RECENT WEATHER AND AIR POLLUTION CHANGES IN BRAZIL

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Abstract : Weather changes play an essential role in air quality levels due to the sensitivity of the air pollutants to weather conditions. In this study, we estimate the changes in ambient air pollution (CO, NO_2, SO_2, O_3, and $PM_{2.5}$) and weather variables (Temperature, Precipitation, Relative humidity, and Wind Speed) in Brazil between 2003 and 2018. We obtained air pollution concentrations on a 6-hour scale from the Copernicus Atmosphere Monitoring Service (CAMS)-Reanalysis and the meteorological data from the ERA-Interim model. Overall, ambient air pollution levels during the study period have decreased in most of the Brazilian states whereas meteorological variables indicate increases in temperature, relative humidity, and wind speed.

Keywords: Climate Change; Air pollution; Southern hemisphere; Brazil

Résumé : Le changement climatique et les conditions météorologiques jouent un rôle essentiel sur la qualité de l'air. Dans cette étude, nous avons estimé les variations de la pollution de l'air (CO, NO_2, SO_2, O_3 et $PM_{2.5}$) et des paramètres météorologiques (température, précipitations, humidité relative et vitesse du vent) au Brésil entre 2003 et 2018. Les concentrations des polluants proviennent de la base de données CAMS (Copernicus Atmosphere Monitoring Service) et les données météorologiques, du modèle ERA-Interim. Au cours de la période d'étude, la pollution de l'air a diminué dans la plupart des États brésiliens, tandis que des augmentations de température, d'humidité relative et de vitesse du vent sont observées.

Mots-clés : Changement climatique; Pollution de l'air; Hémisphère sud; Brésil

Introduction

Air pollution is considered one of the major environmental risks to health. Recent reports from the World Health Organization revealed that 92% of the world population are constantly exposed to PM2.5 levels considered above the WHO standards (WHO, 2016).

Those reports also revealed that 87% of the deaths attributable to air pollution occurred in low or middle-income countries. (WHO, 2016). This value can be considered a consequence of the rapid urbanization and industrialization in developing countries, together with the lack of urban and environmental planning. (Manucci and Franchini,2017).

Several studies also highlighted that weather changes play an important role in air quality levels due to the sensitivity of some pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2) among others, to weather dynamics. (Fernandes et al. 2021, Borge et al., 2019; Requia et al, 2020, Fang et al., 2013).

The literature also suggests an association between ozone (O_3), sunlight, and temperature. The pollutant genesis results from photochemical reactions between nitrogen oxides (NOx) and organic compounds. However, low humidity, low nebulosity, lightning flashes, high temperature, and low wind speed are also related to meteorological factors related to O_3 formation (Lu et al., 2019).

That information, together with the WHO reports, reassures the importance of research on the air pollution and climate change fields, specifically in developing countries where the non-existence of an extensive air quality monitoring network creates a lack of data, resulting in few studies regarding low-income regions such as Africa and South America. (Mannucci and Franchini, 2017).

Our research focused its analysis on this gap, quantifying the average changes in weather factors (temperature, precipitation, relative humidity, and wind speed) and on ambient air pollutants (PM2.5, carbon monoxide (CO), NO_2, O_3, and SO_2) for every state of Brazil.

We performed a trend analysis based on a 16-year daily remote sensing dataset of both pollutants and weather factors stratified by state (Figure 1), to understand the relationship between air pollution and atmospheric variables in Brazil, a country with a high climatic complexity due to its size and biodiversity, expecting to help the improvement of public policies on the air quality and climate change fields.

figure 1. States of Brazil

1.Data and Methods

We obtained air pollution concentrations of these pollutants from the Copernicus Atmosphere Monitoring Service (CAMS)-Reanalysis (from the European Centre for Medium-Range Weather Forecasts – ECMWF) for the period 2003-2018. The data was retrieved at a spatial resolution of 0.125 degrees (approximately 12.5 km), covering Brazil, and a temporal resolution of 6 hours, including daily estimates for 00, 06, 12, and 18 UTC - Universal Time Coordinated. We calculated the daily mean concentration for each pollutant. The validation for the CAMS global model is reported by Inness et al. (2019). We removed the values above the 95th percentile to eliminate the effects of outliers and aggregated the datasets into a daily scale.

The meteorological data were collected from the ERA-Interim model consisting of a global atmospheric reanalysis performed by the ECMWF. The meteorological dataset was also retrieved at a temporal resolution of 6 hours and a spatial resolution of 12.5 km. As for the air pollution data, we calculated the daily means over the entire period of interest for each weather variable, then aggregated the data by the Brazilian state. We removed the weather values above the 95th percentile and aggregated both datasets into a daily scale to remove the effects from outliers.

We used generalized additive models (GAM) to estimate the long-term trends in temperature, humidity, precipitation, and wind speed for the study period (2003-2018). The GAM model was applied using the mgcv package for RStudio (Wood, 2017).

2.Results

Figure 2 highlights the results concerning the average change for every variable (pollutants and meteorological) for the 16-year study period (2003-2018) in the Brazilian states.

Regarding weather parameters, it is possible to notice that the majority of the Brazilian states had registered average increases in temperature during the study period. Only the states of Paraíba, in northeast Brazil, Mato Grosso do Sul at Midwest region, and Rondônia, at North region, have registred decreases on this variable. Paraíba registered an average decrease of 0.52 ° celsius in the 16-year period.

The state of Rio de Janeiro and Minas Gerais, both in the Southeast region of Brazil, on the other hand, registered the highest average increases of temperature, reaching 0.87 and 0.84 °C of increases respectively.

Twenty-four of twenty-seven states have registered decreases in precipitation during the study period. The highest decreases were both registered at Northern states, Roraima, with a decrease of 2.14 mm, and Amapá with 2.1 mm. The states where an increase in precipitation was registered are located in the Southern region of Brazil, except for Paraíba.

The northern states of Amazonas and Acre registered the lowest increase of relative humidity with an average amount of 2.34 % and 2.54% respectively. Meanwhile, Mato Grosso do Sul in the Midwest region, and Piaui, in the Northeast, registered the highest increases of relative humidity, with 18.52% and 18.14%.

The majority of the states also registered an increase in wind speed, highlighting Rio Grande do Norte and Pernambuco with increases of 0.44 and 0.42 m/s during the study period.

The results from the weather trends agree with the literature. Recent studies have shown a significant reduction in precipitation over the Northeastern states followed by an increase in temperature (Costa, 2020; Dubreuil et al, 2019; Marengo et al., 2017). Our findings showed a similar pattern for the North, Midwest, and Southeast states. The Northern states had the most substantial negative oscillation of precipitation. In this region, the Amazon biome predominates with the highest precipitation levels in the country (Da Silva et al, 2019).

Our findings are also in agreement with the recently published Sixth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC, 2021). For the Southern states of Brazil, according to the IPCC, there is high confidence of increase, in mean and extreme temperatures as well as in annual precipitations and extreme precipitations. The report also shows decreases in annual precipitation for the other Brazilian regions, except for the South America Monsoon region, which includes the Midwest Brazil. However, there is low confidence for increases in precipitation intensity and high confidence for evidence concerning temperature increases for the entire country.

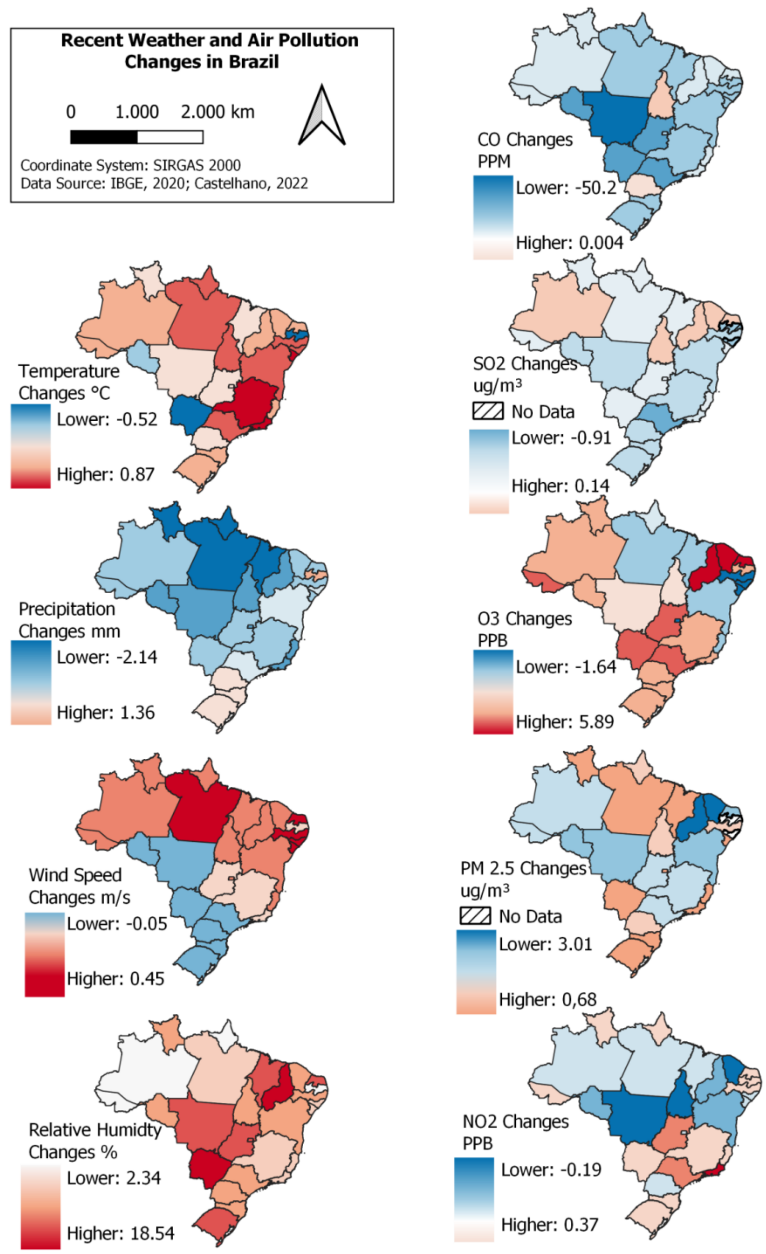

figure 2. Recent Weather and Air Pollution Changes in Brazil

Concerning air pollutants, both CO and SO_2 have registered decreases in the majority of the states during the study period. CO registered an increase only at Paraná, in the South region (0.002 ppb) and the Tocantins in the North region (0.004 ppb). SO_2 registered increases only in five states, three of them in the Northeast region (Rio Grande do Norte, Ceará and Piaui), and the others in the North region (Amazonas and Tocantins).

PM 2.5 registered increases in fourteen states, with the peak at Roraima (northern region, 0.68 $\mu g/m^3$) and Rio Grande do Sul (south region, 0.55 $\mu g/m^3$). All states with decreases in precipitation registered increases on PM2.5.

The reduction of ambient air pollutants concentration was expected, specifically for CO, PM2.5, and SO_2. Indeed, the Brazilian government has been implementing a continuous program to reduce traffic emissions since 1986. The Brazilian Motor Vehicle Air Pollution Control Program (PROCONVE) aims to reduce atmospheric contamination by setting emission standards at the country level, thereby inducing technological improvements in industrial processes and monitoring new vehicles and engines to reach the emission limits standardized. This program is based in the U.S. Program Low Emission Vehicle (LEV) from the California Air Resources Board (CARB) (Ribeiro et al., 2021; Saldiva, 2018).

In the Amazon states, however, we highlight the increase in PM2.5 in the eastern states (Pará, Amapá, Roraima, and the Tocantins). That may be related to the high amount of wildfires and biomass burning in these regions. The increases in the deforestation process on the borders of the Amazon forest, due to agricultural uses, are more intense in those states, and brings together the increases in fires which can be related to an increase in PM 2.5, even with increases in wind speed and temperature, meteorological factors that should help on the dispersion of this pollutant (Schmidt and Eloy, 2020; Rocha and Nascimento, 2021).

NO_2 registered a similar pattern, with increases in fourteen states and decreases in thirteen. The majority of northern and northeastern states registered decreases with a peak of -0.19 ppb of average decrease on Tocantins (Northern region). On the other hand, South, Midwest, and Southeast states registered increases on this pollutant, with a peak of an average increase of 0.37 at Rio de Janeiro state (Southeast region).

The pollutant with the most registers of increases along the Brazilian states is the tropospheric ozone. Eighteen states registered increases in this pollutant, highlighting the northeast region with Rio Grande do Norte and Ceara reaching the highest values (5.89 ppb and 4.43 ppb respectively). The ozone results can be associated with an increase in temperature and decrease in precipitations faced by most of the Brazilian states since ground-level O_3 is formed through photochemical reactions in the atmosphere, involving NOx and VOCs in the presence of sunlight.

Conclusion

Our study revealed that most of the ambient air pollution levels in Brazil during the period 2003-2018 have been decreasing in most of its states for CO and SO_2. Tropospheric ozone is been increasing in the majority of the states whereas PM2.5 and NO_2 for half of the states. Regionally, we identified that the southern states of Brazil (Paraná, Santa Catarina, and Rio Grande do Sul) are where most pollutants (O_3, PM2.5 and NO_2) are increased. At the same period, we also identified significant trends in meteorological factors. There has been an increase in temperature, relative humidity, and wind speed in every Brazilian region. Concerning temperature, the Southeast region registered the most intense increases, while the midwest registered increases in relative humidity and the Northeast region at wind speed levels.

The regional analysis purposed of this study highlights the need to develop specific regional policies not only to control and monitor the pollutants, but also to mitigate climate change based not only on their natural climate conditions, but also on their social, economical, and cultural characteristics. Analysing state by state, we can emphasize that the climate is not the only driver of the air quality issue. The success of public policies such as the PROCONVE, mentioned above, reinforces the social and political role on this subject, but it is suggested to be an isolated policy that contributed only to a few states. The investment in more local policies to control deforestation and biomass burning could not just decrease the air pollutants emissions but also, contribute to the reduction of climatic changes seen in Brazil.

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