International Baccalaureate

Extended Essay

Environmental Systems and Societies

The impact of the COVID-19 outbreak on air pollution rates based on PM2.5 air pollutant concentration: A global analysis done for 40 countries

Word Count- 3945

Research Question:

To what extent has the outbreak of disease COVID-19 pandemic, affected the air pollution rates based on PM2.5 air pollutant?

May 2024

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1. Introduction

Today in our world air pollution started to be a crucial issue that is threatening the life of the living creatures and having an important aspect of impacts on the natural environment in many ways. With the very first beginning of instant production, air pollution rates had started to increase. The air pollution may be affected from various factors such as the rate of production in factories, coal-burning power plants, human population (since the human cause air pollution) and vehicle usage etc. ("Ambient PM2.5," n.d.). These factors are mostly anthropogenic. The primary causes of air pollution are considered as energy supply, traffic, agricultural, and industrial. Burning material releases chemicals that can contaminate the air or react with it to produce a polluting impact ("Hava Kirliliği Nedir? Nasıl Önlenebilir?", n.d.). If air pollution is evaluated only within the scope of PM2.5, it is noted that human actions such as smoking, cooking, heating, burning candles, incense and coal and sweeping lead to the formation of PM2.5 (Aquilina & Camilleri, 2022). Pandemics are also one of the biggest factors that can be related to the general trends of air pollution. For example, according to research made in Kolkata, India, the study shows that the average PM2.5 concentration is 70.43 $\frac{\mu g}{m^3}$ in 2019 sharply declined to 37.77 $\frac{\mu g}{m^3}$ in 2020 which makes about 46.37% decrease in PM2.5 concentration due to the restrictions and lockdowns (Biswas et al., 2022). As me and my peers had seriously affected in many aspects from COVID-19 pandemic which was declared as a pandemic in 11th of March 2020, many lockdowns had applied in various cities considering the monitoring of physical activities that includes transportation, restriction in tourism and curfews that prevent people going out. I chose to investigate about the relation between COVID-19 and air pollution rates because this pandemic had led human in many social, economic, and health problems during the spread of disease. On the other hand, when this case is considered from the point of view of environmental impact, it has been stated that there was an almost 50% decrease in the rate of ultrafine particles by the very beginning of the pandemic due to the decrease of usage in vehicles, especially airplanes and automobiles (McKoy, 2022). So, in this extended essay, the data of air pollution based on PM2.5 air pollutant before and during COVID-19 will be put into analyze of a paired sample t-Test to see whether COVID-19 had a significant impact on air pollution rates.

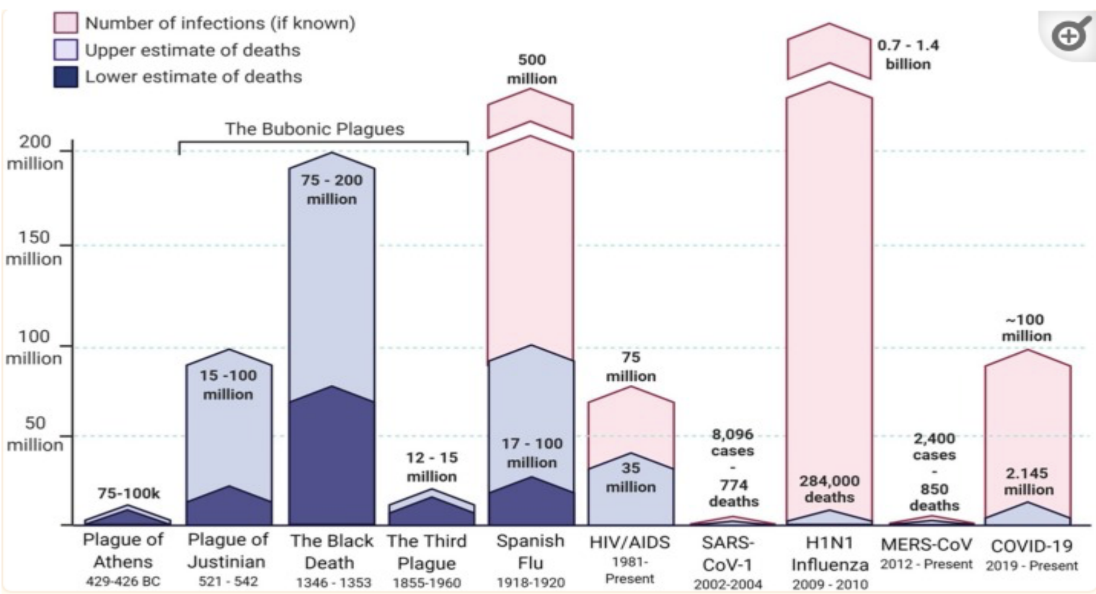
My purpose is to investigate the impact of the COVID-19 pandemic on global air pollution by using the statistical values of PM2.5 air pollutant concentration and investigating the air pollution before and during the pandemic. I wanted to investigate whether there was a significant mean difference in PM2.5 concentration before and during COVID-19.

1.1 COVID-19 as a "Pandemic"

Pandemics cause economic, social, and environmental impacts, and COVID-19 (SARS-CoV-2) has recently been one of the most emanative pandemics, going down in history as a pandemic that has affected civilization in many ways.

Globally, COVID-19 has extended to numerous parts rapidly, and in fact, because of its rapid spread, it has spread to almost every part of the world, which is why it is called a pandemic (Feehan & Apostolopoulos, 2021).

Figure 1: An archive of the major pandemics' historical timeline, displaying infection rates, upper and lower bounds on fatality estimates in 2021 July.



Source: Feehan, J., & Apostolopoulos, V. (2021). Is COVID-19 the worst pandemic?. *Maturitas*, *149*, 56–58. https://doi.org/10.1016/j.maturitas.2021.02.001

1.2 Environmental Problem: Air Pollution

Up to 2023, It is recorded that there are estimated 7 million premature deaths worldwide each year due to air pollution, making it one of the biggest environmental dangers to public health ("Pollution Action Note – Data you need to know", 2021).

Also, according to previous research, air pollution is directly related to the concept of climate change, and greenhouse gases have similar origins. Air pollution is also related to climate change and it has an adverse effect on ecosystems, food production, and human health. For example, ozone has a warming effect on climate by mostly forming photochemical smog in atmosphere, also by various components of PM may have both cooling and warming effects on climate ("Air Quality and Climate Change Research", n.d.). The emission of NO_X and SO_2 will lead to acid rains with various reactions in the atmosphere by forming HNO_3 and H_2SO_4 (they are both considered as "strong acids"). Eventually the precipitation of acid rain will destroy the crops and natural environment which are the shelters of species so biodiversity will get in danger. Also, as the water gets more acidic, the marine life will not support life for aquatic species. Moreover, the excess concentration of PM and its various components shortens the lifespan of human and animals by leading to health problems specifically based on respiration. Besides, methane and black carbon warms the atmosphere by absorbing sunlight, therefore the excess concentration of them will conclude with global warming ("Climate impacts of air pollution", n.d.).

Alarmed by the Deputy Executive Director of United Nations Environment Programme (UNEP), everybody, everywhere is impacted by the environmental and public health emergencies that are caused by air pollution ("World' s largest platform for air quality data launched at Tenth World Urban Forum", 2020). The improvement of air quality is one of the major requirements that should be implemented to have a provision of healthy life. Defined by the UNEP, it has been said that in 2019, almost 4 million individuals had passed away just because of the exposure of the particulates in the air. Sources of particulate emission are listed by UNEP (See page 12) ("Pollution Action Note – Data you need to know", 2021).

1.3 Significance of the Clean Air and Primary Air Pollutants

It has been recorded that air pollution gained a huge pace from the beginning of the Industrial Revolution started in 1800's. The human started to interact with machines and factories, production rates started to increase drastically, that's why the rates of air pollution had increased.

From the previous investigations, World Health Organization (WHO) declared first 5 primary pollutants as ("Ambient (outdoor) air pollution", 2022):

- **Nitrogen dioxide (NO_2),**

Nitrogen oxides are usually emitted from the combustion of fossil fuels.

- **Ozone (O_3),**

Ozone is the major component of the photochemical smog[1].

- **Particulate matter (PM),**

Particulate matters are the solid particulates which are mostly composed of smoke, dust and dirt ("Particulate Matter (PM) Basics", n.d.).

- **Carbon monoxide (CO),**

The combustion of carbon-containing fuels, mainly fossil fuels, gasses, and wood, releases carbon monoxide ("Carbon Monoxide & Health", n.d.).

[1] **Photochemical smog occurs when volatile organic compounds (VOCs) and nitrogen oxides react with sunlight, a combination of pollutants known as photochemical smog is created ("Photochemical smog- what it means for us", 2004).*

- **Sulfur dioxide (SO_2)**

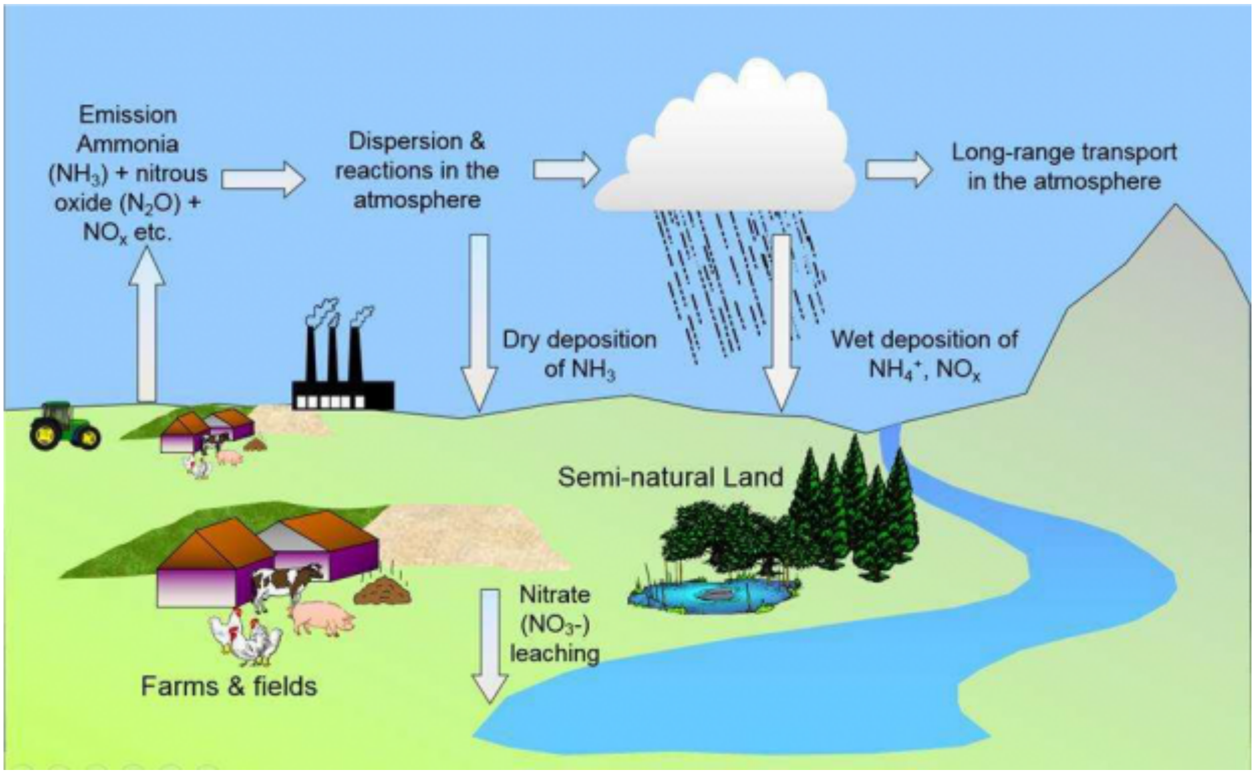
Sulfur dioxide is mostly released from combustion of fossil fuels, primarily oil and gas, moreover the gases which are released from the volcanoes also form sulfur dioxide. (Sulfur dioxide, 2022).

Primarily, clean air is necessary for the healthy life of every living creature, also it is important for the ozone layer's function. The excessive air pollution affects the whole population starting with severe respiratory diseases and health issues. In terms of society, the pollution rates are not equal in every country, most of the low-income countries such as India, Afghanistan or Nepal has the highest rates of air pollution and therefore the society will be affected from the air pollution unequally ("Why clean air?", 2024). Besides, the clean air is highly important for the biodiversity and natural environment. Nitrogen and ammonia oxides, sulfur oxides and carbon monoxides lead to acid rains with the reactions occurred in the atmosphere and they are highly toxic for plants, animals, trees, and for the aquatic organisms by causing the natural environment to deteriorate ("Effects of air pollution on natural ecosystems", 2023).

For example, nitrogen is the base of nitrogenous compounds which cause excessive pollution in the air, natural environment, and water bodies.

Here in the figure 2, the nitrogen cycle is shown in a diagram which is illustrated by the United Kingdom Centre for Ecology and Hydrology.

Figure 2: Nitrogen cycle in the environment.



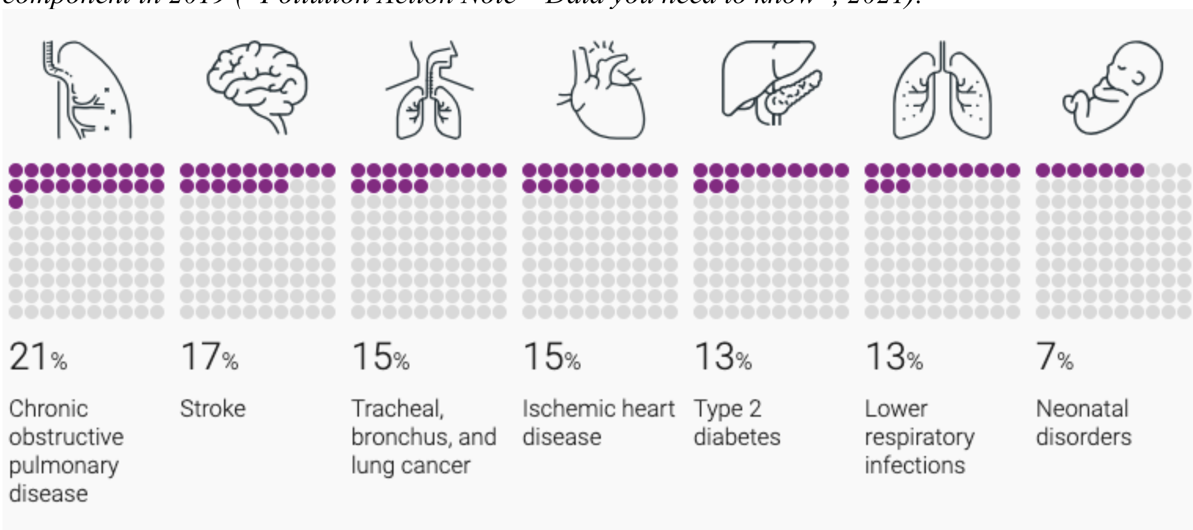
Source: Effects of air pollution on natural ecosystems 2023

As shown in the figure, the emission of ammonia to the air will consequently get through some reactions in the atmosphere and will mix in the aquatic environment. After the precipitation of the nitrogenous compounds through the water systems, nitrogen will accumulate in the water body by causing the formation of algae's and eventually leading to eutrophication, which is a huge problem for the water body (Water Science School, 2018).

1.3.1 Air Pollution Impact on Human

Air pollutants and their particulate form poses a serious threat to humankind by leading to such deaths according to the chronic obstructive pulmonary disease, stroke, tracheal, bronchus and lung cancer, ischemic heart disease, type 2 diabetes, lower respiratory infections, and neonatal disorders ("Pollution Action Note – Data you need to know", 2021).

Figure 3: The percentage of death rates among from any illness linked to outdoor air pollution with a fine component in 2019 ("Pollution Action Note – Data you need to know", 2021).



Source: Air pollution note – data you need to know. UNEP. (2021, September 7). https://www.unep.org/interactives/air-pollution-note/

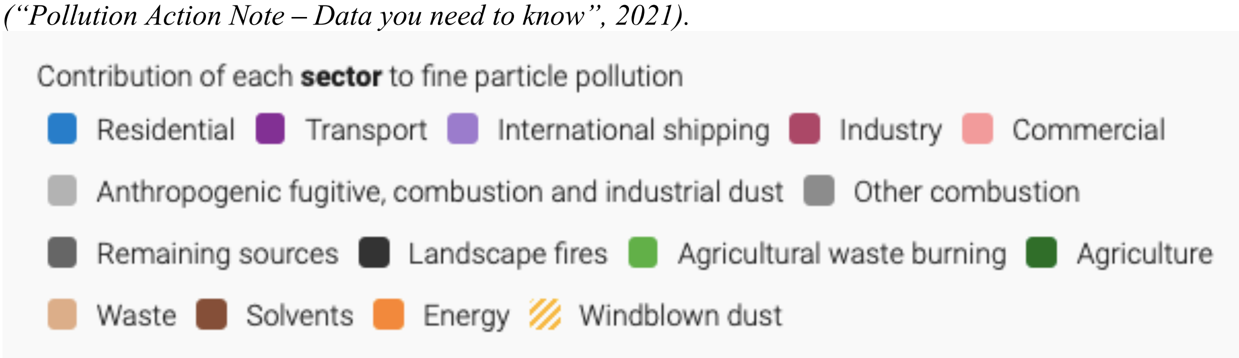
As it is seen below, the deaths caused by the particulate matter in the air causes serious health problems, and besides it is observed that air pollution do not just affect the lungs, it also affects other major organs ("Pollution Action Note – Data you need to know", 2021).

1.4 Impact of COVID-19 on Air Pollution

Since air pollution is one of the great issues that is being addressed by every country, it has been recorded that air pollution rates have been significantly affected from the COVID-19 pandemic. The closures in different cities and further restrictions which are done periodically in many states include, curfews, on the travel between and among cities, the closure of companies, the shutdown of rural towns and schools, decrease local, public transportation (Sarmadi et al., 2021) and the period of factories which have a break on production due to lack of works and so on. It is therefore possible to say that the change in air pollutants concentration is related to the lockdowns and quarantines that were generally put in place with the global spread of COVID-19, because of these mobility restrictions, such as curfews and quarantine's applied, are thought to contribute to the reduction of air pollution (Barua & Nath, 2021).

It is nearly impossible to indicate the sources of air pollution accurately, however, if we make a generalization, the sources of air pollution may be described as in the figure 4, according to the data which are updated in 2023 by UNEP.

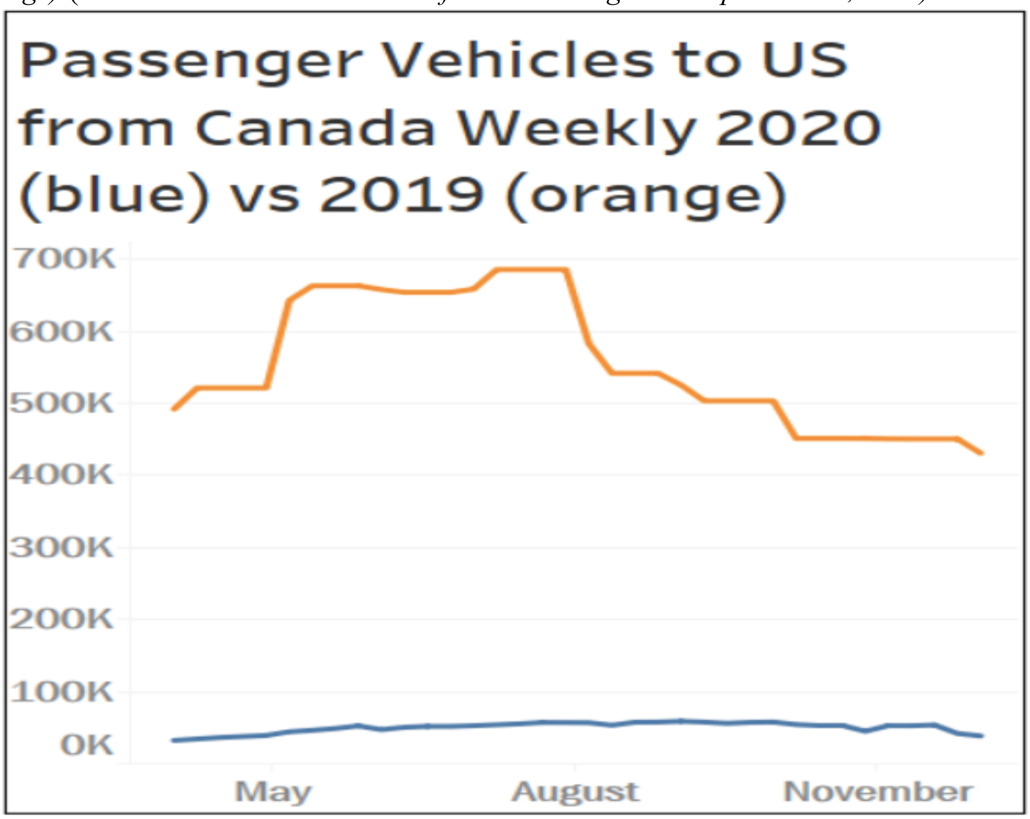
Figure 4: A list of contribution of sectors to the fine particle pollution, recorded in 2021, updated in 2023 ("Pollution Action Note – Data you need to know", 2021).



Source: Air pollution note – data you need to know. UNEP. (2021, September 7). https://www.unep.org/interactives/air-pollution-note/

As it is seen above, there are many sectors which release pollutants to the air, causing air pollution. If the concept of air pollution is associated with the COVID-19 pandemic, it is generally expected that the quarantines are implemented and the restrictions applied to reduce citizens' interactions with each other by the government would make the air pollution rates to decrease. For instance, when the contribution of transportation to air pollution rates are investigated from research made in America, thus, compared to the 498 billion travels made by Americans in 2019, the predicted 370 billion journeys made by Americans in 2020 represented a 26% decrease (“COVID-19 Takes a Bite out of 2020 Passenger Transportation”, 2021). The general trend in a decrease of transportation can be given as an example in figure 5.

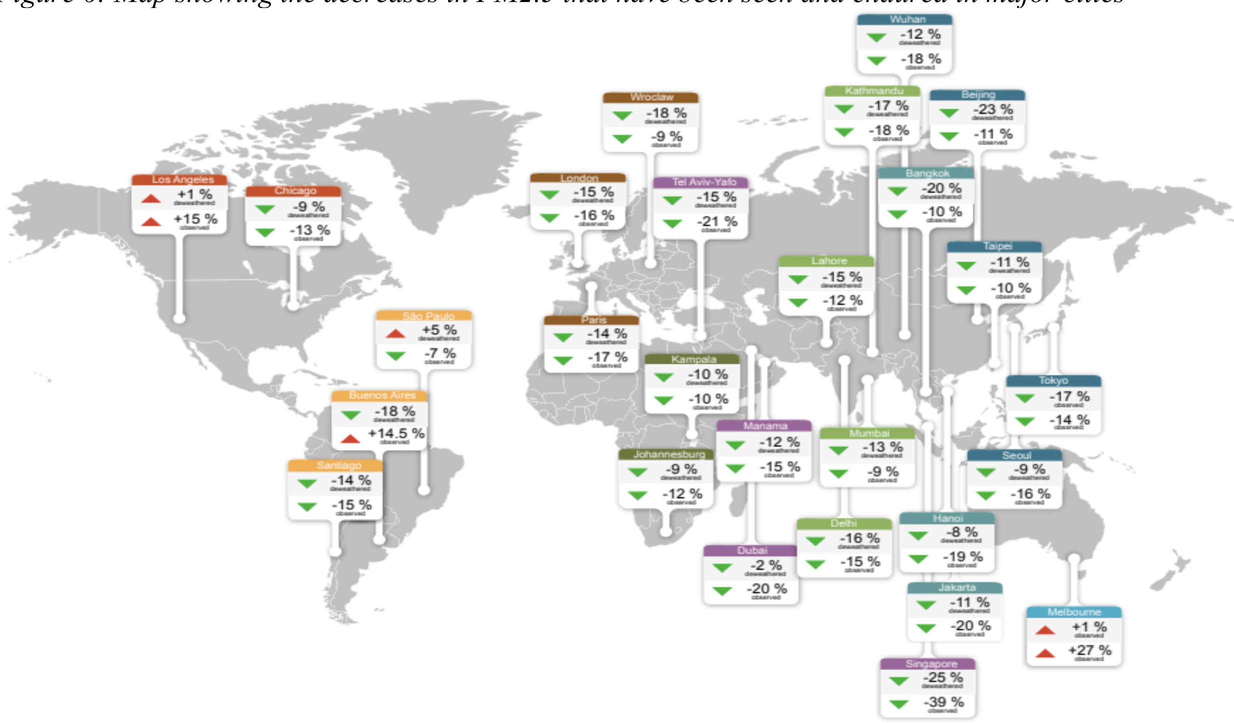
Figure 5: Graph showing number of passenger vehicles to the US from Canada Weekly 2020 (blue) vs 2019 (orange) (“COVID-19 Takes a Bite out of 2020 Passenger Transportation”, 2021)



Source: Covid-19 takes a bite out of 2020 passenger transportation. COVID-19 Takes a Bite out of 2020 Passenger Transportation | Bureau of Transportation Statistics. (2021, February 16). https://www.bts.gov/data-spotlight/covid-19-takes-bite-out-2020-passenger-transportation

There were 1.8 million fewer passenger automobiles entering the United States from Canada in 2020 compared to 2019, a 91% decline had observed ("COVID-19 Takes a Bite out of 2020 Passenger Transportation", 2021). Even considering the reduction in passenger vehicles to the US from Canada, it would have a great impact on reducing the PM2.5 rate at the very first beginning of the transportation restrictions in 2020, that are applied in America.

Figure 6: Map showing the decreases in PM2.5 that have been seen and endured in major cities



Source: 2020 World Air Quality Report Region & City PM2.5 Ranking IQ Air

Also, the concentration of PM2.5 is decreased during COVID-19 pandemic. Regarding to the data restrained by IQAir (See figure 6), the greatest reductions of PM2.5 observed in Singapore by a decrease of 25% when the values of 2019 and 2020 are compared. Secondly, Beijing has the highest ratio of decrease after Singapore with 23% of decrease. Overall, a general reduction of PM2.5 concentration is observed from this map ("World Air Quality Report", 2020).

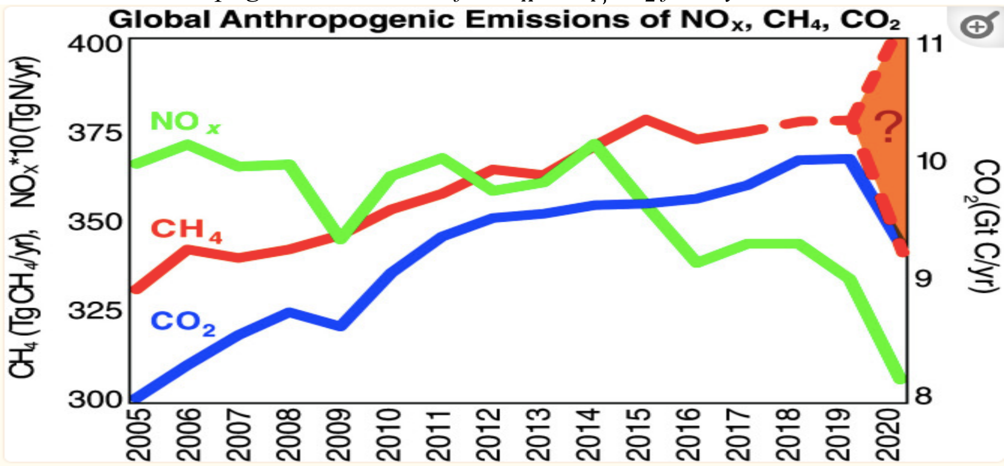
1.4.1 COVID-19 Restrictions and Society

The quarantines and curfews were applied by the government due to the high spread of COVID-19, therefore these restrictions caused:

- The suspension of the production in factories due to the absence of workers in the factories, in short, the factories could not operate that much as they were doing before,
- usage of local vehicles has decreased dramatically,
- public transportation use, almost dropped to zero during curfews,
- decrease in fire activity (Poulter et al., 2021),
- human-based wildfires had decreased,
- recreational cruise trips were cancelled,
- most of the international flights were postponed for a while,
- decrease in anthropogenic activity is observed,
- the rates of industrialized activities had reduced.

As it was recorded, it has been noticed that the emission of air pollutants (sulfur dioxide, nitrogen oxides, ozone, PM, carbon monoxide) and their concentration in the air decreased when commercial and local activities were reduced due to restrictions had made by the government. For instance, figure 5 can be given as a statistical model that represents the global anthropogenic emissions decline, based on various air pollutants, in 2020.

Figure 7: The Global Anthropogenic Emissions of NO_X, CH_4, CO_2 from years 2005-2020



Source: Laughner, J. L., Neu, J. L., Schimel, D., Wennberg, P. O., Barsanti, K., Bowman, K. W., Chatterjee, A., Croes, B. E., Fitzmaurice, H. L., Henze, D. K., Kim, J., Kort, E. A., Liu, Z., Miyazaki, K., Turner, A. J., Anenberg, S., Avise, J., Cao, H., Crisp, D., de Gouw, J., … Zeng, Z. C. (2021). Societal shifts due to COVID-19 reveal large-scale complexities and feedbacks between atmospheric chemistry and climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(46), e2109481118. https://doi.org/10.1073/pnas.2109481118

The graph which is indicated as figure 7 is the representation of NO_X, CH_4, CO_2 emissions through years starting from 2005 to 2020. As shown, there is a sharp decrease in the emissions of NO_X and CO_2 in 2020. The shift in worldwide emission of CH_4 was similar to the shift in emission of CO_2 according to this graph.

As it is seen in the figure 7, there is a clear decrease in global anthropogenic emissions of toxic gases through the air in 2020, therefore the reason of the sudden decrease of air pollution in 2020 got me through research about the impact of COVID-19 pandemic to air pollution rates. I wondered if there is a significant difference (a significant decrease) of the emission of air pollutants in 2020 compared to before COVID-19 pandemic, so I decided to do a scientific and statistical research utilizing from the secondary data. I had read lots of academic papers that states there is a significant decrease of air pollutants in 2020 as a result of restrictions of people's activities (See page 15) because of the COVID-19 pandemic, so I wanted to investigate this case by myself using statistical evidence.

2. Methodology

This investigation regarding to my research question is held in the following way:

1. Firstly, one air pollutant should be determined as an example. This investigation will be PM2.5 air pollutant based. PM2.5 are the particulate matters which are 2.5 microns or less in diameter ("Inhalable Particulate Matter and Health (PM2.5 and PM10)", n.d.). I choose PM2.5 as the indicator air pollution because it includes various chemicals such as ammonium, elemental and organic carbon, silicon, sulfate, nitrate, and sodium ion (Dominici et al., 2015). Moreover, particulate matter is now thought to be the most hazardous to human health of criterion pollutants. (2020 World Air Quality Report Region & City PM2.5 Ranking).
2. Then, 40 countries are selected to be driven in Paired Sample t-Test. I tried to select those 40 countries from as various continents as possible. Also, the data includes low, lower-middle, upper, middle and high income countries. By that way, I will have an idea of how the general PM2.5 rate has changed in the world and the data won't be limited considering with just a particular region. The reason for selecting 40 countries is increasing the sample size will able me to reach to more reliable and more accurately represented outcomes, that are more precise (Andrade, 2020). Also, the minimum sample size should be "30" in t-Test because it depends on the assumption that the sample means are normally distributed, and the distribution of sample means may not be normal and the test findings may not be trustworthy if the sample size is too small (Rubik Top, 2023).

3. The average annual PM2.5 concentration values of each country in 2018, 2019 and 2020 will be collected separately. Then, the average PM2.5 concentration in 2018 and 2019 for each country will be calculated to form the “first group of data” which indicates the PM2.5 rates “before” COVID-19.
4. The “second group of data” is determined as PM2.5 rates “during” COVID-19 and it is composed of the data of air pollution concentrations in 2020 for each country.
5. The data of PM2.5 concentrations is taken from a verified source “IQAir”, which is also supported by UNEP. All the statistical analysis process is done in Microsoft Excel.
6. Then “Paired Sample t-Test” is applied to look for whether there is a significant mean difference between the two groups. The test will show me whether COVID-19 had an impact on the air pollution, based on PM2.5 concentration. This type of t-Test is used because it is carried out on the groups that are reliant. In this investigation the paired values, which are essentially two measurements of the same title, are evaluated using it.

The essay was carried out to analyze how the COVID-19 pandemic had impacted air pollution. This investigation includes secondary data to maintain raw data, therefore all the data are collected from reliable and verified sources. The PM2.5 concentrations data are taken from an online database named IQAir. It is a reliable website which is also in collaboration with Greenpeace, UNEP and UN Habitat. It explores air pollution prediction and real-time information on air quality and it is the biggest free real-time information portal on air quality in the world ("About IQAir", n.d.). Moreover, other references include data from organizational websites, credible businesses, and well-known, reliable news websites. All the references are given in the "References" part.

3. Data Analysis

3.1 Average Annual PM2.5 Concentrations of 40 Countries in 2018 and 2019

As it was previously mentioned in the methodology part, 40 countries are considered for the paired t-Test. The first step is to indicate 40 countries based on an annual average of PM2.5 concentration, $(\frac{\mu g}{m^3})$. The average of 2018 and 2019 PM2.5 concentration data will be used in paired t-Test.

Table 1: 40 countries of 2018 and 2019 data of annual PM2.5 concentrations (conc.). They are not in a specific order.

Country	2018 PM2.5 conc. $(\frac{\mu g}{m^3})$	2019 PM2.5 conc. $(\frac{\mu g}{m^3})$	Country	2018 PM2.5 conc. $(\frac{\mu g}{m^3})$	2019 PM2.5 conc. $(\frac{\mu g}{m^3})$
Pakistan	74,30	65,80	**Norway**	7,60	6,90
Bahrain	59,80	46,80	**Luxembourg**	11,20	9,60
Bangladesh	97,10	83,30	**Ireland**	9,50	10,60
Kuwait	56,00	38,30	**Cyprus**	17,60	19,70
United Arab Emirates	49,90	38,90	**Philippines**	14,60	17,60
Uzbekistan	34,30	41,20	**Kosovo**	30,40	23,50
Peru	28,00	23,30	**Czech Republic**	20,20	14,40
Chile	24,90	22,60	**Singapore**	14,80	19,00
Turkey	21,90	20,60	**Brazil**	16,30	15,80
Sri Lanka	32,00	25,20	**France**	13,20	12,30
Mexico	20,30	20,00	**Russia**	11,40	9,90
Italy	14,90	17,10	**Netherlands**	11,70	10,90
Israel	18,60	20,80	**Germany**	13,00	11,00
South Korea	24,00	24,80	**Belgium**	13,50	12,50
Thailand	26,40	24,30	**Switzerland**	11,60	10,90
Romania	18,60	18,30	**Japan**	12,00	11,40
Poland	22,40	18,70	**United Kingdom**	10,80	10,50
Australia	6,80	8,00	**Portugal**	9,40	9,30
Puerto Rico	13,70	10,20	**Canada**	7,90	7,70
New Zealand	7,70	7,50	**Lithuania**	17,50	14,50

Source: *World's most polluted countries in 2022 - PM2.5 ranking*. IQAir. (n.d.). https://www.iqair.com/world-most-polluted-countries

3.2 Average Annual PM2.5 Concentrations of 40 Countries in 2020

For the application of paired t-Test, the average PM2.5 concentrations of 2018 and 2019 will be used. The average values will be calculated in excel. This table (See table 2) will be used in paired t-Test.

Table 2: The average values of PM2.5 concentrations of 2018 and 2019 values of 40 countries

Country	**Average PM2.5 conc. in 2018 and 2019 ($\frac{\mu g}{m^3}$)**	**Country**	**Average PM2.5 conc. in 2018 and 2019 ($\frac{\mu g}{m^3}$)**
Pakistan	70,05	**Norway**	7,25
Bahrain	53,30	**Luxembourg**	10,40
Bangladesh	90,20	**Ireland**	10,05
Kuwait	47,15	**Cyprus**	18,65
United Arab Emirates	44,40	**Philippines**	16,10
Uzbekistan	37,75	**Kosovo**	26,95
Peru	25,65	**Czech Republic**	17,30
Chile	23,75	**Singapore**	16,90
Turkey	21,25	**Brazil**	16,05
Sri Lanka	28,60	**France**	12,75
Mexico	20,15	**Russia**	10,65
Italy	16,00	**Netherlands**	11,30
Israel	19,70	**Germany**	12,00
South Korea	24,40	**Belgium**	13,00
Thailand	25,35	**Switzerland**	11,25
Romania	18,45	**Japan**	11,70
Poland	20,55	**United Kingdom**	10,65
Australia	7,40	**Portugal**	9,35
Puerto Rico	11,95	**Canada**	7,80
New Zealand	7,60	**Lithuania**	16,00

Source: *World's most polluted countries in 2022 - PM2.5 ranking*. IQAir. (n.d.). https://www.iqair.com/world-most-polluted-countries

To determine whether there is a significant difference between the means of the PM2.5 concentration values of 2020 and the average of 2018 and 2019, annual average PM2.5 concentrations of 2020 are indicated (“SPSS Tutorials: Paired Samples T Test”, n.d.).

Table 3: The average concentration of PM2.5 in 2020 for 40 countries

Country	**2020 PM2.5 conc. ($\frac{\mu g}{m^3}$)**	**Country**	**2020 PM2.5 conc. ($\frac{\mu g}{m^3}$)**
Pakistan	59,00	**Norway**	5,70
Bahrain	39,70	**Luxembourg**	9,00
Bangladesh	77,10	**Ireland**	8,60
Kuwait	34,00	**Cyprus**	15,80
United Arab Emirates	29,20	**Philippines**	12,80
Uzbekistan	29,90	**Kosovo**	20,00
Peru	17,90	**Czech Republic**	12,30
Chile	19,30	**Singapore**	11,80
Turkey	18,70	**Brazil**	14,20
Sri Lanka	22,40	**France**	11,10
Mexico	18,90	**Russia**	9,30
Italy	18,50	**Netherlands**	9,70
Israel	16,90	**Germany**	10,10
South Korea	19,50	**Belgium**	8,90
Thailand	21,40	**Switzerland**	9,00
Romania	15,80	**Japan**	9,80
Poland	16,90	**United Kingdom**	8,30
Australia	7,60	**Portugal**	9,10
Puerto Rico	3,70	**Canada**	7,30
New Zealand	7,00	**Lithuania**	11,70

Source: *World’s most polluted countries in 2022 - PM2.5 ranking*. IQAir. (n.d.). https://www.iqair.com/world-most-polluted-countries

3.3 Processed Data Table

Table 4: Mean and standard deviation calculation for the 2018 and 2019 average PM2.5 concentration of 40 countries and 2020 PM2.5 concentrations of 40 countries

	2018 and 2019 average PM2.5 conc.	**2020 PM2.5 conc.**
Mean	21,99	17,70
Standard Deviation	17,46	14,23

3.4 Paired Sample t-Test of 40 Countries

The paired sample t-Test will be done in Microsoft excel. To be able to apply a paired sample t-Test, there should be “two” hypothesis which are “null hypothesis (H0)” and “alternative hypothesis (H1)” should be indicated.

H0: There is no significant mean difference between the annual average of PM2.5 concentration of 40 countries in 2018 & 2019 and the annual average PM2.5 concentration of the same 40 countries in 2020.

H1: There is a significant mean difference between the annual average of PM2.5 concentration of 40 countries in 2018 & 2019 and the annual average PM2.5 concentration of 40 countries in 2020.

According to these hypotheses, random variation accounts for every discernible difference (“Paired T-Test”, 2024). In paired sample t-Test, alpha has determined as 0.05.

Table 5: The data of PM2.5 conc. of average of 2018 & 2019's data and 2020's data that will be used in paired sample t-Test

Country	2018 & 2019 average PM2.5 conc. ($\frac{\mu g}{m^3}$)	2020 PM2.5 conc. ($\frac{\mu g}{m^3}$)
Pakistan	70,05	59,00
Bahrain	53,30	39,70
Bangladesh	90,20	77,10
Kuwait	47,15	34,00
United Arab Emirates	44,40	29,20
Uzbekistan	37,75	29,90
Peru	25,65	17,90
Chile	23,75	19,30
Turkey	21,25	18,70
Sri Lanka	28,60	22,40
Mexico	20,15	18,90
Italy	16,00	18,50
Israel	19,70	16,90
South Korea	24,40	19,50
Thailand	25,35	21,40
Romania	18,45	15,80
Poland	20,55	16,90
Australia	7,40	7,60
Puerto Rico	11,95	3,70
New Zealand	7,60	7,00
Norway	7,25	5,70
Luxembourg	10,40	9,00
Ireland	10,05	8,60
Cyprus	18,65	15,80
Philippines	16,10	12,80
Kosovo	26,95	20,00
Czech Republic	17,30	12,30
Singapore	16,90	11,80
Brazil	16,05	14,20
France	12,75	11,10
Russia	10,65	9,30
Netherlands	11,30	9,70
Germany	12,00	10,10
Belgium	13,00	8,90
Switzerland	11,25	9,00
Japan	11,70	9,80
United Kingdom	10,65	8,30
Portugal	9,35	9,10
Canada	7,80	7,30
Lithuania	16,00	11,70

Source: *World's most polluted countries in 2022 - PM2.5 ranking*. IQAir. (n.d.). https://www.iqair.com/world-most-polluted-countries

Table above indicates the data of PM2.5 concentration in each country classified into 2 groups. 2018 & 2019 average PM2.5 conc. and 2020 PM2.5 conc. were determined as the title of group 1 and 2 respectively to be used in t-Test.

Table 6: Bar graph of PM2.5 concentrations values in 40 countries before and during COVID-19 pandemic

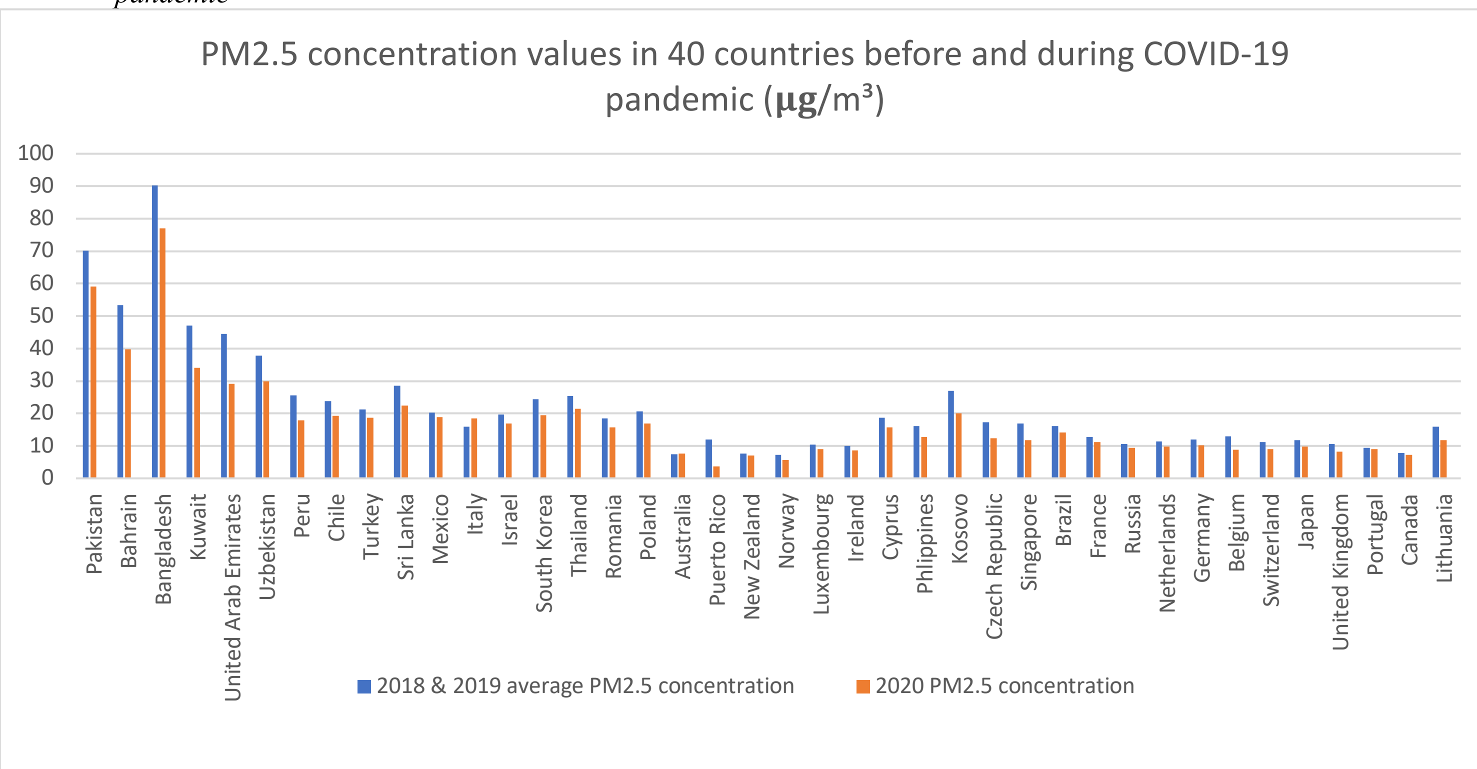


Table 7: Paired Sample t-Test applied for the two data sets in excel

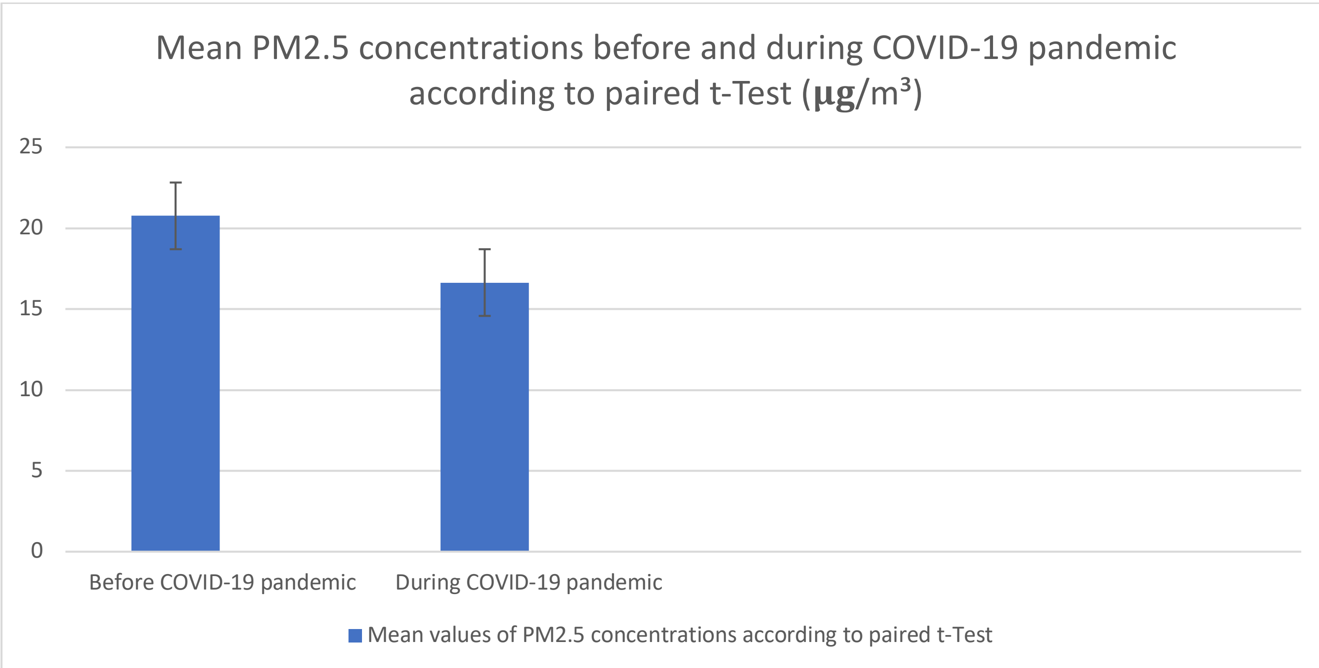
t-Test: Paired Two Sample for Means

	70,05	*59*
Mean	20,76153846	16,63846154
Variance	250,4963765	161,7582186
Observations	39	39
Pearson Correlation	0,983687446	
Hypothesized Mean Difference	0	
df	38	
t Stat	6,391174402	
P(T<=t) one-tail	8,28581E-08	
t Critical one-tail	1,68595446	
P(T<=t) two-tail	1,65716E-07	
t Critical two-tail	2,024394164	

One-tailed p value searches for a "decrease" or "increase" in the parameter, whereas a two-tailed test searches for a "change" in the parameter (Statistics for Beginners One-Tailed or Two-tailed Tests). The “p-value” (P(T<=t) one-tail) which is $8{,}29 \times 10^{-8}$ is taken into account because I wanted to look at if there is a significant mean difference between the groups and to see whether there is a decrease in concentrations of PM2.5 in 2020. In this investigation it had been expected that the mean value of PM2.5 concentration in 2020 is lower than the average of PM2.5 concentration in 2018 & 2019. Since the p-values of the test are smaller than “alpha” which has been indicated as “0,05” before, then it means that we can reject H0.

So, we can generalize that, as a matter of fact, with the pandemic in 2020 and resulting in curfews and restrictions on human activities, PM2.5 conc. values have decreased significantly. Consequently, it can be said, COVID-19 had a positive impact on air pollution rates, primarily in PM2.5 air pollutant.

Table 8: Bar graph representing mean of PM2.5 concentrations before and after according to paired t-Test



4. Discussion and Evaluation

The results, which indicates there is a "decrease in PM2.5 concentration, obtained from paired t-test has statistically showed that there is a significant mean difference between PM2.5 concentration before and after COVID-19. Therefore, it is possible to say although COVID-19 lead to approximately "7 million" deaths worldwide, it affected the environment, specifically the air pollution, in a positive way. So, the pandemic was an advantage, in the aspect of "air pollution". This research can be improved in several ways, for example, more than 40 countries can be evaluated to get more accurate and consistent results. Also, to make the study more comprehensive related to air pollution, other pollutants such as PM10, NO_2, O_3, CO and SO_2 can be driven to analysis. I calculated the average PM2.5 concentration of 2018 and 2019 because since the air pollution increases every year compared to the previous year, I thought the pollution in 2018 & 2019 was the highest in these two years before 2020. Moreover, the data of air pollution concentration before COVID-19 pandemic can be extended to more years such as taking the average of 2000-2019 PM2.5 concentration rates as the pollution "before" to make the average concentration more based on a general rate. This investigation could be used to make the society to see the significant decline in PM2.5 and relate the results and interpret the possible factors which drive the decline in air pollution and relate the concept to find newer solutions for the today's air pollution problem. I did the statistical analysis in excel, which made me to obtain reliable results. I also gathered the PM2.5 data from various continents, which abled me to observe a more comprehensive general trend in the change of air pollution.

However, the data could be collected from the most densely populated and most industrialized cities, there would probably have been a more significant mean difference observed.

5. Conclusion

In this essay, the impact of COVID-19 pandemic to the environment and nature is studied in terms of the topic “air pollution”. My essential purpose of doing this investigation was to see whether COVID-19 pandemic had an impact on air pollution rates. I thought that the impact would be in a positive way because the pandemic had led to closures and various restrictions (See Page 15) that prevent people from doing activities (See Page 15), so eventually the air pollution rates had decreased. Therefore, I wanted to investigate this case by myself to see whether COVID-19 influenced air pollution rates. I compiled the PM2.5 concentration values of 40 countries from different continents. From my research and results, I saw that there is a significant mean difference between the PM2.5 concentration of the average in 2018 & 2019 data and 2020, which shows an observable decrease of mean value of 20,76 ($\frac{\mu g}{m^3}$) to 16,64 ($\frac{\mu g}{m^3}$). The mean difference was also given by the t-Test.

From this investigation based on PM2.5 air pollutant, I achieved to find a significant mean difference between the air pollutant concentration decrease in 2020, therefore the results answered my research question. The p-value of the t-Test is smaller in a big scale than alpha, 0,05, which means the PM2.5 concentration rates had decreased in a great scale. Since I have done this research based only on PM2.5, I do not know what the results of the t-Test will be for other air pollutants; however, the overall results will probably not change on a large scale, because a research of 22 countries shows that during the first months of COVID-19 pandemic, the concentration of PM10 declined by 31%, NO2 declined by 18% and CO concentration of CO decreased by 10% (Ghahremanloo, 2022).

For further research, the investigation of other air pollutants and data analysis may be done. In this study, there is only a limitation which is taking the annual average PM2.5 concentration values in 2020 for each country. The issue is that the disease is declared as a pandemic on 11 March 2020 therefore the first three months of 2020 should not be considered as in the second group which is indicated as PM2.5 concentration "during" pandemic because there are no restrictions had done in January and February that might not cause a decrease in air pollution rates. However, since the average value is taken, I do not think that these three months can cause a huge deviation in the results so that's why the annual average PM2.5 concentration in 2020 was considered.

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