is obtained by adding the cataracts of each group recorded over the period and dividing by the total population of that group (age, sex assigned at birth) up at the beginning of the period. The cumulative incidence was determined for two groups: those who were < 60 years old in the year they developed operable cataracts and those who were ≥60 years old.

2.3. Climate Trends and Air Pollution Analysis

Climate data were sourced from the Environmental Information Network of the Junta de Andalucía, known as "REDIAM" (www.juntadeandalucia.es/medioambiente (accessed on 30 January 2022)) [46]. We examined temperature data, including annual averages, maximum temperatures, and absolute maximum temperatures. The average annual temperature is the average of all the daily temperature values recorded throughout the year; this expression is valid for average annual insolation and average annual relative humidity. The annually averaged maximum temperature is the average of all the maximum temperatures for each day of the year; an increase in the values of this variable indicates a sustained increase in maximum temperatures throughout the year, or a month whose maximum values were so high that they increased the average for the year. The annual maximum absolute temperature is the record of the maximum value reached on the hottest day of the year; it is often associated with summer heat waves (defined as the 95th percentile of the total sample of daily maximums for the months of maximum heat). In addition, both the annual maximum absolute temperature and heat waves are also associated with days of maximum intensity of ultraviolet radiation. Finally, the annual precipitation is calculated through the sum of precipitation collected during the year (total precipitation). For the spatial analysis, all these variables were averaged using the daily, monthly, and annual values of all the years of the study series; when possible, the daily, monthly, and annual values of the last thirty years were used.

This information was then extrapolated to each municipality by calculating the altitudinal gradient of each variable and applying it to the geodesic vertex of each municipal head, following methodologies outlined in [47,48]. To gather data related to altitude, especially temperature and precipitation, we utilized the digital terrain model from the National Geographic Institute (pnoa.ign.es (accessed on 10 February 2023)) [49].

Additionally, we analysed data on precipitation, sunshine, and average relative humidity. Air pollutant or constituent levels, including CO_2, CO, N_2O, CH_4, PM_{10}, and $PM_{2.5}$, were grouped at the municipality level. Unfortunately, segregated data on ozone and NO_2 emissions were not available at the municipal level. However, it is worth noting that NO_2 is a gas involved in the formation of ozone in urban areas and N_2O in agricultural areas [50,51]. Fortunately, sufficient data on N_2O were accessible for the intended analysis.

For climate and pollution data, a series from 2010 to 2020 (versus 2011–2021 for cataracts) was used to see the effects of climate and pollution on the occurrence of operable cataracts in the following year, which were then compared.

2.4. Statistical Analysis

Two types of statistical analyses were conducted. First, a time trend analysis was performed using the Mann–Kendall test [52] with the Xlstat software 2023.3.0.1415 (Lumivero, Free version). The non-parametric Mann–Kendall test [53,54] addresses the analysis of trends with statistical significance without the need to use a large number of samples and with tolerance to noise in the series [55]. The statistical test obtains the Z-score, which must be greater than 1.96 or less than −1.96 to reveal trends; the tau value, which indicates the rank correlation coefficient, with negative or positive values for this score (between 1 and −1); and *p*, or the value of statistical significance, in this case calculated for 95% (0.95). In addition, the S value shows the total sum of negative and positive values. Twenty-six variables were considered to analyse their independent time trend; after that, those which obtained lower significance ($p > 0.05$) or low Z-scores (>−1.96 or <1.96) were omitted.

Second, to compare all the variables, they were standardized to eliminate differences in origin and dimensions using Equation (2):

$$((x - \overline{x})/\sigma) \quad (2)$$

where x is the punctual value of a variable; $\overline{x}$ represents the inter-annual average of the same variable; and σ denotes the inter-annual standard deviation of the variable. Afterwards, a bivariate correlation analysis at a 95% confidence level was conducted to examine the similarities and differences that the variables experienced throughout the time series. This analysis was performed using SPSS Statistics v25 software from IBM, Armonk, NY, USA. Additionally, with the same software, a 95% confidence bivariate correlation analysis was carried out, focusing on the relationships between the dependent variables (cataracts groups: <60 years old, ≥60 years old, cataracts in men, cataracts in women) and the independent variables based on their respective locations.

Furthermore, a cluster analysis was conducted using hierarchical clusters to group variables according to their interrelationships, utilizing Pearson's correlation and Euclidean distance as criteria. This analysis encompassed both temporal relationships and examinations at the municipal level, seeking to identify spatial and temporal correlations. This method shows a graphic clustering where the X axis shows the distance between groups when they were joined (from 0 to 25): the greater the distance, the more different the groups are from each other. In this manner, groupings are formed based on the proximity of variables, aiding in the identification of sets of closely related variables whose relationships might be overlooked or minimized in a basic bivariate analysis. The supplementary material (Figures S1–S8) displays distribution maps of the most relevant variables utilized in this study. These maps were created using ArcMap 10 (ESRI, Redlands, CO, USA).

3. Results

3.1. Dataset Description

The distribution of the number of cataracts throughout the county during the studied period (2011–2021) reveals distinct patterns for individuals under 60 years old compared to those aged 60 years old and over (as shown in Tables 1 and 2). Among individuals under 60, women exhibit both lower numbers and lower cumulative incidence rates of cataracts when compared to men in the same age group. However, although this pattern seems to be reversed when looking at the number of cataracts among people over 60 years of age, this is because there are a greater number of women in this age group, since, in fact, the cumulative standardized incidence is also lower in women in this age group. Table 3 illustrates the evolution of occupational, climatic, and pollution-related variables that were used for comparison and analysis.

Table 1. Distribution of cataracts according to sex at birth in Axarquía.

	Population ([a])			Cataracts ([b])			Standardized Cumulative Incidence ([c])		
Group (Years)	**15–59**	**≥60**	**Total**	**15–59**	**≥60**	**Total**	**15–59**	**≥60**	**Total**
Men	48,639	18,474	67,113	502	4130	4632	0.0064	0.0506	0.0588
Women	46,728	20,382	67,110	361	4494	4855	0.0048	0.0503	0.0612
Total	95,367	38,856	134,223	863	8624	9487	0.0056	0.0504	0.0600

([a]) Population at 1 January 2021. ([b]) Total number of cataract operations up to 21 December 2021. ([c]) 2011–2021. The total population aged between 15 and 59 years old was analysed from 2011 to 2021 to determine how many developed cataracts before the age of 60. Population changes in both age groups were considered, as both groups had people joining and leaving over the period.

Table 2. Temporal changes in the number of cataracts and annual and cumulative incidence (per 10^{-4} inhabitants) in the study area.

Year/Variable	Number of Cataracts (≥60 Years)	Number of Cataracts 15–59 Years	Total Cataracts	Cataracts Incidence Men 15–59	Cataracts Incidence Women 15–59	Total Cataracts Incidence 15–59	Cataracts Incidence Men ≥60	Cataracts Incidence Women ≥60	Total Cataracts Incidence ≥60	Total Cataracts Incidence Men	Total Cataracts Incidence Women	Total Cataracts Incidence
2011	606	65	671	4.82	3.57	4.21	37.19	32.40	34.68	42.01	35.97	38.88
2012	626	76	702	5.91	3.80	4.87	34.29	35.49	34.92	40.21	39.28	39.79
2013	687	91	778	7.10	4.61	5.88	36.51	40.74	38.73	43.62	45.35	44.61
2014	734	87	821	6.15	5.41	5.78	38.66	53.15	46.28	44.81	58.56	52.06
2015	711	92	803	6.70	5.56	6.14	45.18	43.88	44.50	51.87	49.43	50.63
2016	783	88	871	7.35	4.33	5.86	51.80	45.06	48.28	59.15	49.39	54.14
2017	716	66	782	4.32	4.43	4.37	45.73	42.08	43.40	50.05	46.51	47.78
2018	1028	82	1110	6.37	4.40	5.40	60.99	60.16	60.56	67.36	64.56	65.96
2019	643	57	700	4.77	2.64	3.72	40.73	33.60	37.00	45.51	36.23	40.72
2020	964	78	1042	6.53	3.52	5.04	56.75	51.59	54.06	63.28	55.11	59.10
2021	1126	81	1207	4.68	5.68	5.18	57.99	64.83	61.56	62.67	70.52	66.73

Note: Cataract incidence indicates the value per 10^{-4} inhabitants. Incidence refers to point or annual incidence. Men or women refers to sex at birth.

Table 3. Temporal changes in occupational, climatic, and pollution-related variables in the study area.

Variable	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1. Agriculture Employment %	7.42	7.81	8.23	9.58	10.16	11.20	11.54	13.17	13.22	11.75	12.37
2. Industrial Employment %	4.83	5.03	5.01	5.36	5.34	5.36	4.80	4.67	4.46	4.90	4.20
3. Construction Employment %	32.98	31.55	30.81	24.21	20.56	16.72	15.20	14.03	12.98	12.73	12.51
4. Services Employment %	54.76	55.61	55.96	60.84	63.93	66.73	68.45	68.13	69.34	70.62	70.92
5. Average Annual Temperature (°C)	16.70	16.95	16.83	16.52	17.09	17.41	17.28	17.35	16.48	17.06	17.31
6. Annually Averaged Maximum Temperature (°C)	21.07	21.69	21.94	21.35	22.12	22.49	22.24	22.55	21.52	22.25	22.54
7. Annual Maximum Absolute Temperature (°C)	27.10	27.54	28.30	26.65	28.10	28.63	28.04	28.48	26.35	27.88	28.93
8. Insolation ([a])	2168	2265	2345	2288	2205	2080	2301	2433	2104	2385	2244
9. Sum of Annual Precipitation (mm)	880.4	568.0	529.0	473.0	564.7	408.7	564.7	341.4	842.8	336.3	336.3
10. Average Annual Relative Humidity (%)	53.6	54.6	53.3	55.5	55.2	54.1	55.2	52.3	52.7	50.0	53.7
11. Total CO_2	408.2	401.3	323.2	304.8	318.1	322.1	328.6	331.1	335.6	338.0	352.7
12. Total CO	3111	2933	2871	2505	3225	2448	2417	2260	2231	2265	2599
13. Total CH_4	1021.1	964.4	891.5	852.7	862.6	854.7	871.9	864.7	827.6	801.4	792.7
14. Total N_2O	86.7	83.3	82.0	87.0	94.7	84.0	85.9	86.6	84.5	85.9	91.5
15. Total PM_{10}	350.2	356.2	349.2	327.4	390.0	320.4	311.6	295.1	287.9	293.0	337.0
16. Total $PM_{2.5}$	278.8	282.5	270.8	255.3	308.8	252.2	239.4	223.5	216.0	219.9	229.8
17. Total pollutants	400.6	393.8	320.2	301.8	316.2	318.7	324.7	326.9	331.1	333.2	386.4

([a]) Insolation: number of sunny hours per year. Note: CO_2 and total pollutants are measured in kilotonnes/year for the total county; Kt = kilotonnes/inhab/year; CO, CH_4, N_2O, PM_{10} and $PM_{2.5}$ are measured in tonnes/year to the county total; t = tonnes/inhab/year.

3.2. Trend Analysis

The Mann–Kendall test showed *p*-values lower than 0.05 and Z-scores > 1.96 or <−1.96 for 12 of the 26 variables analysed, as presented in Table 4 and Figure 2. These variables were examined using data from the entire study population (without municipal segregation), including temperature, air pollution values, and cataracts incidence, in individuals both over and under 60 years of age.

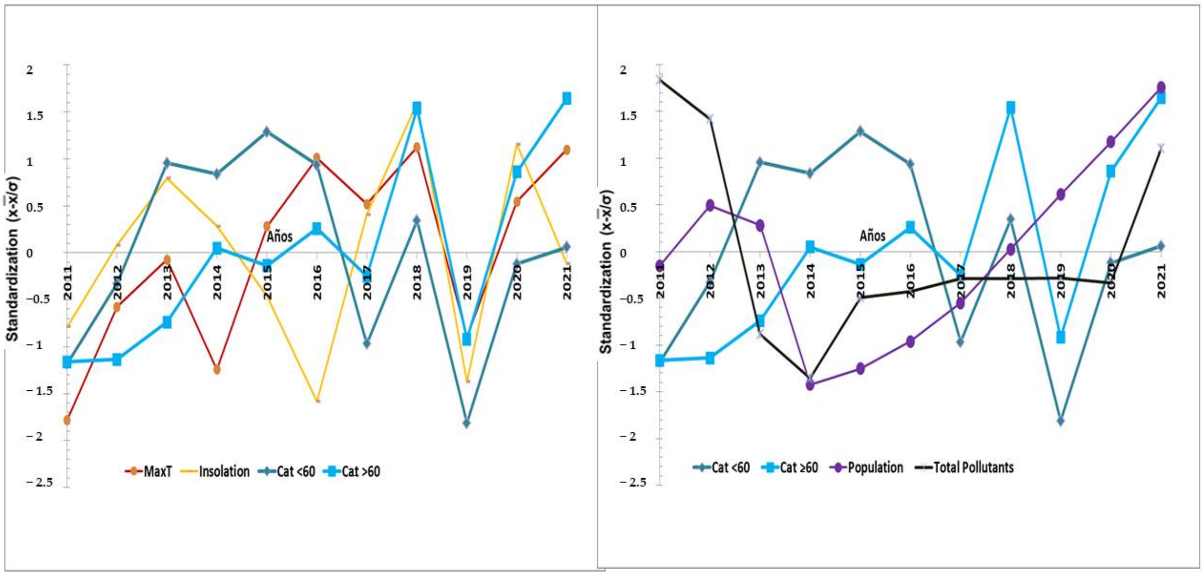

Figure 2. Standardized comparison of the inter-annual temporal changes in temperature, insolation, and standardized cataract incidence (**left**); and population, air pollution, and standardized cataract incidence (**right**) in the East Malaga-Axarquia health area. Note: Cat = standardized cataract incidence.

Table 4. Temporal changes in the studied variables and statistical significance according to the Mann–Kendall test.

Variable	Z-Score	Tau (M-K)	(S)	*p*
Cataracts' standardized annual incidence in men ≥ 60 years old	3.22	0.673	37	0.004
Cataracts' standardized annual incidence in women ≥ 60 years old	2.33	0.491	27	0.036
Total standardized annual incidence in people ≥ 60 years old	2.86	0.600	33	0.01
Total standardized annual incidence in men	3.04	0.636	35	0.006
Total standardized cataracts annual incidence	2.86	0.600	33	0.01
% Agricultural employment	4.11	0.822	37	<0.001
% Industrial employment	−2.06	−0.539	−24	0.031
% Construction employment	−5.01	−1	−45	<0.001
% Services employment	4.65	0.956	43	<0.001
Total CO	−2.86	−0.511	−23	0.047
Total CH_4	−3.58	−0.644	−29	0.009
Total PM_{10}	−2.86	−0.556	−25	0.029
Total $PM_{2.5}$	−3.4	−0.689	−31	0.005

Note: Variables with less statistically significant *p*-values, but Z-scores higher than ±1.96.

The left figure shows a comparison between the number of cataracts and climate variables. The right figure shows a comparison between the number of cataracts, the population, and pollutants.

It is noteworthy that variables related to air pollution (CO, CH_4, PM_{10}, and $PM_{2.5}$), which have either followed a downward trend or remained stable due to environmental control measures implemented in many Spanish municipalities, showed different temporal changes with respect to cataract incidence: men and women ≥ 60 years old, total annual incidence in men, and total annual incidence showed a positive trend (increasing). Furthermore, variables related to cataracts in individuals under the age of 60 were absent, because they displayed no significant temporal trends. In a population primarily engaged in the service sector, with a significant focus on tourism and a secondary presence in the construction sector (which declined from 33% in 2011 to 12.5% in 2020), the thriving agricultural sector, particularly centred on subtropical crops, has seen a substantial increase (124%) and has surpassed the construction sector. Meanwhile, there is a sustained increase in maximum temperatures and a decrease in precipitation, both variables showing high Mann–Kendall Z-scores (2.68 and −2.68, respectively), but with low significance ($0.09 > p > 0.05$); when both variables are taken for longer series, the trend is significant, but we lack values on cataracts to correlate.

3.3. Temporal Bivariate Correlation Model

The bivariate correlation model (Pearson's correlation coefficient) was employed to assess the degree of interdependence between the variables related to cataracts and all the other variables analysed throughout the 11-year study period, with a 95% confidence interval. The results are presented in Table 5.

As can be seen, five variables stand out in their relationships with cataracts when examining the data for the former (independent variables) from 2010 to 2020 and the data for the latter (dependent variables subject to the causal effect of the independent variables with a lag of one year) from 2011 to 2021: (i) The percentage of employment in the construction sector between 2010 and 2020 displays a significant and strong negative correlation ($r > -0.75$; $p < 0.05$) with the progression of cataracts in men aged 60 years old and over from 2011 to 2021, and the total annual incidence of cataracts in men; (ii) the percentage of employment in the services sector between 2010 and 2020 displays a significant and strong correlation ($r > 0.75$; $p < 0.05$) with the progression of cataracts in men aged 60 years old and over from 2011 to 2021 and the total annual incidence of cataracts in men; (iii) the annually averaged maximum temperature exhibits a significant and strong correlation ($r > 0.75$; $p < 0.05$) with the annual incidence of cataracts in men aged 60 years old and over, the total cataract incidence in people aged 60 years old and over, the total annual incidence of cataracts in men, and the overall total annual incidence of cataracts; (iv) the sum of annual precipitation is significantly and strongly negatively correlated ($r > -0.75$; $p < 0.05$), serving as a protective factor, with the annual incidence of cataracts in women aged 60 years old and over, the annual incidence of cataracts in people aged 60 years old and over, the total annual incidence of cataracts both in men and women, and the overall total annual incidence of cataracts; and (v) the percentage of employment in the agricultural sector between 2010 and 2020 displays a significant and strong correlation ($r > 0.75$; $p <0.05$) with the progression of cataracts in men aged 60 years old and over from 2011 to 2021.

Significant but moderate correlations are, among others: sum of annual precipitation and incidence of cataracts in men aged 60 years old and over, but also total cataracts in people < 60 years old, both negatively correlated ($r = -0.71$ and -0.64, respectively; $p < 0.05$); % industrial employment and cataracts incidence in men < 60 years ($r = 0.69$; $p <0.05$); annual maximum absolute temperature shows moderate correlation with all incidence of cataracts in those over 60 years old ($0.55 < r < 0.66$; $p < 0.05$); finally, average annual temperature shows moderate correlation with total incidence of cataracts in men aged 60 years old and over, total cataracts incidence in people aged 60 years old and over, and total cataracts incidence ($0.64 < r < 0.74$; $p < 0.05$).

3.4. Spatial Bivariate Correlation Model

The bivariate correlation model was employed to assess the degree of interdependence between the variables related to cataracts and all the other variables analysed in the 23 municipalities within the study area. In this instance, data were collected per municipality and the standardized cumulative incidence over the 11 years of the study, specifically for cataracts in the population aged between 15 and 59 years. This reduced the number of dependent variables to three. Additionally, average values for the independent variables were considered (as shown in Table 6). To ensure that the variables had a uniform degree of correlation, the values were standardized beforehand. Climatic, occupational and socioeconomic, and pollutant variables, along with cataract-related variables for each municipality in the study area, are presented in the Supplementary Material (Tables S3 and S4).

Spatial analysis of the standardized cumulative incidence of cataract in men under 60 years old showed a strong and significant correlation only with average N_2O emissions ($r = 0.9$; $p < 0.05$), and moderate positive and significant correlations with average CO, PM_{10}, $PM_{2.5}$, total pollutants, and altitude above sea level ($0.7 > r > 0.66$; $p < 0.05$). However, in the group of women under 60 years of age, where the temporal analysis revealed hardly any significant correlations, it showed a significant and strong correlation with the percentage of employment in the agricultural sector; in this group (women), several variables showed significant but moderate and positive correlations ($0.75 > r > 0.5$; $p < 0.05$): maximum annual temperature, absolute maximum temperature, annual insolation, and average CO_2 emissions. In addition, the same group showed significant, but moderate and negative, correlations ($-0.75 > r > -0.5$; $p < 0.05$) with the average annual relative humidity and net income per capita.

The CO_2 and CO volumes, primarily stemming from road traffic (according to REDIAM data [46]) and the size of the population centre, are concordant. In the case of N_2O, the highest concentrations are found in municipalities where agriculture plays a prominent role, although the size of the population means that the highest values are also found in the most densely populated municipalities. In addition, the regional capital (Vélez-Málaga) is by far the one with the highest emission values (see Table S3, Supplementary Material).

Table 5. Temporal bivariate correlation (Pearson's correlation coefficient) between cataract variables and occupational, climatic, and environmental variables.

Occupational or Environmental Variable	Cataracts Incidence Men 15–59	Cataracts Incidence Women 14–59	Total Cataracts Incidence 15–59	Cataracts Incidence Men ≥60	Cataracts Incidence Women ≥60	Total Cataracts Incidence ≥60	Total Cataracts Incidence Men	Total Cataracts Incidence Women	Total Cataracts Incidence
1. % Agriculture Employment %	−0.17 (0.62)	−0.06 (0.88)	−0.15 (0.74)	**0.77** (<0.05)	0.53 (0.07)	0.67 (<0.05)	0.73 (<0.05)	0.50 (0.10)	0.64 (<0.05)
2. Industrial Employment	0.69 (<0.05)	0.23 (0.51)	0.61 (<0.05)	−0.35 (0.28)	−0.25 (0.48)	−0.31 (0.36)	−0.27 (0.43)	−0.21 (0.55)	−0.25 (0.47)
3. Construction Employment %	0.15 (0.67)	−0.01 (0.96)	0.10 (0.79)	**−0.80** (<0.05)	−0.56 (0.05)	−0.70 (<0.05)	**−0.77** (<0.05)	−0.53 (0.07)	−0.67 (<0.05)
4. Services Employment %	−0.18 (0.61)	0.02 (0.95)	−0.11 (0.76)	**0.81** (<0.05)	0.56 (0.05)	0.70 (<0.05)	**0.77** (<0.05)	0.53 (0.07)	0.67 (<0.05)
5. Average Annual Temperature (°C)	0.18 (0.61)	0.35 (0.29)	0.34 (0.31)	0.73 (<0.05)	0.51 (0.08)	0.64 (<0.05)	0.74 (<0.05)	0.51 (0.08)	0.65 (<0.05)
6. Annually Averaged Maximum Temperature (°C)	0.28 (0.42)	0.35 (0.29)	0.40 (0.21)	**0.82** (<0.05)	0.65 (<0.05)	**0.76** (<0.05)	**0.84** (<0.05)	0.64 (<0.05)	**0.77** (<0.05)
7. Annual Maximum Absolute Temperature (°C)	0.32 (0.35)	0.50 (0.09)	0.52 (0.08)	0.63 (<0.05)	0.55 (0.05)	0.62 (<0.05)	0.66 (<0.05)	0.56 (<0.05)	0.64 (<0.05)
8. Annual Insolation (hours)	0.16 (0.65)	0.20 (0.57)	0.23 (0.51)	0.31 (0.36)	0.49 (0.1)	0.43 (0.17)	0.33 (0.33)	0.48 (0.11)	0.44 (0.16)
9. Sum of Annual Precipitation (mm.)	−0.46 (0.13)	−0.53 (0.07)	−0.64 (<0.05)	−0.71 (<0.05)	**−0.85** (<0.05)	**−0.83** (<0.05)	**−0.75** (<0.05)	**−0.85** (<0.05)	**−0.86** (<0.05)
10. Annual Average Relative Humidity (%);	−0.15 (0.68)	0.53 (0.07)	0.21 (0.54)	−0.49 (0.11)	−0.18 (0.62)	−0.34 (0.31)	−0.50 (0.10)	−0.12 (0.73)	−0.31 (0.36)
11. Total CO_2 (Kt/year)	−0.40 (0.21)	−0.41 (0.2)	−0.52 (0.08)	−0.30 (0.37)	−0.41 (0.20)	−0.38 (0.24)	−0.34 (0.30)	−0.43 (0.18)	−0.41 (0.20)
12. Total CO (t/year)	0.10 (0.78)	0.30 (0.37)	0.25 (0.47)	−0.54 (0.06)	−0.40 (0.22)	−0.49 (0.11)	−0.52 (0.07)	−0.35 (0.29)	−0.45 (0.15)
13. Total CH_4 (t/year)	−0.10 (0.77)	−0.26 (0.45)	−0.22 (0.52)	−0.64 (<0.05)	−0.65 (<0.05)	−0.68 (<0.05)	−0.64 (<0.05)	−0.63 (<0.05)	−0.68 (<0.05)
14. Total N_2O (t/year)	−0.15 (0.67)	0.62 (<0.05)	0.26 (0.45)	0.34 (0.31)	0.42 (0.19)	0.41 (0.21)	0.32 (0.34)	0.45 (0.15)	0.41 (0.20)
15. Total PM_{10} (t/year)	0.19 (0.59)	0.52 (0.08)	0.44 (0.16)	−0.46 (0.14)	−0.23 (0.51)	−0.35 (0.30)	−0.43 (0.18)	−0.17 (0.63)	−0.30 (0.38)
16. Total $PM_{2.5}$ (t/year)	0.30 (0.38)	0.34 (0.31)	0.41 (0.20)	−0.59 (<0.05)	−0.43 (0.17)	−0.53 (0.07)	−0.55 (0.06)	−0.38 (0.24)	−0.48 (0.12)
17. Total Pollutants (Kt/year)	−0.49 (0.11)	−0.21 (0.54)	−0.46 (0.14)	−0.14 (0.70)	−0.18 (0.62)	−0.17 (0.64)	−0.19 (0.59)	−0.19 (0.60)	−0.20 (0.57)

Note: Incidence refers to annual standardized incidence. Bold: variables with strong correlation. In brackets: statistical significance (*p*).

Table 6. Bivariate correlation between cataract-related variables (in population under 60 years old) and occupational and socioeconomic, climatic, and environmental variables, according to their spatial distribution.

Occupational, Socioeconomic, or Environmental Variable	Cumulative Incidence of Cataracts in Men 15–59 Years Old	Cumulative Incidence of Cataracts in Women 15–59 Years Old	Total Cumulative Incidence of Cataracts in those 15–59 Years Old
% Agricultural employment	0.33 (0.11)	0.95 (<0.05)	0.85 (<0.05)
% Industrial employment	−0.18 (0.41)	0.21 (0.32)	0.03 (0.87)
% Construction employment	0.18 (0.41)	0.12 (0.59)	0.42 (<0.05)
% Services employment	−0.27 (0.21)	−0.38 (0.05)	−0.42 (<0.05)
Average Annual Temperature	0.28 (0.18	0.16 (0.46)	0.22 (0.29)
Annually Averaged Maximum Temperature	0.47 (<0.05)	0.6 (<0.05)	0.52 (<0.05)
Annual Maximum Absolute Temperature	0.47 (<0.05)	0.6 (<0.05)	0.52 (<0.05)

Table 6. *Cont.*

Occupational, Socioeconomic, or Environmental Variable	Cumulative Incidence of Cataracts in Men 15–59 Years Old	Cumulative Incidence of Cataracts in Women 15–59 Years Old	Total Cumulative Incidence of Cataracts in those 15–59 Years Old
Annual Insolation (hours)	0.47 (<0.05)	0.6 (<0.05)	0.52 (<0.05)
Sum of Annual Precipitation (mm.)	0.42 (<0.05)	0.62 (<0.05)	0.47 (<0.05)
Average Annual Relative Humidity	−0.47 (0.17)	−0.60 (<0.05)	−0.52 (<0.05)
Average CO_2 (Kt)	0.47 (<0.05)	0.60 (<0.05)	0.52 (<0.05)
Average CO (t)	0.70 (<0.05)	0.31 (0.13)	0.32 (0.11)
Average CH_4 (t)	0.66 (0.13)	0.23 (0.27)	0.32 (0.11)
Average N_2O (t)	**0.90** (<0.05)	0.18 (0.41)	0.34 (0.09)
Average PM_{10} (t)	0.67 (<0.05)	0.24 (0.26)	0.30 (0.14)
Average $PM_{2.5}$ (t)	0.66 (<0.05)	0.24 (0.26)	0.31 (0.13)
Total Pollutants (Kt)	0.66 (<0.05)	0.24 (0.25)	0.31 (0.13)
Altitude above sea level	0.70 (<0.05)	0.31 (0.13)	0.32 (0.11)
Net income per capita	−0.47 (<0.05)	−0.60 (<0.05)	−0.52 (<0.05)
Household income	0.32 (0.12)	0.04 (0.87)	−0.05 (0.82)

Bold: values with highest correlation. In brackets: statistical significance (*p*).

Thus, it is necessary to look for more complex relationships between cataract-related variables.

3.5. Cluster Analysis

The first analysis model, focusing on temporal relationships, obtained results based on the closest distance between variables (Figure 3a). The second one, focusing on spatial relationships, obtained results based on rescaled Euclidean distance. Both models showed the distance between variables on the *x*-axis: the higher the value at which the link occurs, the greater the distance between the variables, and therefore the smaller the relationship.

In this case (Figure 3a), the model shows two large clusters associated through the minimum distance between variables. The first cluster includes almost all the variables related to cataracts (variables 2 to 9), which are close to temperatures (average, maximum and absolute maximum; variables 14, 15 and 16, respectively), insolation (variable 17), the agricultural and service employment (variables 10 and 13), and the total N_2O emissions (variable 23). The second cluster contains the standardized cataract incidence in men under 60 years old (variable 1), industrial and construction employment (variables 11 and 12), relative humidity and precipitation (variables 19 and 18), and most constituents (variables 21, 22, 24, 25, and 26).

The second model of analysis (Figure 3b) focuses on spatial relationships. In order to avoid redundancy with the bivariate correlation analysis, we presented a cluster as a function of Euclidean distance between data applied to the variables according to their spatial distribution. The clustering of variables based on their proximity is particularly noteworthy in this spatial analysis, specifically when examining cataracts in the population aged between 15 and 59 years old.

Although with varying degrees of proximity, the spatial cluster again provides relationships with the same variables, leaving pollutants in a separate group from the standardized cumulative incidence of cataracts. The three groups of standardized incidence of cataracts in people under 60 years old (men, women, and total) show some distance with respect to the rest of the variables; however, family income and the rest of the climatic variables (with the exception of precipitation) are closer to the incidence of cataracts, together with agricultural employment.

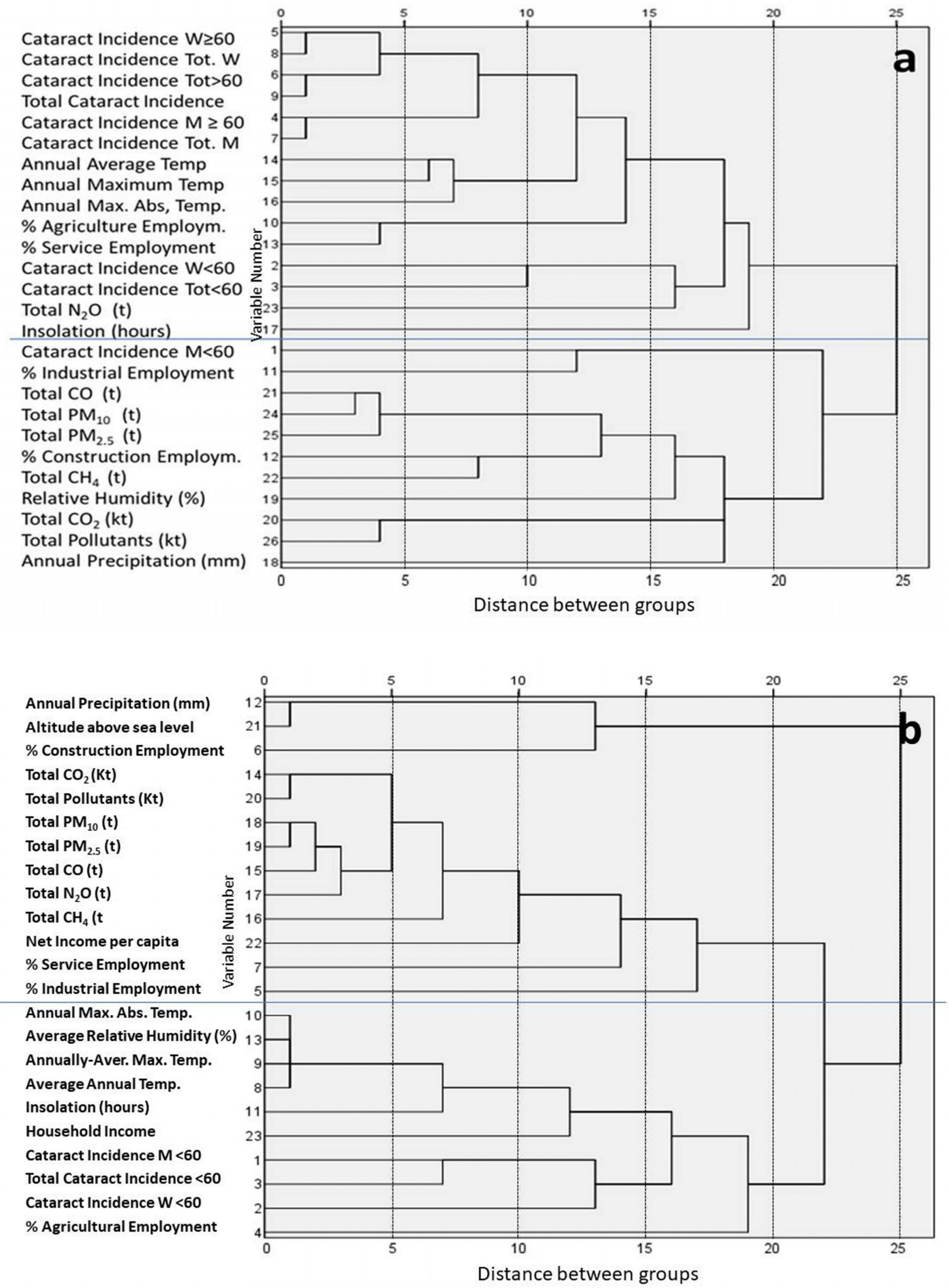

Figure 3. Dendrogram of average linkage from rescaled distance and temporal data (**a**), and average linkage from rescaled Euclidean distance and spatial data (**b**). a: Incidence data are based on annual standardized cataract incidence. b: Incidence data are based on cumulative standardized cataract incidence. The blue line in both figures separates the two main groups of variables.

4. Discussion

Cataract surgery is one of the most frequently performed surgical procedures worldwide, with an estimated annual count of over 22 million operations [56]. The association between ultraviolet radiation (UVR) and cataracts has been extensively studied, revealing an odds ratio that indicates an 11- to 25-fold increased risk of cortical and subcapsular cataracts with heightened exposure to UVB radiation [24,27,57,58]. However, the utilization of sunglasses has demonstrated an odds ratio of 0.62 for posterior subcapsular cataracts, signifying protection against the development of this particular cataract type. A long absence of rainfall is usually coupled with a long absence of clouds (especially, vertically developing clouds), which absorb a large amount of ultraviolet radiation (UVR); it is also related to lower humidity, higher temperatures, and higher solar exposure [17]. Unfortunately, ultraviolet radiation data for the study area and the time series used were not available.

Considering that the average cost of cataract surgery in Spain typically ranges between EUR 910 and 1541 [59], and that the number of cataracts in Spain has been increasing at a faster rate than the population growth [60,61], it becomes imperative to address the predisposing factors. Taking preventive measures is essential to ensure that healthcare expenditure does not become unsustainable [43]. From the analysis conducted, it can be deduced that the factors influencing the development of senile cataracts differ from those of early cataracts.

The number of cataracts is a value which is increasing significantly in the county under study, almost doubling in 11 years (as can be seen in Table 2: 79.9% in terms of number of cataracts, but 75.2% in terms of standardized cumulative incidence), and therefore growing faster than the population (3.84%) and even faster than the population $\geq$60 years old (18.25%). This should imply higher public spending on health, although the health budget in Andalusia has grown between 2010 and 2021 less than the general budget allocated to this economic community (an increase of 19.41% compared to 19.97%) [62].

A strong and significant correlation has been observed between standardized cataracts incidence in men aged 60 years old and over (r = 0.82; $p < 0.05$) and the crude incidence of annually averaged maximum temperatures. This correlation is similar for the incidence of the total population (r = 0.76; $p < 0.05$), but moderate (r = 0.65; $p < 0.05$) in women aged 60 years old and over. This association with annually averaged maximum temperatures can be attributed to the connection between cataracts and solar radiation, particularly concerning exfoliation syndrome [63,64]. High correlations have been established between exfoliation syndrome and populations engaged in activities related to the sea [65] or exposed to elevated ultraviolet radiation [27,66]. Consequently, the development of cortical cataracts may be associated with altitude, affecting populations residing both at low altitudes (such as those in our case, situated near the sea) and at high altitudes (exposed to heightened ultraviolet radiation) [24,67]. This duality diminishes the direct correlation between altitude and the incidence of cataracts, and requires further correlation studies.

Additionally, it is worth noting the connection between exfoliation syndrome and infrared and microwave radiation [26,68]. Workers in fields such as glassblowing and welding are exposed to abnormal levels of infrared radiation, while microwave and radio wave radiation affect individuals working with powerful satellites, radars, radios, or other transmitting equipment.

Considering the strong correlation between temperature and infrared radiation [69], it is essential to pay more attention to this particular band of the electromagnetic spectrum concerning its connection with cataracts of anthropogenic origin. However, it is important to note that this relationship can be influenced by humidity levels. A recent study conducted in China unveiled an odds ratio (OR) of 1.04 between temperature and cataracts in the elderly, indicating a 4% increase in the number of cataracts for each degree of a rise in temperature. Interestingly, relative humidity was found to have a slightly protective effect (OR = 0.99), with a 1.4% reduction in the number of cataracts for every 1% increase in humidity [70]. The low correlation obtained in our study suggests that, perhaps, in countries drier than China, such as Spain, this protective factor is not present. Furthermore, other research studies [71] have identified a 44% higher prevalence of severe visual impairment among older American adults (excluding Hispanics) in areas with a mean annual temperature equal to or exceeding 15.5 °C. The relationship between exfoliation syndrome and additional factors such as sun exposure and environmental temperature has also been explored by other authors [64].

In our study, the correlation with temperature only reached a high level of correlation and signification concerning annually averaged maximum temperatures, as noted above, while it was less than 0.75 for annual means and absolute maximums ($0.75 > r > 0.5$; $p < 0.05$), although its relationship with heat waves might suggest a stronger correlation with cataracts [72]. The most noteworthy finding was an increase of 370.8 cases for each degree of rise in the annually averaged maximum temperature. It should be noted that official data on temperatures (average, maximum and absolute maximum) in Spain show a sustained increase year after year [72]. As for humidity, the correlation is very low and with low significance, ruling out its incidence in the temporal changes of cataracts.

On the other hand, the annual volume of rainfall appears to be a protective factor in people aged 60 years old and over: the higher the annual volume, the lower the likelihood of developing cataracts ($-0.71 < r < -0.86$; $p < 0.05$). A strong negative correlation ($r = -0.85$ to -0.86; $p < 0.05$) was observed for the groups including the entire female population and the entire population, indicating that, for every hundred millimetres of increased rainfall, there were 102 fewer cases of cataracts. This suggests that drought conditions may exacerbate the incidence of cataracts. Senile cataracts have shown an upward trend that surpasses the corresponding population growth. As noted above, over the course of 11 years, there has been a 79.88% increase in the number of cataracts, whereas the population has only grown by 3.8% during the same period (18.25% in the elderly population). This growth has been concentrated in coastal areas (where the annual rainfall volume is lower), while inland population centres have experienced relevant declines. However, early cataracts have shown no clear trend, with a fluctuating increase of 24.6% between 2011 and 2021 (23% for the standardized incidence of cataract), with no clear temporal correlation or statistical significance (r -tau- = -0.09; $p = 0.70$).

Mean temperature, sunshine, and rainfall did not exhibit high temporal correlations with the development of early cataracts. Therefore, alternative methods were employed to approximate potential predisposing factors of climatic, pollutant, or occupational or economic origin. Factors such as intentional or accidental consumption of toxic substances; genetic hereditary and aging factors; myopia; ocular trauma; inflammatory, degenerative, and reactive diseases; and metabolic problems did not show consistent increases over time in relation to early cataract development [26,30–33,36]. However, there may be spatial variations in these factors due to altitude, sun exposure (sunrise–sunset, windward–leeward), geographical position (coastal, inland, valley bottom), settlement type (dispersed habitat vs. concentrated habitat), predominant economic activities, or social and educational levels. Although previous analyses have found only a moderate correlation between altitude above sea level and cataract incidence in men under 60 years of age (but not in women or in the total population under 60 years of age), probably due to the dichotomous factor explained above, the initial mapping indicated an apparent inverse relationship. In fact, this inverse relationship is influenced by several correlated factors: higher altitudes are associated with lower temperatures (average, maximum, and absolute), and there is a positive relationship between temperature and the incidence of cataracts, as noted above. Higher altitudes also tend to have increased precipitation, but there is an inverse relationship between precipitation and the incidence of cataracts. Additionally, villages located at higher altitudes typically have smaller populations, resulting in fewer cataract cases (even zero incidence). Consequently, there are some mountain municipalities where no one under 60 years old has undergone cataract surgery within the studied time frame (see Supplementary Material, from Figures S1–S8). This is a relationship to be explored in future research.

To explore potential environmental factors contributing to the development of early cataracts, we employed cluster analysis tools to assess the proximity between variables. We applied these tools to both temporal and spatial analyses to uncover possible multifactorial relationships among occupational and economic, climatic, and environmental pollutant variables and the onset of early cataracts. In both scenarios, the clustering is determined based on the proximity of values, with absolute mode calculation employed for time series values to ascertain the closest distance and minimum rescaled Euclidean distance utilized for spatially analysed values. For this case, cluster analysis emerged as a valuable complement to bivariate correlation models, uncovering potential combined effects of multiple factors concurrently. In the realm of temporal analysis, this tool has unveiled Euclidean proximity clustering that shows the relationships between the occurrence and standardized annual incidence of early cataracts among males and females under 60 years of age, as well as certain climatic, occupational, and pollution factors. These factors include temperatures (average annual, annually averaged maximum, and annual maximum absolute temperatures), the proportion of agricultural and service employment, as well as secondary factors like sunshine hours and N_2O concentrations. N_2O is a by-product of nitrate and NO_2 reduction or aerobic ammonium oxidation [51]; it usually comes from both agricultural activity (hence its possible association in the cluster analysis) and industrial activities. Exposure to N_2O implies prior exposure to NO_2, which has been linked to the development of cataracts [40]. In this sense, N_2O can be a confounding variable, since it is related to agriculture; given that this, in turn, is related to workers working long hours in the sun, it would be necessary to discern whether the NO_2-N_2O binomial is responsible for the appearance of cataracts, or whether it is so because it coincides with agricultural activity.

However, in the spatial analysis, where the distribution is mainly influenced by the population size of each municipality, the standardized cumulative incidence of cataracts in men under 60 years old appears to be more closely associated with the presence of specific pollutants or constituents, such as CO, N_2O, PM_{10}, $PM_{2.5}$, and total pollutants ($0.5 < r < 0.9$; $p < 0.05$). Nevertheless, the cluster analysis distances this relationship, limiting it, again, to the presence of agricultural employment; this variable appears strongly associated with cataracts in women < 60 years of age and moderately associated with the overall population under 60 years of age.

As can be seen, CO_2, whose relationship is very moderate ($0.4 < r < 0.6$; $p < 0.05$), and CH_4 (no correlation) are left out of any association. In fact, while there is no scientific evidence implicating CO_2 or CH_4 in cataract development, studies have documented connections between the use of biomass cookstoves (which emit CH_4 initially, along with CO_2 and CO during combustion) and the onset of cataracts, particularly in women [73,74]. For this reason, these gases were included in the study. On the other hand, CO, N_2O, PM_{10}, and $PM_{2.5}$ have been identified as pollutants responsible for cataract development [40,75], with PM_{10} being typically associated with atmospheric dust, ashes, and pollens. $PM_{2.5}$, originating from industrial chemical emissions, consists of finer particles (<2.5 microns) capable of passing through the pulmonary barrier into the bloodstream. Continued exposure to $PM_{2.5}$ has been linked to a 5% increase in the risk of developing cataracts [76].

Numerous pollutants have been identified as having health implications, although their role is not as prominent as those mentioned above. Among them, accidental exposure to naphthalene has been linked to the development of cortical cataracts [77]. In the data analysed herein, the collection of pollutants measured over time in the region showed a distinct pattern: a notable decrease in the early years, a slight increase between 2014 and 2019, and finally, a new upswing in 2020. It is worth noting that this increase occurred in the very year when emissions were expected to decline due to the economic slowdown caused by the COVID-19 pandemic. These data corroborate previous studies conducted in various Spanish cities which indicated that COVID-19 had a limited impact on the control of greenhouse gas emissions [78].

Regarding the analysis procedure, the one-year shift in the sequence of standardized cataract incidence after the effect of independent variables appears to be appropriate, especially when correlating senile cataracts with climatic variables. Annually averaged maximum temperature stands out as the most closely related variable in this context. However, factors related to accumulated toxicity over a longer period of time could be involved in the development of early cataracts. This may require a latency period of more than one year between the year in which there is an increase in average maximum temperatures and the increase in the annual incidence of cataracts in people under 60 years old. This delayed effect could also be associated with the relationship between pollutants and early cataracts. Given the younger age of the population under 60, they may exhibit greater resilience to external factors compared to older age groups.

The present study leaves some questions to be resolved in future research on cataracts which were not possible to clarify in the current study due to the short series of years (only 11): (i) Is there a long latency in the development of early cataracts concerning temperatures and pollution in general? (ii) What is the reason why men develop earlier cataracts? Is the origin occupational? Is it due to more frequent consumption of toxic substances by men, for example, tobacco? (iii) Does one's educational level (which could not be analysed due to a lack of disaggregated data at the municipal level) play a role in the development of cataracts? (iv) If environmental variables play such a relevant role, is it possible to reduce their incidence by improving pollution levels and implementing global measures to control greenhouse gases so that temperatures do not continue their accelerated upward trend?

5. Conclusions

The increase in temperatures related to global warming is having numerous effects on human health. The present study found an increase in the standardized incidence of senile cataracts. The annual incidence of these cataracts is related to the annual increase in maximum temperatures, especially in men; by contrast, annual precipitation has a negative impact (a protective factor), particularly in women. However, the causes of the development of early cataracts need further investigation, as they not only do not follow a similar temporal pattern but also appear to be influenced by multiple other factors. The cluster analysis tool is useful for discerning proximity relationships that may be masked by multifactorial interactions or, conversely, for identifying instances where independent factors counteract each other. The application of this tool reveals that not only temperatures and insolation, but also employment in the agricultural and service sectors, have a temporal influence on the development of early cataracts. Moreover, viewed from a spatial standpoint, the distribution of standardized early cataract incidence in men exhibits a bivariate correlation with the presence of various pollutants (CO, N_2O, PM_{10}, $PM_{2.5}$, and total pollutants), a relationship not supported by cluster analysis. However, the cluster analysis reaffirms the relationships between cataract incidence and environmental variables (temperatures, sunshine, and humidity), as well as the percentage of the population with agricultural employment.

All these characteristics indicate a higher incidence of cataracts in coastal localities, which have larger populations and more activity in the service sector, but also in localities dedicated to the agricultural sector. Thus, cartographic analysis tools are necessary in order to examine the slightly different patterns in the standardized cumulative incidence of early cataracts, especially between men and women. It is possible that the differential factor is related to exposure to various pollutants more common in men's occupational settings (industrial or construction sector). Moreover, there is a need to increase the number of specialists in hospitals in the regions most affected by climate change to address the rising prevalence of cataracts. The projected increase in healthcare expenditure in regions experiencing higher temperatures and lower rainfall is evident. This study's findings can be extrapolated to other similar areas or those more severely impacted by climate change, posing a relevant challenge in countries with limited economic resources.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environments11050087/s1, Table S1. Evolutionary data on the general population of the study area; Table S2. Evolutionary data on the population over 15 years old in the study area; Table S3. Spatial and population data for the study area. Standardized Cumulative cataract incidence in population 15–59 years old (2011–2021); employment data (average 2010–2020) and income (2019 data); Table S4. Climate and pollution data for the study area 30-year average values (1990–2020) for climate data (except insolation and humidity), and 11-year average values (2010–2020) for pollution data; Figure S1. Average Annual Temperature; Figure S2. Annually-Averaged Maximum Temperature; Figure S3. Annual Absolute Maximum Temperature; Figure S4. Average Annual Insolation; Figure S5. Sum of Annual Precipitation; Figure S6. Standardized Cumulative Cataract Incidence in men under 60 years old; Figure S6. Standardized Cumulative Cataract Incidence in men under 60 years old; Figure S7. Standardized Cumulative Cataract Incidence in women under 60 years old; Figure S8. Standardized Cumulative Cataract Incidence in people under 60 years old.

Author Contributions: Conceptualization, L.E.-L. and J.M.S.-G.; Methodology, L.E.-L. and J.M.S.-G.; Formal analysis, J.M.S.-G. and J.R.-C.; Investigation, L.E.-L.; Data curation, J.M.S.-G.; Writing—original draft, L.E.-L. and J.M.S.-G.; Writing—review & editing, J.M.S.-G.and J.R.-C.; Visualization, J.M.S.-G. and J.R.-C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s. The Spanish data protection law expressly prohibits the publication of personal data on pathologies. For the treatment of these data, this study had to undergo an exhaustive inspection by the Health Research Ethics Committee, whose approval is available to anyone who requests it from the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

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