Data Analysis of the Air Quality (PM2.5) before, during and after the COVID-19 Pandemic lockdowns in Hanoi and Ho Chi Minh City, Vietnam

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Abstract: - The COVID-19 pandemic has significantly concerned people's daily activities, especially when governments imposed pandemic lockdowns in their countries. These lockdowns, in turn, affected people's daily life, their environment, and even the air quality of where they live. In this context, this paper looks at how the levels of Particulate Matter (PM) 2.5 air pollutants in the cities of Hanoi and Ho Chi Minh City, Vietnam, have changed because of the COVID-19 lockdowns. We analyze the data from the AirNow database and provide *Heat-Map* analyses of PM 2.5 *before*, *during*, and *after* the pandemic lockdowns. Results suggest that lockdowns affect the overall pollution. The results also suggest that this approach could be useful in designing novel policies to reduce air pollution and lessen the impact of future lockdowns, as well as in developing strategies to address future pandemics.

Key-Words: - Air Pollution, Air Quality, PM 2.5, Pollution Monitoring, COVID-19 Pandemic, COVID-19 Lockdown, Air Quality Policy.

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1 Introduction

Particulate Matter (PM) is the name given to the minute liquid and solid debris that can be suspended within the air. Precisely, PM 2.5 refers to particular matter in the order of 2.5 microns width, [1]. To expand on this quote, it means that debris may also originate in many locations, including factories, electricity plants, construction sites, and vehicles. PM 2.5 is a whole lot smaller than the width of a human hair and might enter the circulate and lungs at exceptional depths, leading to an expansion of health issues. In contrast, some classifications of PM, including PM 10, relate to particles with a diameter of 10 micrometers or less. Even though they may be larger than PM 2.5, these particles can still harm human health. In this context, the study of air pollution, particularly PM 2.5, is important for at least 3 reasons:

Health effects – Various negative health impacts, including respiratory issues, cardiovascular illness, lung cancer, early death, and unfavorable pregnancy outcomes, can be attributed to air pollution, particularly PM 2.5.

Environmental Deprivation and Climate Change – PM 2.5, will have many harmful repercussions on the environment. These particles have the potential to damage the environment over the years if they land on the ground or make their way into bodies of water. This may bring to loss of biodiversity, escalating sea levels, and intense weather.

Economic impact – Beyond simply the expense of illness and lost productivity, air pollution, especially PM2.5, can have major economic repercussions. For example, pollution can affect agricultural production with economic implications and impact towards farmers. In a different context, industries can be forced to limit their production or be fined for increasing environmental pollution.

The Southeast Asian country of Vietnam is located on the Indochinese peninsula and is bordered to the north by China, the northwest by Laos, and the southwest using Cambodia. Vietnam is one of the most populous international locations in the vicinity, with a populace of over 96 million, [2]. Vietnam's capital, *Hanoi*, is situated in the north of the country. On the other side, the largest city in Vietnam is *Ho Chi Minh City* which is situated in the south of the nation. With a strong business district and expanding economy, it serves as Vietnam's commercial and financial center. These two towns are good examples to study air pollution, e.g. PM 2.5 since they have high levels of air pollution with emerging urban developments. The growing urbanization and industrialisation of each city and the upward push on vehicle use have all contributed to the deteriorating air quality, [3], [4]. Those cities have experienced worrisome increases in air pollution in recent years, frequently exceeding the recommended values of the *World Health Organisation* (WHO). Comparing the effects of alterations in human activity on air pollution levels, particularly about PM 2.5, is made possible by the COVID-19 lockdowns in Hanoi and Ho Chi Minh City, [5], [6], [7]. The lockdowns provided a controlled experiment to research the connection between human activities and air pollution levels since they reduced traffic and industrial activity, [8], [9]. The best ways to reduce air pollution and enhance public health can be found by determining the effects of changes in human activity on air quality, [10], [11].

The COVID-19 outbreak has caused widespread lockdowns and behavioral changes that have had an impact on many facets of society, including the environment. Since the lockdowns reduced human activity and emissions, one of the most noticeable effects was on air quality. Poor air quality in Vietnam is a concern and has been for a long period [6], [12], [13], [14]. Traffic is not the only source of where the poor air quality comes from [12]. Research states that the power sector is responsible also 'Emissions from the power sector will be responsible for the largest increase in ambient PM2.5 in northern Vietnam between 2015 and 2030', [15]. Air pollution comes at an expensive cost to Vietnam due to the increase in the number of vehicles as well, [16], [17], [18], [19], [20]. Recent works have studied the relationship between poor air quality and the mortality rate, [11]. Meanwhile, there has been research done into the effects of lockdowns where analysis showed the effect of COVID-19 lockdown vs pollution, [21]. These investigations showed that the levels of PM 2.5 were regularly over the threshold that the World Health Organization had recommended. However, the lockdowns brought on by the COVID-19 pandemic and the subsequent pandemic had a substantial impact on both cities' air quality. Lockdowns caused a drop in industrial and transportation activity, which in turn improved the air quality as shown by the decline in PM2.5 concentrations therefore it is worth further investigating how pollution can be affected by these set of conditions which have been triggered by COVID-19 lockdowns, [22], [23].

In this context, it would be beneficial to consolidate an analysis where all the aforementioned aspects of the problems, which have been currently discussed in the literature, are put together: namely, in this paper, we want to look at the COVID-19 pandemic and how the consequence of this pandemic, that is the lockdown which were locally activated by the government could have influenced the traffic of vehicle and therefore, in turn, may have affected the quality of the air. Moreover, this paper aims at analyzing whether COVID-19 lockdown had an impact on the PM 2.5 pollution in the cities of Hanoi and Ho Chi Minh.

The paper is organized as follows: the next section, Section 2, presents the material and methods and how data were extracted, prepared, and processed. In this section, we also present a timeline of the main events related to the COVID-19 pandemic which could have effectively influenced the air quality trends. The following section, Section 3, presents the results using a heat-map representation. The 4th section focuses on the discussion and conclusion. Then, Section 5 reports some observations and future improvements vs current analysis.

2 Materials & Methods

2.1 AirNow Data

AirNow is a US website that provides data about the air quality of different regions and cities, [24]. The data are collected from a set of stations that monitor the air quality. Out of this data, an *Air Quality Index* or AQI parameter is defined as the extent of pollution vs the impact that such smog may have on people's health, [25]. Accordingly, Table 1 shows the range of values of the PM 2.5 parameter vs the AQI level, from *good* to *dangerous*.

For the management of the environment and public health, AirNow's air quality data is crucial. It can assist people in making well-informed choices about their daily activities, such as whether to exercise outside or choose safety precautions like masks or staying indoors.

Additionally, AirNow data on air quality can assist regional and federal decision-makers in managing pollution levels and enhancing public health. Data from AirNow can also be used for academic study.

Table 1. Air quality ratings according to AirNow setting

	US AQI Level	PM2.5 [μg/m³]
	Good	0.0-12.0
	Moderate	12.1-35.4
	Unhealthy for Sensitive Groups	35.5-55.4
	Unhealthy	55.5-150.4
	Very Unhealthy	150.5-250.4
	Hazardous	250.5 +

Infographics source: [24], [25]

2.2 Data Processing

The *CSV AirNow Dataset* has been processed with the *Python Pandas Library* according to these steps:

1. **import pandas as pd**: data are imported and labeled as *pd*.
2. **df = pd.read_csv('airnow_data.csv')**: air quality data are extracted from the CSV file and labeled as *df*.
3. **valid_qc_names = ['Valid', 'Passed']**: a validation of the names is performed and checked.
4. **df = df[df['QC Name'].isin(valid_qc_names)]**: data are cleaned and saved into a variable *df* where all invalid values have been removed.
5. **df = df[(df['NowCast Conc.'] != -999) & (df['AQI'] != -999)]**: The code filters the DataFrame again to remove any rows where the NowCast Conc. or AQI columns have a value of -999. The resulting DataFrame is stored back in the variable *df*.
6. **df.to_csv('cleaned_airnow_data.csv', index=False)**: The code saves the cleaned dataset to a new CSV file named "cleaned_airnow_data.csv". The "index=False" parameter specifies that the index column should not be included in the output file.

2.3 Factors that May Impact the Air Quality

There are different factors that can affect and impact the air quality. The main important ones are:

Lockdowns - Lockdowns normally bring about decreased human activities, which include transportation and industrial operations, which could result in a lower PM 2.5 emissions. With fewer cars on the roads and constrained business production, the primary sources of PM 2.5, such as car exhaust, industrial emissions, and construction dust, are drastically decreased. Therefore, the concentrations of PM 2.5 in the air are possibly to decrease at some stage in lockdowns, resulting in advanced air quality.

Quarantine Measures - Quarantine measures are intended to limit the motion and interactions of people who can also be exposed to a contagious disease. Even as the direct impact of quarantine on PM 2.5 levels can be minimal, the associated lockdown measures can indirectly contribute to stepped-forward air quality, as defined above.

Border Controls - This frequently causes reduced global travel and restricted movement of products, which can have both positive and negative impacts on PM 2.5 levels. On one hand, the lower in air visitors and shipping activities can lessen emissions from worldwide transportation, resulting in lower stages of PM 2.5. However, if there are disruptions in delivery chains or elevated reliance on local manufacturing, there can be an ability will increase in PM2.5 emissions from home assets, such as expanded business activities or transportation to catch up on decreased imports.

Testing - Testing measures all through a pandemic the main recognition of identifying infected people and stopping the spread of the sickness. Whilst testing itself does not directly impact PM 2.5 ranges, it plays an essential function in managing and controlling the pandemic, which could in a roundabout way affect air quality. Using detecting and setting apart infected people, testing can contribute to lowering the quantity of severe COVID-19 instances and associated healthcare interventions. This, in turn, can doubtlessly lead to reduced emissions from healthcare facilities and reduced air pollution associated with medical activities.

It is crucial to notice that the precise impacts of those measures on PM 2.5 ranges will vary depending on the strictness, period, and effectiveness of the implemented measures, as well as local situations and resources of pollution. Moreover, the improvements in air quality as a cause of these measures may be brief unless followed by sustained efforts to reduce emissions from human-brought sources in the long term.

Finally, an important factor affecting all the analysis regards the effective timeline of the key policy responses that occurred during the COVID-19 pandemic.

Table 2. Timeline of key policy responses of Vietnam to COVID-19, [26]

Timeline Feb 1st – May 12th , 2020	
Date	**Key Policy Responses**
Feb 3rd, 2020	Schools are closed until further notice
March 13th, 2020	Credit institutions directed to offer interest and fee restructuring/waivers for affected loans (amounting to about VND 285 trillion)
March 16th, 2020	Key policy rates cut by 50-100 basis points
April 1st, 2020	Declared a national pandemic: (1) non-essential activities and 2) international flights suspended
April 5th, 2020	Telecom companies ordered to reduce/waive communication fees for education and healthcare-related communications (estimated cost around VND 15 trillion)
April 8th, 2020	Announced a support package including deferred tax repayments and land rend for enterprises impacted by COVID-19 (estimated cost around VND 180 trillion)
April 9th, 2020	Announced a support package of nearly VND 62 trillion for COVID-19-affected employees and individual businesses
April 14th , 2020	Eased restrictions nationwide All activities, including non-essential business and services, are allowed to resume, as long as they follow proper infection control measures
May 4th, 2020	Some schools in Ho Chi Minh City and Hanoi reopened

Timeline - The following key events have characterized the key policy response of the Vietnam Government during the COVID-19 pandemic (Table 2):

- February 1, 2020 - Hanoi and Ho Chi Minh City implement nationwide social distancing measures.
- February 2, 2020 - Hanoi and Ho Chi Minh City enter 15 days of strict lockdown.
- February 17, 2020 - Hanoi and Ho Chi Minh City extend the lockdown measures for an additional week as a precautionary measure to prevent the spread of COVID-19.
- February 23, 2020 - Hanoi and Ho Chi Minh City ease some lockdown restrictions, allowing non-essential businesses to resume operations, but with strict guidelines on hygiene and social distancing.
- May 15, 2020 - Hanoi and Ho Chi Minh City further relax lockdown measures, allowing the reopening of schools and allowing larger public gatherings with certain restrictions.
- July 27, 2020 – due to an expansion of the COVID-19 pandemic, a partial lockdown is imposed in Hanoi.
- July 28, 2020 – The same partial lockdown is imposed in Ho Chi Minh City.
- August 12, 2020 – partial lift off the lockdown in Hanoi and Ho Chi Minh City.
- February 2, 2021 – new lockdown in Hanoi and Ho Chi Minh City during the Tet holiday period.
- February 17, 2021 – lift off the lockdown in Hanoi and Ho Chi Minh City.
- June 1, 2021 - Hanoi and Ho Chi Minh City face a surge in COVID-19 cases and implement localized lockdown measures in affected areas, including travel restrictions and closure of non-essential businesses.
- June 11, 2021 - Hanoi and Ho Chi Minh City extend the localized lockdown measures as the number of cases continues to rise, with residents advised to stay at home and follow strict protocols.

These dates are the ones to take particular note of for the data analysis, as they will give a good idea of whether air pollution is largely affected by the vehicles on the streets of Hanoi and Ho Chi Minh City. As stated before the factors caused by the pandemic will give a unique situation of reduced vehicles on the roads. The dates above are crucial in performing this data analysis, as they will give a strong indication that vehicles on the road have a strong effect on air pollution.

Fig. 1: Data processing, calculation of the monthly averages along the years

2.4 Data Analysis

There are many ways in which this data analysis can be performed, the first data analysis which will be performed as a generic way of looking at the data is to find a monthly average and compare the years of air pollution in Hanoi and Ho Chi Minh City. This will be performed by reporting *Line Graph* and *Heat Map* plots of the data analysis. The adoption of these plots has some advantages, such as_simplicity and readability with the possibility of comparing different locations and long-term trends vs seasonal variations. Disadvantages consist of a limited granularity with issues due to the data aggregation and quality. Data were clustered according to their Date, Year, Month *1-st order labels*: each 1-st order label was then sub-clustered into a *2-nd order label*, where, for example, data referring to a specific month were categorized. For each cluster – provided a concatenation of the data for that cluster – average values were then calculated.

The data analysis is focused on finding important links between the lockdowns and air pollution from the COVID-19 Pandemic. Therefore, it is important to analyze particular months to get more ideas of trends that are more short-term. The two most important months are *February* and *April*: *February* because that is when schools close. *April* because that is when the first national lockdown happened. Comparing these months will hopefully solidify the patterns and trends that will be revealed from the data. Again, this will be done visually by a *Line Graph* and a *Heat Map* to view the data.

Fig. 2: Data processing, displaying the Heat Map of the monthly average

Again, there are some advantages and disadvantages to this approach, namely the advantages are the possibility of detecting air pollution variation, seasonal patterns, and events as well as to perform year to year comparisons.

Disadvantages include the sensitivity vs data consistency, the complexity of the processing, and the noise on the data which may present some interpretation challenges.

The following approach was used for the *Line Graph* and *Heat Map* for the monthly averages of the years. A summary of the code performing the following steps is also reported in Figure 1 and Figure 2.

- ✓ Imports the necessary libraries for data manipulation, plotting, and visualization
- ✓ Defines a list of dataset file paths
- ✓ Loads and preprocesses the datasets, including converting date columns to datetime format, extracting year and month information, and filtering out missing values
- ✓ Concatenates the processed *dataframes* into a single *dataframe*
- ✓ Specifies the desired order of months for plotting
- ✓ Calculates the average AQI values for each month and year combination
- ✓ Either Create a bar plot or heat map comparing the monthly average AQI values across different years for Hanoi and Ho Chi Minh
- ✓ Sets plot title, axis labels, and legend
- ✓ Displays the plot on the screen

Overall, the code aims to analyze and visualize the monthly average AQI values for Ho Chi Minh across different years, providing insights into air quality trends.

Similarly, a summary of the following code was used to find the weekly average in a monthly average using the *Line Graph* or *Heat Map*:

- ✓ Imports the necessary libraries for data manipulation, plotting, and visualization
- ✓ Defines a list of dataset file paths
- ✓ Initialises an empty list to store *dataframes*
- ✓ Reads and preprocesses each dataset, including converting date columns to datetime format and extracting year and month information
- ✓ Drops rows with missing values in the 'Month' or 'Year' columns
- ✓ Creates a copy of the dataframe and converts the 'Year' column to integers
- ✓ Appends each processed dataframe to the list

- ✓ Concatenates all the dataframes vertically into a single dataframe
- ✓ Specifies the desired order of months for plotting
- ✓ Filters the combined dataframe to include data for February only
- ✓ Calculates the weekly average Air Quality Index (AQI) values for each year in February
- ✓ Adds a new column 'Week' to the 'weekly_avg' dataframe, calculating the week number based on the day of the month
- ✓ Filters the 'weekly_avg' dataframe to include only the first four weeks of February
- ✓ Group the 'weekly_avg' dataframe by 'Week' and 'Year' columns, calculating the mean AQI value for each combination
- ✓ Creates a new figure for the plot with a specific size
- ✓ Creates a Line Graph or heat map, visualizing the weekly average AQI values. The bars are grouped by week and colored by year
- ✓ Sets the title, x-axis label, y-axis label, and legend title for the plot
- ✓ Displays the plot on the screen

Overall, the code loads and processes multiple datasets extracts monthly and weekly average AQI values and creates a bar plot to compare the weekly average AQI values for the first four weeks of February across different years. The plot provides insights into the variations in AQI values over weeks and across years for Hanoi and Ho Chi Minh.

3 Results

Here we display the main results vs the Heat Map in Hanoi and Ho Chi Minh. We also cluster the results according to the period, namely in terms of monthly average and in two critical times that is February and April.

3.1 The Line Graph and Heat Map for the Monthly Average for Hanoi

The two diagrams (Figure 3 and Figure 4) reveal a lot from the data analysis and it is unfortunate however that the year 2019 was incomplete and contained corrupted data which didn't record properly. Although in all of the years, there is a general trend of the Air Quality being poor then improving then going poor again, however, there are some interesting observations that can be made. Especially when comparing the year 2021 with its previous years, the year 2021 seems to have lower air pollution apart from the month of January which is almost always lower compared to any other year. What will be good to observe is if it is the same correlation in Ho Chi Minh. What is also interesting to observe is the year 2021 has very poor air pollution at the very beginning and very end of its year, however, it scores the best in other months. The most important observation from this however is that the air pollution seems to be getting worse but then the lockdowns happen which bring down the air pollution. Then the air pollution in the year 2022 increases because the lockdowns are over hence because there is now more traffic on the streets of Hanoi.

Fig. 3: Heat Maps of Hanoi and Ho Ci Minh on the left and right panels, respectively

3.2 The Line Graph and Heat Map for the Monthly Average for Ho Chi Minh

Much like the data in Hanoi Air Pollution seems to be getting worse as time goes on apart from the improvement that can be seen during July 2018. Ho Chi Minh follows the same trend that Hanoi does, the effect of the lockdowns saw air quality improve but in 2022 they see an increase in air pollution the majority of the time when compared to its previous years thus giving the impression that the lockdowns were the cause of the improved air pollution. The year 2020 has better air quality when compared to the years before the pandemic such as 2017,2018 and 2019. This is good because it helps to reinforce the hypothesis that this paper started with, it is important to note however that this is just an average of a month therefore it does not go into great detail on what period of the month is getting worse or getting better which is why this will be followed by a *week by week* analysis next. Comparing the two cities that are Hanoi and Ho Chi Minh has been greatly beneficial because it ensures that the results are not one off, in science it is crucial to look and compare other results in different places to see if there really is a trend, and trend that can be seen here is that lockdowns do improve the air quality in cities in Vietnam.

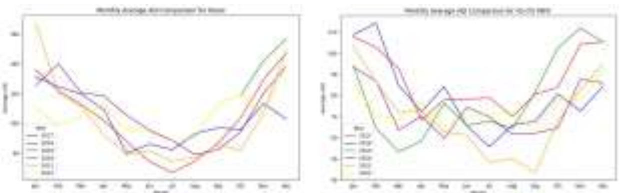

Fig. 4: Line Graphs of Hanoi and Ho Ci Minh on the left and right panels, respectively

3.3 The Line Graph and Heat Map for the Weekly Average for February in Hanoi

In this data analysis (Figure 5), we see a closer look with a lot of more varied values being shown compared to the last data analysis, however here it is not as prominent when comparing this to the monthly average of air pollution. The most interesting trend found in this data analysis is how the year 2022 has quite improved air quality when compared to its previous years however it is important to note that because this data is a lot narrower when compared to the big average that was done previously it may be common to find outliers in the data because the data is not as vast. Another curious result is how at the end of the month that is February 2020 there was a massive increase in poorer air quality this could be the result of panic from schools being the first to close down, remember that the full-scale lockdowns have not started yet and that only schools have closed down. So maybe this could indicate that there was a last-minute fright from people who were flying back home to their own countries so they would not be stuck in Vietnam, or maybe something as simple as not being able to go to the shops because of the uncertainty that lockdowns brought along so people began to stockpile more. It is also important to note how the year 2019 is missing from this so we have less data to compare it to.

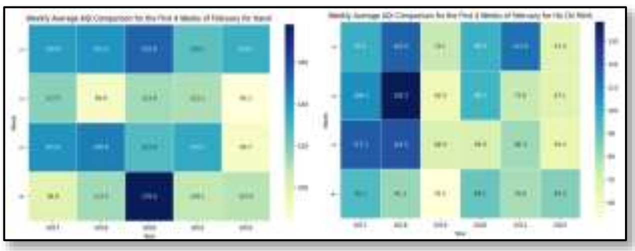

Fig. 5: Heat Maps of February of Hanoi and Ho Ci Minh (left and right panels, respectively)

3.4 The Line Graph and Heat Map for the Weekly Average for February in Ho Chi Minh

The results in Ho Chi Minh are more what is to be expected when comparing this to the work of the data analysis for the weekly average for February in Hanoi, we also have more data to compare it with as we have the year 2019 for the Ho Chi Minh dataset. For example, we can see that in weeks 1,2 and 3 the air quality is better in 2020 than in 2017 and 2018. The only exception is in week 4 but in week 4 2020 it still has better air quality than in 2017. So, it can be stated that during the year of the pandemic air quality was better than in 2017 in the month of February. However, what is very interesting to note is how consistently well the air pollution is in February 2019, this could have been for two reasons.

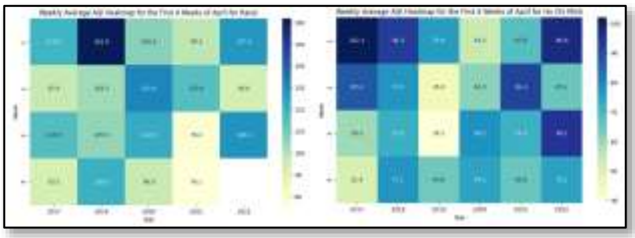

Fig. 6: Heat Maps of April of Hanoi and Ho Ci Minh (left and right panels, respectively)

First, the Tet-holiday (Vietnamese New Year) could have resulted in lower air pollution through decreased industrial activities: During Tet, many factories and industries in Vietnam temporarily shut down or operate at reduced capacity as workers take time off to celebrate with their families. This reduction in industrial activities can lead to a decrease in emissions from factories, power plants, and other industrial sources, resulting in lower air pollution levels. Reduced traffic congestion Tet is a time when many people travel back to their hometowns or go on vacations. As a result, there is a significant decrease in traffic congestion in major cities.

Secondly, the 2019 North Korea – US which was held in Hanoi, could have potentially resulted in lower air pollution in Vietnam through various mechanisms. Temporary traffic restrictions, during high-level diplomatic events like the Hanoi Summit, stringent security measures are often implemented, including traffic restrictions and road closures in certain areas. These restrictions can lead to a reduction in vehicular traffic and subsequently lower emissions from vehicles, resulting in temporary improvements in air quality.

Enhanced environmental preparations: Before hosting an international summit, host countries typically undertake preparations to present a positive image and ensure a smooth and clean environment for delegates and visitors. These preparations might include increased street cleaning, dust suppression measures, and waste management practices. Such measures can indirectly contribute to lower air pollution levels during the event.

3.5 The Line Graph and Heat Map for the Weekly Average for April in Hanoi

The two diagrams in Figure 6 are for the weekly average of air pollution for April in Hanoi. Unfortunately, there is no data for the year of 2019. However, as can be seen in the diagrams, in weeks 2 and 3 air pollution is worse than in 2017 and 2018 in the Pandemic year that is 2020, but in weeks 1 and 4 air pollution is better in 2020 than in the years 2017 and 2018. What is most interesting is that from 2017-2020 air pollution is getting typically increasingly worse, but what can be seen in 2021 is healthier air quality. Air pollution may have improved in some areas a year after the COVID-19 pandemic due to reduced industrial activities, during the pandemic, many industries scaled back or temporarily shut down their operations, resulting in decreased emissions of pollutants from factories, power plants, and other industrial sources. This reduction in industrial activities contributed to improved air quality in the surrounding areas. Another explanation could be Lifestyle changes. The pandemic forced people to stay at home, leading to a decrease in commuting and travel. As a result, there was a decline in individual vehicle usage and a shift towards remote work, reducing daily emissions associated with transportation. Additionally, reduced commercial activities, such as shopping and dining out, further curtailed vehicle movements and subsequently lowered pollution levels.

3.6 The Line Graph and Heat Map for the Weekly Average for April in Ho Chi Minh

The two diagrams above are for the weekly average of air pollution for April in Ho Chi Minh. This is incredibly similar to the data for the weekly average of air pollution for April in Hanoi, it can be seen that 2019 is one of the best years for air quality in April. However, what is most interesting is how all the data is typically lower than in February. This could be because the national holiday that is based in Ho Chi Minh (also known as Saigon) was the victory of the Viet Cong in the Vietnam War known as Black April. Reduced traffic: During holidays or celebrations, there might be a decrease in vehicular traffic as people engage in festivities or take time off from work. This could lead to a temporary reduction in emissions from vehicles, resulting in a slight improvement in air quality. However, the overall effect would likely be modest as can be seen from the data, as other sources of pollution, such as industrial emissions or natural factors, would still contribute to the overall pollution levels.

4 Conclusion

The cities of Hanoi and Ho Chi Minh City are facing an intense air pollution disaster that poses an enormous risk to the well-being of residents and the sustainability of the surroundings. Business activities and rapid urbanization are the primary reasons for this trouble, freeing pollutants into the environment and exacerbating pollution levels. The transportation zone, with its increasing wide variety of motors, additionally contributes drastically to air pollution, mainly in densely populated areas.

The consequences of air pollutants in those cities are far-reaching, impacting public health and the surroundings. Long-term exposure to polluted air is related to breathing diseases, cardiovascular problems, and reduced life expectancy, with vulnerable populations being at higher risk. Moreover, air pollutants harm ecosystems, disrupt natural approaches, and contaminate food sources, threatening the delicate balance of biodiversity in the area.

Throughout the pandemic lockdowns, there has been a temporary improvement in air quality as industrial activities ceased, traffic decreased, and production work was restrained. But, as lockdown regulations eased and the economy reopened, pollutant levels rose once more, highlighting the continual and aggravating nature of the problem.

These results suggest that lockdown may have a beneficial effect on overall pollution, even if, in the long term, it could be useful to rely on novel design policies to reduce air pollution, rather than on such a temporary effect.

These results are in line with previous analysis where following the lockdown improvements in air quality were found also beneficial in terms of economic impact and in terms of reduction of premature deaths, [14].

Addressing this escalating problem requires collaborative efforts and a multi-faceted approach, [9]. Governmental guidelines have to be applied to promote stricter emission standards for industries and motors, at the side of regular monitoring and enforcement.

5 Future Works

The analysis that we presented could be further improved with the introduction of other metrics and with the introduction of other parameters which may had a significant influence on the air quality. The implementation of Machine Learning methods and the support of other information such as, for example, meteorological data could further support our findings. Here is a set of other contributions which may be taken into account for future works.

Air pollution trend analysis and prediction: machine learning models could significantly help here to predict air pollutant levels based on historical data and different relevant features. Using training regression models, along with decision trees, or ensemble methods, forecast pollutant levels for particular periods or locations could be inferred. Incorporating different variables like meteorological data, traffic patterns, or commercial activities could also improve the accuracy of these predictions.

Sentiment analysis: it would be good to consider incorporating sentiment analysis techniques to recognize public perception vs government policies (e.g. lockdowns) and their attitudes closer to air pollutants. Learning algorithms could support and examine social media statistics, information articles, or public opinion surveys to gauge the sentiment and emotional reaction of the population regarding air pollution. This data can offer additional context and increase the evaluation of the social effect of pollution.

Technological integration: this work prospects possible integration of this analysis with sensorial- and surveillance-based systems with traffic monitoring & and management systems, [27], [28], and with pandemic-related analysis, [9].

Model evaluation and validation: ensuring and validating machine learning models to consolidate their overall performance and reliability. Use of the classic appropriate assessment metrics - which include Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), or the Coefficient of Determination (R-squared) - will ensure the measurement of the accuracy of predictions and their credibility.

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- M Van Eker has designed the software and carried out the data processing.
- EL Secco has supervised the work and organized the paper.

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