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Air pollution and mortality in Portugal (2010-2021): AirQ+ analysis and COVID-19 impact

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INTRODUCTION

In 2019, air pollution caused 6.7 million premature deaths, making it the fourth leading global risk factor and a major public health concern. This study analyses mortality attributable to air pollution in Portugal (2010–2021) and the impact of the COVID-19 pandemic, using pre-pandemic projections from the AirQ+ model. Developed by the World Health Organization (WHO), AirQ+ estimates mortality linked to pollutants such as fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and tropospheric ozone (O_3), supporting strategies aligned with the United Nations (UN) 2030 Sustainable Development Goals (SDGs).

MATERIALS AND METHODS

Impact on Human Health – AirQ+ Model

The **AirQ+ model (version 2.2)** was employed to estimate mortality attributable to long-term exposure to **NO_2, PM2.5**, and **O_3** among the at-risk population (aged 30+ years), covering **43 municipalities** in Portugal.

Health and Pollution Data

- **Mortality data** from natural causes, respiratory diseases (ICD-10: J00–J99), and COVID-19 [Sources: **PORDATA** (accessed January 2024) and Statistics Portugal – **INE** (accessed January 2024)]
- **Pollution data:** NO_2, $PM_{2.5}$, and O_3 concentrations obtained from **55 monitoring stations** in the Air Quality Monitoring Network **(QualAr)** [Source: Portuguese Environment Agency **(APA)**]

Statistical Methods

Temporal Variation Analysis (2010–2021):

- Assessed using **Linear Mixed Models (LMM)** to examine tendencies in pollution-attributable mortality.

Time Series Analysis:

- **Seasonal AutoRegressive Integrated Moving Average (SARIMA) models** were developed to forecast pre-COVID mortality tendencies (2015–2019) and validated for 2020–2021.
- Comparisons between forecasted and observed values were conducted using **LMM**.

Software:

- **IBM SPSS Statistics (version 29)** was used for statistical analyses and time series modelling.
- Level of statistical significance: **5%**.

RESULTS

Table 1 presents the estimates obtained using the AirQ+ model for the number of attributable deaths, based on the population-weighted average of atmospheric pollutant concentrations.

Table 1. Premature deaths attributable to air pollution by NO_2, $PM_{2.5}$ and O_3.

		NO_2 exposure		$PM_{2.5}$ exposure		O_3 exposure	
Year	Population at risk	Annual mean level	AirQ+ estimates	Annual mean level	AirQ+ estimates	Annual mean SOMO35 uncorrect	AirQ+ estimates
2010	7129263	26.2	5935	11.7	6392	4695	209
2011	7178177	25.3	5450	12.1	6413	4051	182
2012	7199849	23.4	5022	10.1	5640	3491	184
2013	7207969	20.7	4004	9.5	5273	5097	242
2014	7210716	18.3	3058	9.3	5071	3617	166
2015	7215077	21.9	4520	11.0	6227	2986	152
2016	7218039	18.9	3450	9.1	5257	3311	169
2017	7221494	22.2	4685	10.1	5787	3022	147
2018	7227371	24.1	5556	9.2	5431	4209	211
2019	7242878	20.7	4187	9.0	5250	3081	143
2020	7365949	17.2	3143	7.9	5116	3592	153
2021	7407241	15.2	2307	8.0	5243	3588	139

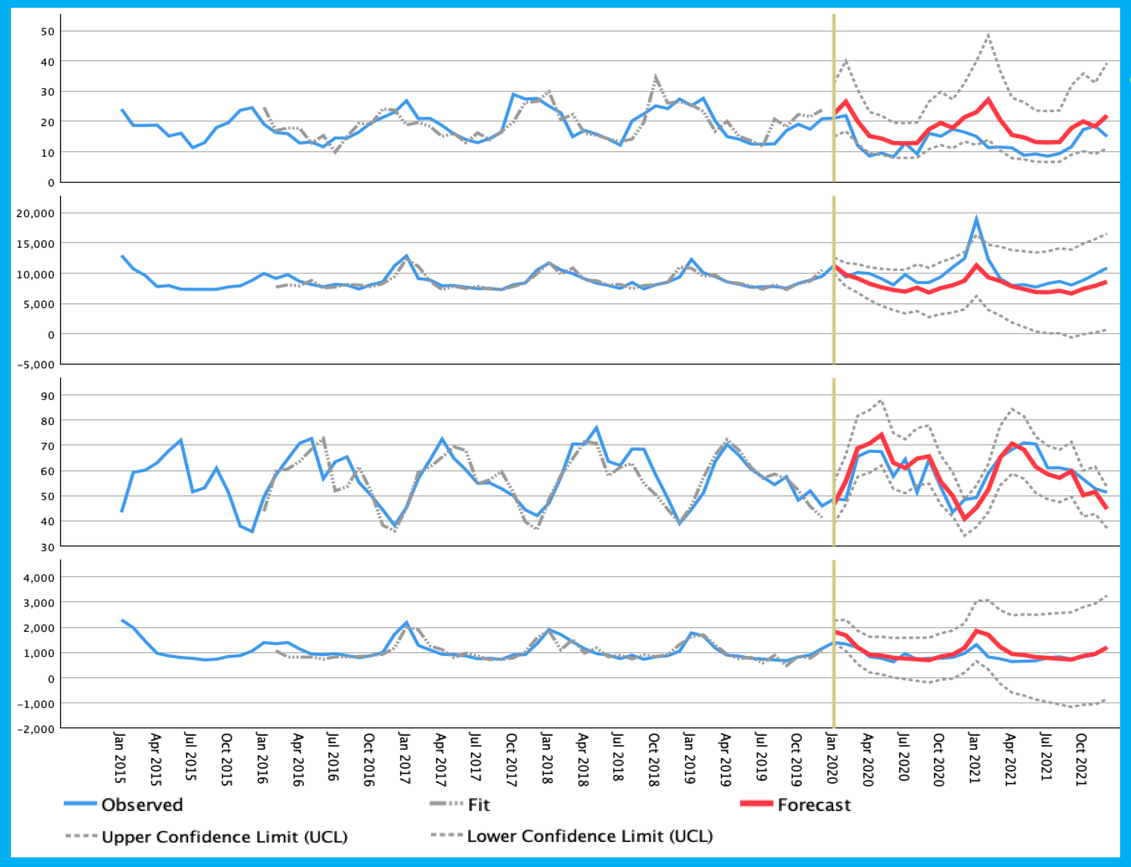

Figure 1. Observed and predicted values for the time series of NO_2 and O_3 concentrations (in µg/m³) and various causes of mortality during the period 2015–2021.

As shown in Figure 1, the SARIMA models forecasted atmospheric levels of **NO_2** and **O_3**, as well as mortality rates for the COVID-19 pandemic, based on pre-pandemic data (2015-2019). The results revealed that:

- **observed mortality from all-natural causes was higher** than expected.
- **observed NO_2 levels and mortality from respiratory diseases were lower** than expected.

CONCLUSIONS

- In 2020 and 2021, significant reductions in **NO_2** and **$PM_{2.5}$** concentrations were observed, accompanied by a slight, non-significant increase in **O_3** exposure, likely influenced by pandemic-related restrictions, emission sources, and meteorological factors.
- Annually, over **5000 deaths** were attributed to exposure to **NO_2 and $PM_{2.5}$**, and at least **139 deaths** from respiratory diseases were linked to **O_3** exposure between 2010 and 2021.
- Based on pre-COVID-19 data, **observed mortality from all-natural causes was higher** than expected, whereas **observed NO_2 levels and mortality from respiratory diseases were lower** than expected.
- **Disruptive events** such as the pandemic can alter the relationship between air pollution and mortality, with implications for public policy.
- This study underscores the **importance of interpreting time series data with caution in the context of sudden disruptions.**

REFERENCES

Simões, J., Bernardo, A., Lima Gonçalves, L., Brito, J., 2025. Assessment of air pollution and mortality in Portugal using AirQ+ and the effects of COVID-19 on their relationship. Sci Rep Apr 15; 15 (1):12862. https://doi.org/10.1038/s41598-025-97704-x

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