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# Environmental pollution and COVID-19 outbreak: insights from Germany

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## Abstract

The impact of environmental pollutants and climate indicators on the outbreak of COVID-19 has gained considerable attention in the recent literature. However, specific investigation of industrial economies like Germany is not available. This provides us motivation to examine the association between environmental pollutants, climate indicators and the COVID-19 cases, recoveries, and deaths in Germany using daily data from February 24, 2020, to July 02, 2020. The correlation analysis and wavelet transform coherence (WTC) approach are the analytical tools, which are used to explore the association between variables included in the study. Our findings indicate that PM2.5, $O_3$, and $NO_2$ have a significant relationship with the outbreak of COVID-19. In addition, temperature is the only significant climate indicator which has significant correlation with the spread of COVID-19. Finally, PM10, humidity, and environmental quality index have a significant relationship only with the active cases from COVID-19 pandemic. Our findings conclude that Germany's successful response to COVID-19 is attributed to environmental legislation and the medical care system, which oversaw significant overhaul after the SARS and MERS outbreaks. The current study implicates that other industrial economies, especially European economies, that are still facing COVID-19 outbreak can follow the German model for pandemic response.

**Keywords** COVID-19 · Germany · Environmental pollution

## Introduction

The World Health Organization (WHO) declared the outbreak of the novel coronavirus COVID-19 as a global pandemic on March 11, 2020, as it became a global health threat (Organization 2020). The prevailing COVID-19 pandemic is spreading at a continuous pace with 12,507,849 confirmed cases as of July 12, 2020, worldwide. The European region

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was one of the worst hits by COVID-19 pandemic as several European countries, including Germany and France, reported imported cases of COVID-19 from travelers returning from Italy (Fattorini and Regoli 2020) and Spain (Ceylan 2020). The high infectious rate of COVID-19 in Europe has posed significant challenges for the health system across the globe as epidemiological surveillance capabilities played a key role in detecting COVID-19 cases in European countries. Early research suggests that person-to-person infectious transmission from COVID-19 requires up to two weeks of incubation time (Dutheil et al. 2020). However, the current situation requires drastic measures to protect the further spread of novel coronavirus. Currently, only experimental treatments are available; therefore, effective planning and upgrading health facilities are the only options to control the spread of COVID-19.

Germany is a leading industrial economy in western Europe with one of the highest GDP per capita income in the entire world (Bank 2020). Germany is also the front-runner in adopting clean energy initiatives, e.g., renewable energy significantly increased from 6% in 2000 to 34% in 2016 (Mez 2020). Germany plans to expand this share by up to 95% until the year 2050. Such initiatives have drastically increased environmental quality and have reduced air pollution in Germany. Germany also has one of the advanced healthcare systems among European countries with its proactive healthcare strategies, such as early-stage diagnosis of COVID-19 patients, extensive testing, and availability of medical facilities ensured limiting COVID-19 outbreak. Germany, until July12, 2020, reported 199,802 confirmed cases but, unlike other epicenters of COVID-19, had the lowest death ratio despite having 21% of the total population over the age of 65 (Bank 2020). The successful response of Germany to the COVID-19 pandemic motivates us to study Germany to provide policy implications for other countries.

The current study investigated the impact of air pollutants and climate indicators' association with the COVID-19 pandemic in Germany. Our study is based on the fact that environmental and pollution indicators are crucial in the outbreak of COVID-19 pandemic (Bashir et al. 2020a). Since the late 1970s, Germany began implementing structural reforms to combat environmental pollution (Mez 2020) i.e., to help the East German government to reduce sulfur dioxide, nitrogen dioxide, and mercury by providing innovative coal-burning technology to filter mercury and hydrocarbons in contaminated water (O'Riordan 1989). Because of these policy changes, Germany has become a global front-runner in green technology with a $400 billion of domestic clean energy industry. Also, domestic policy initiatives such as "Energiewende" have been implemented to battle chemical and air pollution in Germany.

Our research contributes in the economic literature in two ways. First, we are the first study to examine the effect of environmental pollutants in COVID-19 pandemic in an industrial economy like Germany. Current literature is mainly focused on the impact of air pollutants (Anderson et al. 2013) in industrial economies (Bashir et al. 2020b; Cheung et al. 2020). The premise of high-pollution in industrial economies is vital because the air and environmental pollution significantly affect the mortality rate from COVID-19 (Fofana et al. 2020; Lalive et al. 2018; Popp 2006). Analytical structure of prior environmental pollutant studies is mainly based on correlation analysis and the results suffer from data endogeneity issues (Kessler et al. 2001; Schulz et al. 2007; Zijlema et al. 2016; Zimmermann et al. 2003). Gehrsitz (2017), one of the few exceptions to investigate the importance of environmental pollutants in Germany, suggested that low emissions zones have overseen 4–8% improvement in air quality in Germany. However, he recommended that these environmental changes are too small to carry a significant effect over human health. The current study adopts a different approach from existing literature by utilizing wavelet transform coherence (WTC) approach to identify the exact channels through which the COVID-19 outbreak is influenced by pollution indicators.

The current study suggests that an advanced healthcare system and institutional reforms can significantly reduce the impact of environmental and air pollutants with COVID-19 pandemic. In recent past, German authorities have introduced significant organizational reforms and invested in medical care facilities to improve medical facilities for unforeseen medical emergencies such as COVID-19. Our findings indicate that well-established state institutions can moderate the impact of air pollutants, and industrial and emerging economies should focus on introducing policies to reduce environmental pollution and the medical care system.

The rest of the sections as follows: the "Air and environmental pollution in Germany" section provides literature review about environmental pollutants in Germany; the "Research methodology" section presents research and data analysis methodology; the "Results and discussion" section narrates empirical results and lastly, the "Conclusion" section provides conclusion and policy recommendations.

## Air and environmental pollution in Germany

Air pollution is a pollutant that enters the ambient air, instigated by an individual or blend of agents, i.e., chemical, radioactive, or biological matter. Existing research indicates that 82% of European Union residents are exposed to air pollution (Gehrsitz 2017). According to EEA (2017), lower air quality is a major environmental issue, which affects humans through environmental and air pollutants i.e., nitrogen dioxide, sulfur dioxide, carbon dioxide, and particulate matter (Collivignarelli et al. 2020). In Germany, urban areas are more affected by air pollution as traffic circulation and demographic density contribute in lower environmental quality (Li et al. 2018; Qiu et al. 2019; Silva et al. 2018).

According to the EEA (2017), PM10 and PM2.5 contribute about 13% of total air pollutants in Germany, mainly due to a higher proportion of diesel trucks emit $NO_2$. Which is why, German federal court's recent rulings have validated recent changes in environmental policies, i.e., ban on diesel vehicles in urban areas to prevent further GHG emissions (Giesberts 2018; Schmitz et al. 2018). Air quality in Germany is one of the key environmental challenges for German government as it encourages sustainable environment, hence signifying the importance of environmental issues to address environmental issues (Zambrano et al. 2010). Currently, there is a lack of scientific studies that empirically analyze whether or not the concentration level of air pollutants can contribute to the outbreak of COVID-19.

## Research methodology

In the current study, the COVID-19 outbreak is represented by total confirmed cases, total deaths, current active cases, and the number of recovered patients with data taken from the German Federal Ministry of Health (Fig. 1). Air and environmental pollution are measured through PM2.5, PM10, Ozone ($O_3$), and Nitrogen dioxide ($NO_2$) and data for these pollutants has been collected from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in Germany. Humidity and average daily temperature represent climate indicators with daily data taken from Deutscher Wetterdienst. Lastly, Environmental Quality Index (EQI) is included as a proxy for environmental pollution, with data taken from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Dataset for all the variables has been taken from February 24, 2020, to July 2, 2020, to provide a comprehensive analysis for COVID-19 pandemic in Germany.

We have employed the correlation analysis and the wavelet transform coherence (WTC) approach as analytical tools to examine the association between COVID-19 outbreak, and air pollution and climate indicators in Germany. As a prerequisite of correlation analysis, we use Kolmogorov-Smirnov $Z$ test to check data normality. As indicated by values in Table 1, our data is non-normal; hence, we use Spearman correlation analysis to examine the correlation; furthermore, we apply WTC to provide graphical association among variables of the study. Wavelet analysis is one of the most widely used analytical approaches in geosciences, environment, weather, and economics (Afshan et al. 2018; Wu et al. 2019). The wavelet function is preferred as an analytical tool as it reveals weak transients and peculiarities within time series datasets (Arneodo et al. 1995; Muzy et al. 1994). The current study has selected wavelet methodology because of its ability to analyze non-normal and non-stationary present in time series data distributions (Masset 2008; Struzik 2001). Moreover, it enables us to study associations between data variables at different frequencies, which helps in identifying the positive and negative associations at multiple frequencies.

## Results and discussion

Table 1 presents the results of the Kolmogorov-Smirnov $Z$ test, which indicates that the variables are not normally distributed. Thus, non-parametric tests are more appropriate for data analysis. The median values of total cases, recoveries, active patients, and deaths of COVID-19 are 160,726, 118,900, 12,306, and 6391, respectively, in our sample data.

Table 2 presents the Spearman's correlation analysis, which indicates that PM2.5, $O_3$, and $NO_2$ are significantly associated with the total cases, recovered, active cases, and deaths from COVID-19. Temperature has a significant association with total cases, recoveries, and deaths. Lastly, PM10, humidity, and EQI only have significant association with active cases from COVID-19 pandemic in Germany. Thus, our

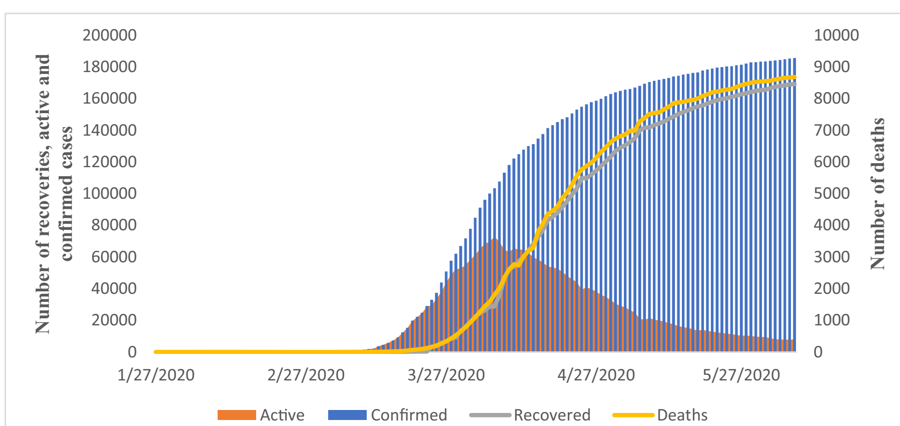


**Fig. 1** COVID-19 outbreak in Germany

**Table 1** Descriptive statistics

| Variables | N | Mean | Median | Kolmogorov-Smirnov *Z* | P value |
|---|---|---|---|---|---|
| Cases | 130 | 123,248 | 160,726 | 3.15 | 0.00 |
| Recoveries | 130 | 95,863 | 118,900 | 2.51 | 0.00 |
| Active cases | 130 | 22,427 | 12,306 | 2.35 | 0.00 |
| Deaths | 130 | 4957 | 6391 | 3.43 | 0.00 |
| PM2.5 | 130 | 36 | 33 | 3.45 | 0.00 |
| PM10 | 130 | 15 | 13 | 3.42 | 0.00 |
| $O_3$ | 130 | 36 | 35 | 4.91 | 0.00 |
| $NO_2$ | 130 | 08 | 07 | 3.01 | 0.00 |
| Temperature | 130 | 54 | 53 | 5.34 | 0.00 |
| Humidity | 130 | 61 | 58 | 5.10 | 0.00 |
| EQI | 130 | 123,248 | 160,726 | 7.11 | 0.00 |

findings indicate that among air pollutants, PM2.5, $NO_2$, and $O_3$ are the key determinants of COVID-19 in Germany. On the other hand, temperature is the only climate indicator, which has a significant influence over COVID-19 pandemic.

Wu et al. (2020) investigated the association of COVID-19 outbreak with fine particulate matter and recommended that a mere increase of 1 μg/m$^3$ results in 15% increase in the mortality cases from COVID-19. Likewise, Fann and Risley 2013, Wang et al. (2020), and Piazzalunga-Expert (2020) arrived at the same conclusions for the USA, China, and Italy, respectively. Recent trends in urbanization have dramatically changed the demographic characteristics of urban areas, which is why a growing number of scientific studies are investigating the association of chronic illnesses with air pollutants such as $NO_2$ and $O_3$. Pandey et al. (2005) studied the health risk associated with $NO_2$ concentration level in New Delhi, India, and suggested that $NO_2$ concentration in industrial and residential areas poses severe health challenges for the elderly and children. They further articulated that HR values for $NO_2$ are 22 times worse than other air pollutants in New Delhi. Similarly, Xue et al. (2020) studied spatio-temporal variations for Shanghai and suggested that increased focus on urban residential planning and introduction of emission management policies have significantly reduced $NO_2$ concentrations in Shanghai. Bernardini et al. (2020) explored the impact of air pollutants, i.e., $O_3$, and suggested that a number of patients into the emergency section have direct correlation with air pollutants. Furthermore, Adach et al. (2020) and Ha (2020) registered similar findings.

**Table 2** Spearman correlation analysis

| Variables | Cases | Recoveries | Active cases | Deaths |
|---|---|---|---|---|
| PM2.5 | − 0.272*** | − 0.273*** | 0.269*** | − 0.281*** |
| PM10 | 0.013 | 0.012 | 0.457*** | 0.005 |
| $O_3$ | 0.214** | 0.216** | 0.467*** | 0.215** |
| $NO_2$ | 0.615*** | 0.614*** | − 0.228*** | 0.614*** |
| Temperature | 0.876*** | 0.878*** | − 0.132 | 0.877*** |
| Humidity | − 0.119 | − 0.118 | − 0.555*** | − 0.119 |
| EQI | − 0.016 | − 0.016 | 0.493*** | − 0.017 |

***, **, and * represent 1%, 5%, and 10% level of significance

Shi et al. (2020), based on Chinese provincial data, evaluated the effect of climate indicators and determined that temperature is a key element, which affects the viral outbreak of COVID-19. Previous studies, to examine the association of temperature and spread of infectious diseases, also suggested that temperature influences infectious diseases with low temperature generally attributed with higher cases from the pandemic (Tan et al. 2005; Vandini et al. 2013). Another key indicator is the humidity. Current literature concludes that high temperature and humidity reduce the spread of coronavirus; furthermore, the arrival of summer significantly reduces the COVID-19 (Luo et al. 2020; Ma et al. 2020; Oliveiros et al. 2020). Environmental quality index serves as a comprehensive indicator to analyze the impact of environmental quality on human health. Based on Chinese provincial dataset from December 01, 2019, to March 20, 2020, Han et al. (2020) concluded that lower environmental quality is negatively correlated with human immune system and as a consequence, it is contributing towards COVID-19 pandemic in countries with poor environmental quality. Similarly, Venter et al. (2020) reinforced comparable discoveries and recommended that better environmental quality lowers the risk of getting infected from COVID-19.

## Wavelet transform coherence

The current study has used the wavelet transform coherence to portray a graphical correlation between variables, which is one of the most extensively used as an econometric tool. In WTC approach, small arrows indicate the direction of correlation running from one variable to the other. The colors inside the circles indicate the strength of such a relationship; furthermore, the strength of the association goes from high to low as we move from yellow to blue color. Cone of influence separates the significant region from the rest with a thick black lining drawn from top to bottom on both sides.

Figure 2a portrays a mild coherence between PM2.5 and total confirmed cases from COVID-19. None of these variables is leading/lagging in this scenario shown by a 0° angle of the arrows. Other yellow areas can be seen scattered throughout the figure but do not represent a significant relationship. Similar coherence can be found in Fig. 2b between PM2.5 and deaths from COVID-19, with only significant coherence between 50 and 60 days of time frame, hence signifying that PM2.5 has no significant association with deaths from COVID-19 pandemic.

Figure 2c represents coherence between active cases and PM2.5, though it represents mild coherence but a significant impact can be observed between 50 and 70 days and 90–110 days time scale, signalling that PM2.5 played an active

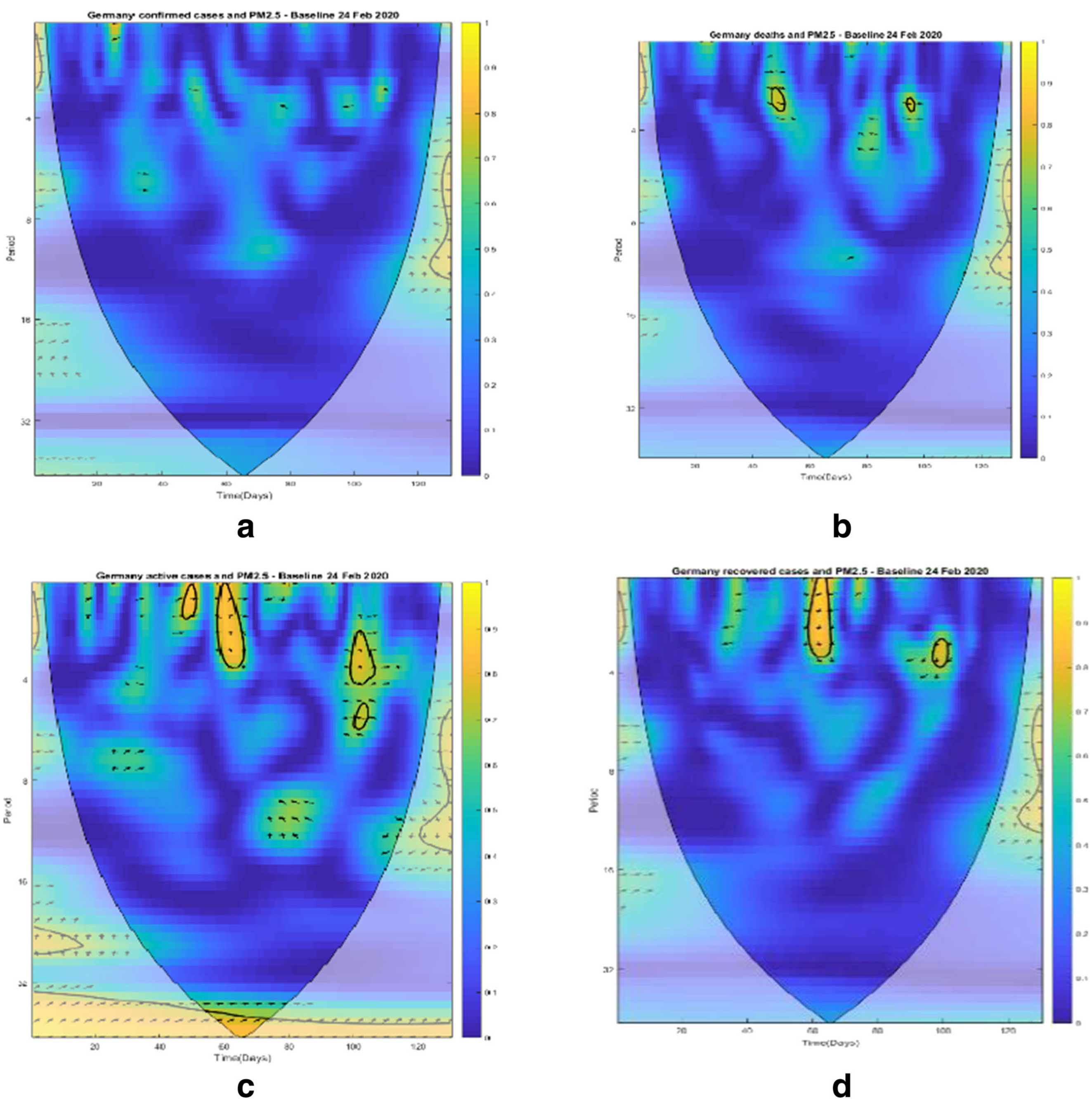


**Fig. 2** **a** Coherence between PM2.5 and total confirmed cases. **b** Coherence between PM2.5 and deaths. **c** Coherence between active cases and PM2.5. **d** Coherence of recoveries and PM2.5

role in COVID-19 pandemic in Germany for such time periods. This implies that decreased PM2.5 contributes to COVID-19 cases but only during a short period of time frequency contribution. Figure 2d shows the coherence of recoveries from COVID-19 and PM2.5 at the start of the 60–80 frequency range displays weak coherence, which indicates that PM2.5 has a weak impact in reducing the recoveries from COVID-19.

Figure 3a reports a mild coherence with negative correlation in same limited areas, between total confirmed cases from COVID-19 and $O_3$. The notable yellow areas with black borders can be seen at the start of the 20–40 and 70–80 frequency range. Next, we analyze coherence between deaths from COVID-19 and $O_3$ with negative correlation areas in Fig. 3b. The frequency range of 40–50 and 70–80 demonstrates that these variables have mild coherence between them.

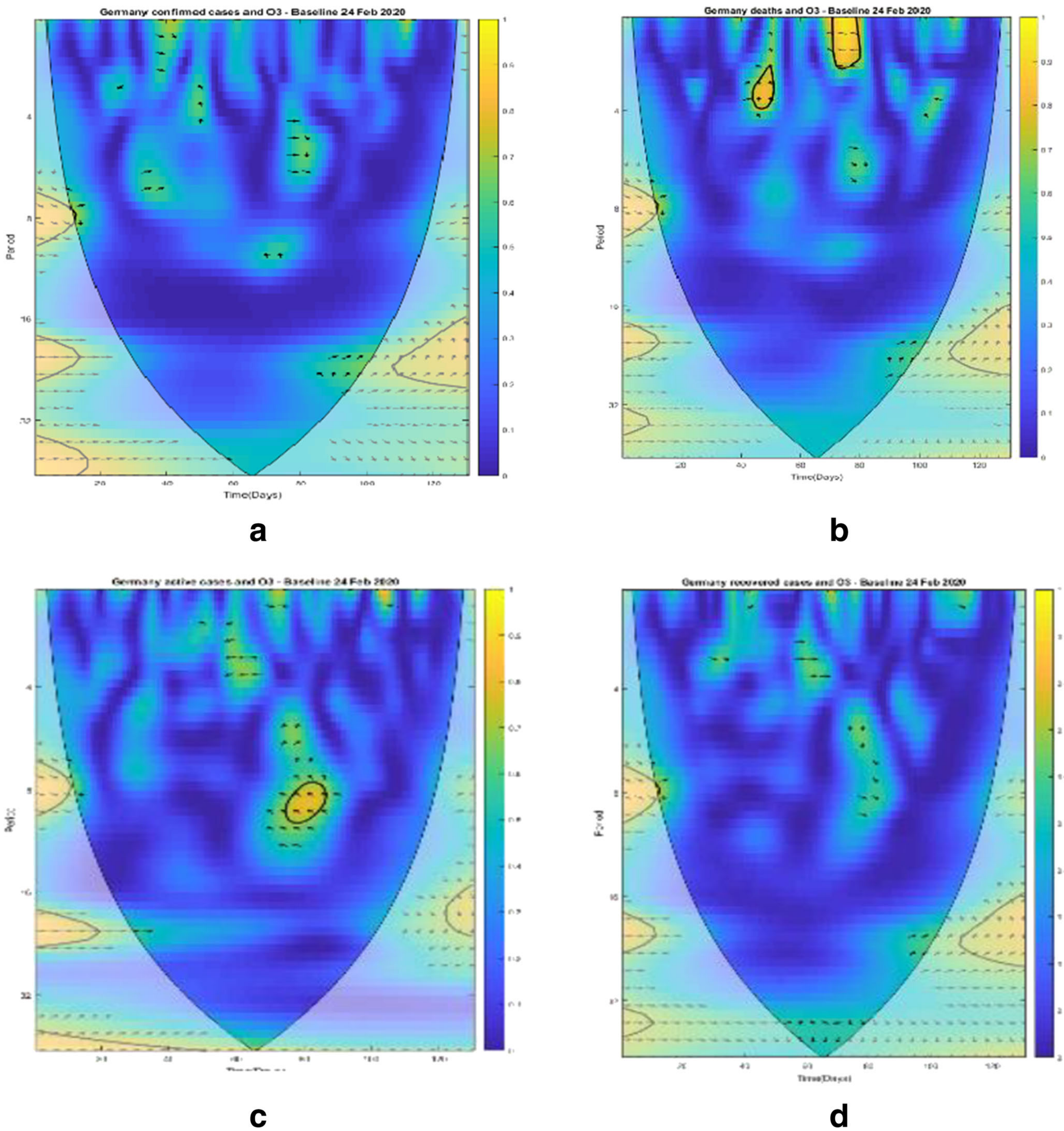


**Fig. 3** **a** Coherence between total confirmed cases and $O_3$. **b** Coherence between deaths and $O_3$. **c** Coherence between active cases and $O_3$. **d** Coherence of recoveries and $O_3$

Additionally, Fig. 3c showcases mild coherence with negative correlation. Lastly, Fig. 3d showcases mild coherence with indecisive correlation between recoveries from COVID-19 and $O_3$ in Germany.

Figure 4 reports the coherence between confirmed cases, deaths, active cases, and recoveries from COVID-19, and temperature. Figure 4a indicates mild positive coherence between total confirmed cases and temperature throughout the 40–60 and 90–100 frequency range. Figure 4b shows coherence with indecisive correlation between deaths and temperature, indicating that deaths from COVID-19 are not significantly affected by the change in temperatures in Germany. Next, Fig. 4c shows coherence with negative correlation between active cases and temperature. Lastly, Fig. 4d highlights weak positive coherence between recovered cases and temperature, showing temperature variation plays a marginal role in recoveries from COVID-19.

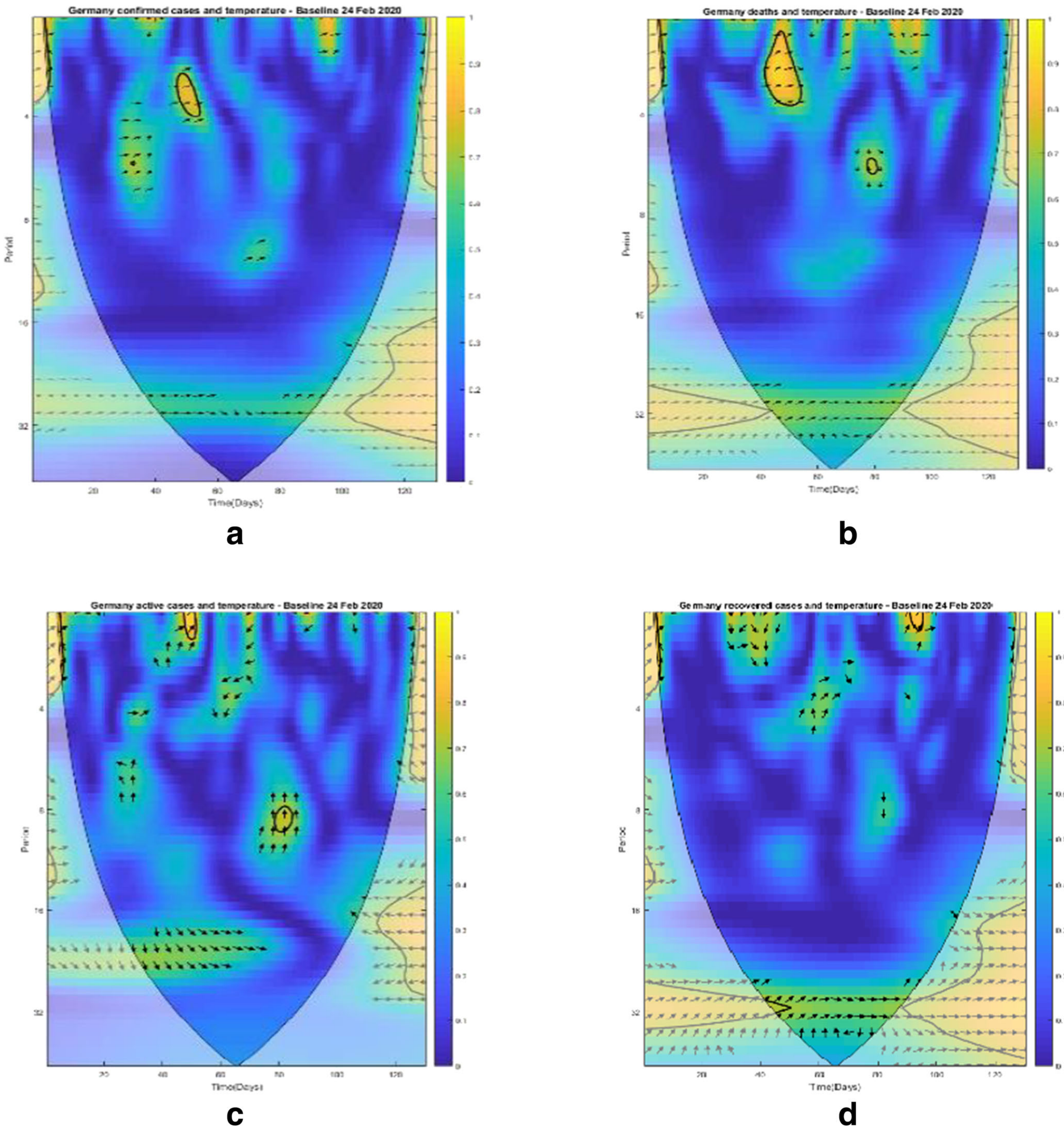


**Fig. 4** **a** Coherence between total confirmed cases and temperature. **b** Coherence between deaths and temperature. **c** Coherence between active cases and temperature. **d** Coherence of recoveries and temperature

Finally, we analyze coherence between $NO_2$ and total confirmed cases, deaths, active cases, and recoveries from COVID-19. Figure 5a shows moderate coherence between total confirmed cases and $NO_2$ with a notable yellow area between 110 and 120 frequency range. Next, Fig. 5b shows that deaths from COVID-19 have a positive but mild coherence with $NO_2$, visible between 40 and 90 frequency range. Next, Fig. 5c shows negative correlation between active cases and $NO_2$, which shows that $NO_2$ has not played a significant role in increased active cases during the COVID-19 pandemic. Finally, the coherence between recoveries and $NO_2$ is visible from Fig. 5d, which highlights mild coherence with indecisive correlation.

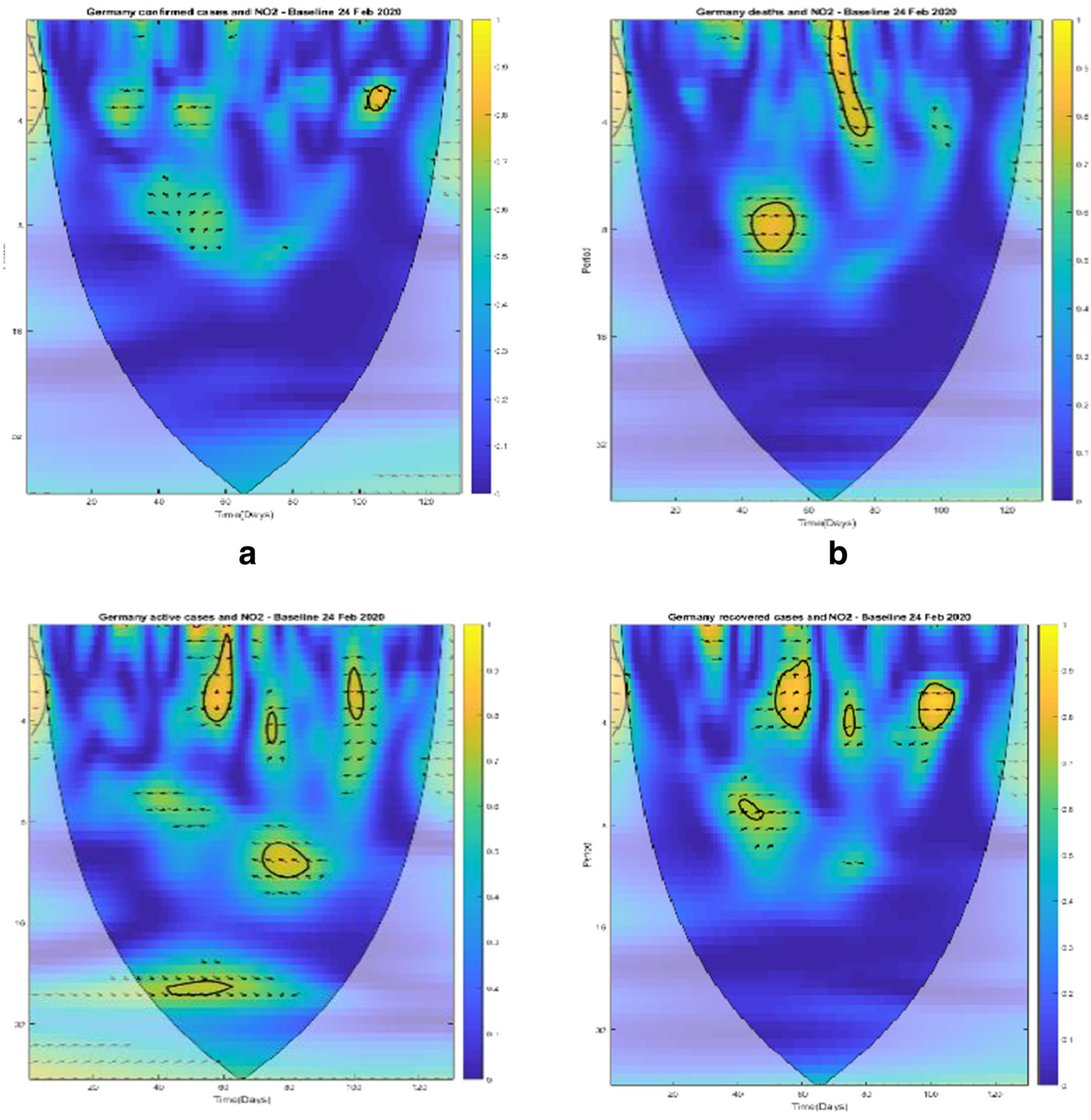


**Fig. 5** **a** Coherence between total confirmed cases and $NO_2$. **b** Coherence between deaths and $NO_2$. **c** Coherence between active cases and $NO_2$. **d** Coherence of recoveries and $NO_2$

## Conclusion

Industrial European economies such as Germany are one of the epicenters of the COVID-19 pandemic, as the number of infections from COVID-19 has an ever-increasing trend; thus, the risk of contracting the virus in these regions is high. Germany offers a unique scenario, as it faced a high infectious rate but still a very marginal mortality rate from COVID-19. In the current study, we have examined the association of COVID-19 outbreak (e.g., total cases, recoveries, and deaths) with environmental and climate indicators in Germany. Our analysis reveals that PM10, $O_3$, temperature, and humidity are the main determinants of the COVID-19 outbreak in Germany. Data analysis supports the fact that lower environmental pollution level has contributed significantly to combat coronavirus pandemic as in the recent past, Germany has introduced significant policy initiatives in its pandemic response strategies after the outbreak of SARS so that environmental policies complement medical initiatives. Statistically, lower exposure to environmental and air pollutants and access to medical facilities significantly reduce the pandemic threat as vulnerable age groups, i.e., elderly and people with chronic diseases are more susceptible to the pandemic. Our study also provides policy implications for health and policy regulators around the globe. We suggest that other countries can take insights from Germany's response by focusing simultaneously on the development of the medical care system and implementing state and federal policies to reduce environmental pollution.

Although our study has interesting findings, the following limitations exist within our work. First, our study is limited to Germany. Furthermore, the current study is based on daily data with limited frequency range; we recommend the researchers to explore the long-term association of environmental and climate indicators with global pandemics by analyzing empirical association within panel dataset of advanced industrial economies. Finally, the wavelet transform coherence serves as a unique analytical tool in comparison against time series and correlation, but research findings should be cautiously interpreted. Also, we encourage the researchers to study inter-regional response towards COVID-19 pandemic to provide a better outlook for understanding the spread of COVID-19 as a global pandemic.

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