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Assessing the Relationship between Nitrogen Dioxide Air Pollution and COVID-19 Pandemic Based on Satellite Data

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Abstract:The rapid spread of the Coronavirus has boosted researchers to find the reasons behind this spread. A relationship between nitrogen dioxide (NO2) concentration as an air pollutant and the number of infections and deaths of coronavirus, has been suggested. This paper mainly seeks to determine whether there is a relationship between exposure to NO2 contamination andexacerbations of infections and confirmed deaths of COVID-19 in different countries in Europe, Asia, and Africa. This paper compared NO2 emissions concentration before and after the governments' lockdown to battle the new pandemic by using The Copernicus Sentinel-5P satellite data. The time series of an average daily NO2 concentration and COVID-19 reported data for March - June 2020 in Italy, China, and Egypt were analyzed and modeled with Python. Pearson's correlation coefficient (PCC) has been applied to evaluate this relationship. The results showed a positive relation between NO2 and COVID-19 infections, as PCC values are 0.47, 0.48, and 0.78 for China, Italy, and Egypt. The PCC values of deaths have reached 0.29, 0.39, and 0.72 for China, Italy, and Egypt. The experimental results indicate that elevated levels of air pollution in Europe and Asia have a detrimental effect on COVID-19 fulminate and there is a positive correlation between NO2 and infections anddeaths of COVID-19. The lockdown activities have led to a significant decrease in NO2 emissions with additional benefits for the environment.

Keywords- Nitrogen Dioxide (NO2), COVID-19, Air Pollution, Pearson Correlation Coefficient, Environment, Copernicus Sentinel-5P satellite, Remote sensing air monitoring, COVID-19 breakdown.

I.INTRODUCTION

The World Health Organization declared COVID-19 a global pandemic in December 2019and called for a firm global response. The 2019 coronavirus disease outbreak (COVID-19) has posed various challenges to public health safety. COVID-19 exacerbation not only threatens public health but also dramatically prevents global economic growth and negatively affects the economy of society. Research into COVID-19's pathogenesis suggests that the disease is caused by way of an exaggerated inflammatory reaction [1], but the exact inclining factors that increase the severity and death rate in patients are still unknown. Individuals aged 60 years or older, as well as those individuals who have pre-existing medical conditions such as cardiovascular or chronic respiratory diseases, diabetes, or cancer, are at increased risk [2]. Recurrent pneumonia caused by the COVID-19 Coronavirus is an exceptionally infectious disease [3, 4]. In most cases of COVID-19 infection, there are visible symptoms such as fever, dry cough, and sore throat. However, many patients could have fatal and even severe complications. Many researchers studied the essential factors influencing COVID-19 transmission. These factors have a significant effect on COVID-19 exacerbationincluding population mobility, and the association of ambient temperature [5]. Air pollution has been linked to increased respiratory and cardiovascular toxicity in several studies. It is possible that air pollution also contributes to the severity of COVID-19[6,7]. COVID-19 transmission and mortality are closely linked to local levels of air pollutants, according to early reports from countries and regions within a single country [8]. Delicate particulate matter with an aerodynamic diameter of less than 2.5m (PM2.5) or 10m (PM10), such as NO2, sulfur dioxide, ozone, and carbon monoxide, affect the airways via inhalation and exacerbate the severity of respiratory virus infections[9]. NO2 is generally produced through various anthropogenic, such as oxidation associated with traffic and industrial heaters. Furthermore, it is made through natural methods such as forest fires and the production of biogenic compounds. NO2 has short and long-term effects on chronic respiratory diseases, even in regions with low air pollution levels [10].

Numerous studies have established that widespread city closures and transportation restrictions significantly slow the exacerbation of COVID-19 [11, 12]. On the other side, the impact of multiple government-adopted traffic control initiatives on air pollution has been documented in the aftermath of the COVID-19 outbreak[13].
The air conditioner during the COVID-19 epidemic is evaluated for the detection of PM2.5 and NO2 in the continental United States. They studied pollution during and before the COVID-19 period. The results show a statistically significant decrease in state counties and urban counties[14]. Statistically, Nitrogen dioxide bio-falls experienced a 25.5% decrease during the COVID-19 period compared to historical data[15]. The air quality is compared before and after the COVID-19 lockdown in European and Asian countries using the published data by international agencies and satellites [16]. Also, the potential impact of the COVID-19 pandemic lockdown on CO levels in Africa was examined, and the results showed a small reduction in CO level air pollution[17].
There are various investigations regarding the impact of air pollution on the COVID-19 exacerbation. In [10], NO2 concentration wasmeasured to account for regional variation in death rates among 66 central regions in four European countries. The results showed that 78% of deaths were recorded in areas with higher concentrations of nitrogen dioxide combined with descending airflow and long-term exposure to this pollutant may be a role in the mortality caused by the COVID-19 virus. To Explore the relationship between COVID-19 exacerbation and ambient air pollutants. Daily air pollution concentrations, confirmed cases, and meteorological variables were obtained for 120 cities in China. They used a generalized additive model to study the associations of 6 air pollutants, including NO2, with cases confirmed by COVID-19. The results confirmed the relationship between infection with COVID-19 and air pollution. This may partially solve the impact of the national blockade and provide suggestions to control this virus [18].
The governments and decision-makers depend heavily on satellite data and computer models to display how pollution rises and how it is moved in the air to develop appropriate mitigation strategies. Air quality monitoring based on remote sensing data has great importance for health research. There are many remote sensing applications [19, 20],that providecharacteristics for monitoring air quality throughout the country due to their extensive territorial coverage and low cost [21]. Another contribution in this direction is [22],which investigated the association between COVID-19 deaths and climatic parameters. The results indicated a positive correlation between the daily COVID-19 death rate and the daytime temperature range. The authors speculated that variations in humidity and temperature could play a significant role in COVID-19 death. Nonetheless, the effect of short-term exposure to air pollution requires additional research.
The paper examines the effect of NO2 on the spread of COVID-19 infection and mortality, as well as the effect of the COVID-19 lockdown on NO2 emission air pollutants in China, Italy, and Egypt, which are located on the continents of Asia, Europe, and Africa, respectively.
The remainder of the paper is divided into the following sections: The second section discusses the materials and methods that were used. Section 3 discusses how to use Python to analyze and model air quality data. The findings and conclusions are discussed in Section 4. Finally, Section 5 provides the conclusion.

II.MATERIALS AND METHODS

The paper investigates the air quality for NO_2 during the COVID-19 pandemicand explores the relation between the ratio of NO_2 and the number of Coronavirusinfections and deaths.The paper involved China, Italy, and Egypt from 30th Jan. to June 2020. The start time is different for every country because the COVID-19 appeared ata different time in each country.NO2 is a critical trace gas in the troposphere and a precursor of photochemical smog.Its accumulation will result in severe air pollution.The association between the ratio of NO2 and the number of Coronavirus deaths from Coronavirus is measured using the Pearson Correlation Coefficient (PCC), which will be discussed in detail in the sections that follow. Additionally, it assesses air quality using the COVID-19 pandemic lockdown for NO_2concentration and studies the reduction in the ratio of NO_2 concentration in Egypt, China, and Italy from Nov. 2019 to June 2020.

A. NO2 emissions measurements

The collective term for nitrogen monoxide (NO) and nitrogen dioxide (NO2) is nitrogen oxides (NOx = NO or NO2). These are significant trace gases found in the Earth's stratosphere and troposphere. They enter the atmosphere as a result of human activities and natural processes. When sunlight is present during the day, a photochemical cycle involving O3 rapidly converts NO2 to NO (and vice versa), making NO2 a good indicator of nitrogen oxide concentrations. Globally, NO2 concentrations in the troposphere and stratosphere are monitored using a variety of instruments, including ground-based, in-situ (balloon, aircraft), and satellite-based instruments, each of which has distinct advantages. The TROPOMI NO2 processing system was adapted for TROPOMI from the DOMINO-2 algorithm development and the EU QA4ECV NO2 reprocessed dataset for OMI. The Sentinel-5 Precursor instrument collects data on air quality that can be used to estimate it, see Fig. 2. TROPOMI is a multispectral sensor that provides high-accuracy and spatial resolution data on a variety of trace gases (CO, NO2, SO2, O3, aerosols...). Additionally, it incorporates measurement consistency with prior and ongoing atmospheric spatial missions.

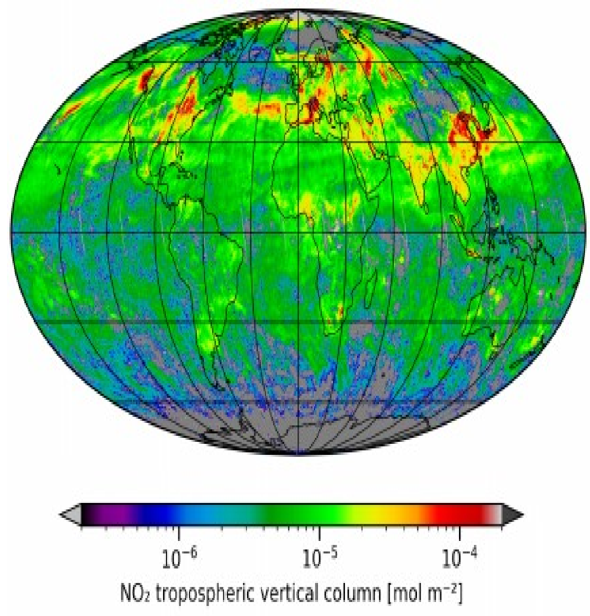

Figure 1: NO_2 tropospheric vertical column over the world 1^{Th} March 2020 [25].

TROPOMI NO2 is a hyperspectral nadir-viewing imager with passive sensing that was installed on the Sentinel-5 Precursor (S5P) satellite on 13 October 2017. TROPOMI is equipped with four spectrometers that are capable of measuring the ultraviolet (UV), ultraviolet-visible (UV–visible), near-infrared, and short-wavelength infrared spectral bands[23]. The NO2 columns were acquired using backscattered solar radiation measurements from TROPOMI's ultraviolet, visible spectrometer.The NetCDF4 file contains both the product's data and metadata. Nitrogen dioxide (NO2) Level 2 data product is available in Near Real-Time (NRTI) and Offline (OFFL) time series. This paper makes use of OFFL data. The work is presented as a single file per satellite orbit for OFF data[24].The NetCDF4 file includes a column for nitrogen dioxide tropospheric concentrations, which indicates the total NO2 concentration in the atmosphere between the tropopause and the surface. The data field nitrogen dioxide tropospheric column precision contains the estimated errors associated with the spectral fit and other retrieval aspects. A QA value serves as a guide for the user regarding the data's quality. To avoid misinterpretation of the data quality, pixels with a QA value greater than 0.75 are excluded from the analysis (or greater than 0.5 in case cloud covered scenes are also of interest)is usedNitrogen dioxide (NO_2) data have been processed using the atmosphere tools Visan, Harp, and spyder package in Python version 3.7. These data from Nov. 2019 to Jun 2020 that were obtained from S5p were Matched. In the next section, the method will be presented in detail.

III.AIR QUALITY DATA ANALYSIS AND MODELING WITH PYTHON

The purpose of this paper is to investigate the association between COVID-19 infections and daily NO2 levels in three different countries: Italy, Egypt, and China.

This section illustrates how to use Python for air quality modeling and data analysis. Figure 2

outlines the air quality monitoring scheme as follows:

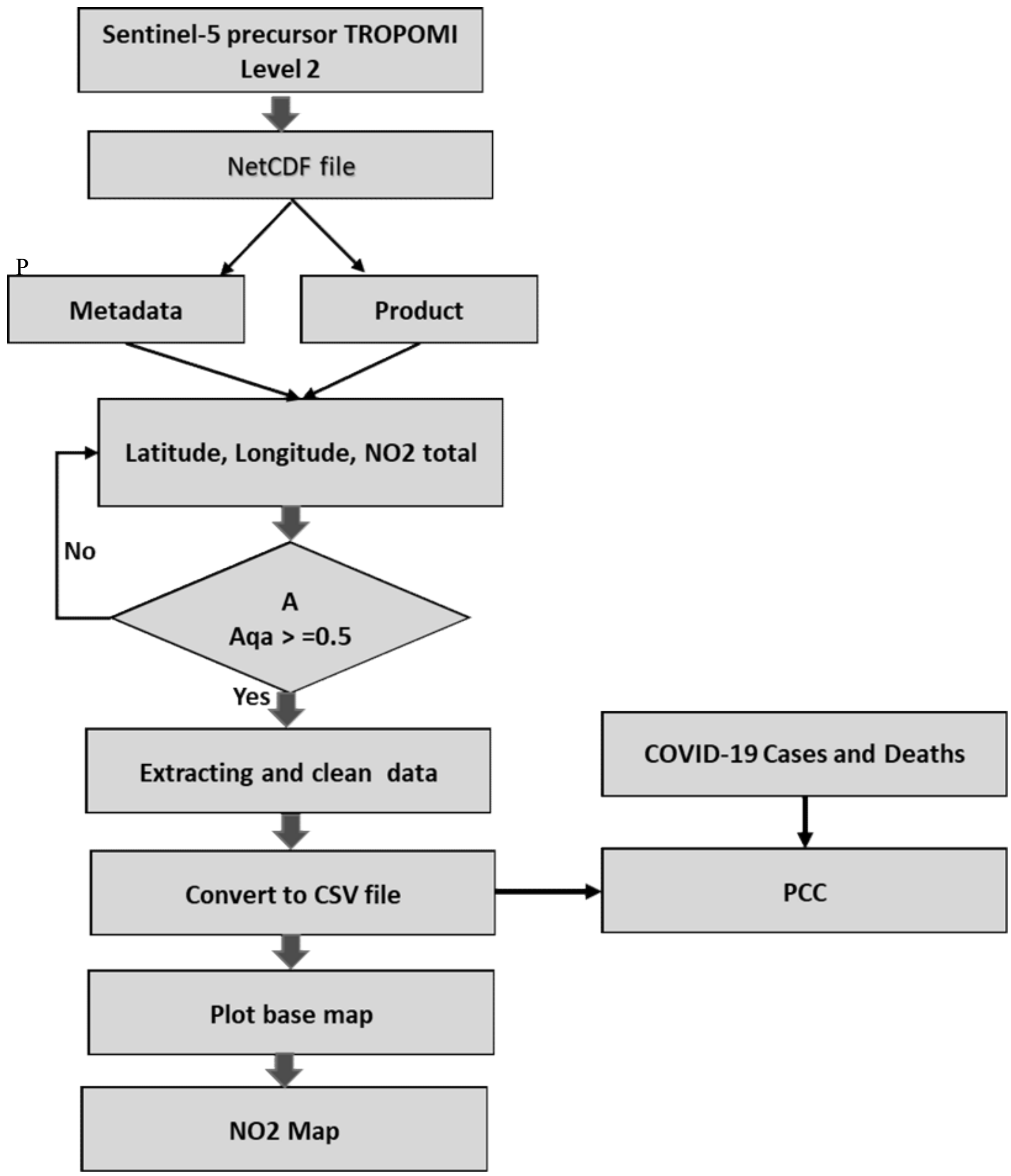

Figure 2: The scheme of the air pollution minoring modeling

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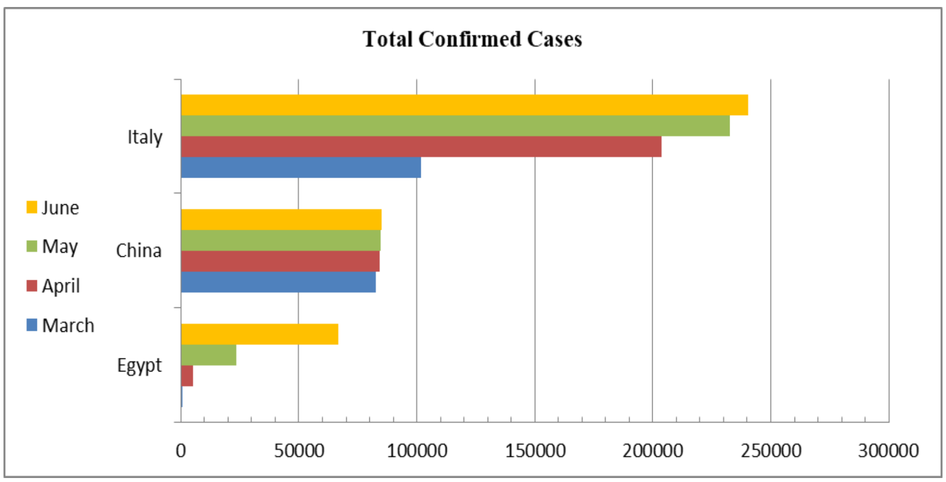
thon is now ubiquitous. Take a look at the TIOBE index. Python has a very diverse software ecosystem; one of the most active communities is the scientific community. Numerous free and community-supported libraries for high-performance computing, publication-quality graphics, and large-scale data analysis are available. The majority of libraries are cross-platform, meaning they run on Windows, Linux, and OS X. This paper's model was executed on Windows.

1. Reading netCDF data
   i. NetCDF is just a storage format. Before any plotting, unpack the data. The netCDF4 package is the tool to do that.

   ii. Use NC view. Nc view is the quickest way to examine a NetCDF file visually, and while it will not give publishable images, it is an excellent tool for initial analysis.
   iii. For georeferenced data, use the matplotlib.base map module.
2. Get necessary attributes
3. Extracting and cleaning the data and getting statistics
4. Plotting georeferenced data: Plot base mapto plot our data
5. Convert the data into CSV
6. Calculate PCC.

A. COVID-19 Reported Cases

WHO publishes the daily situation reports that provide the current COVID-19 pandemic. These reports also highlight significant recent events and actions taken by the WHO. This paper uses the data reported by COVID-19 from March to June 2020. Figure 3 (a) shows the total confirmed cases from (March to June 2020). (b) shows the reported deaths from (March to June 2020).



(a)

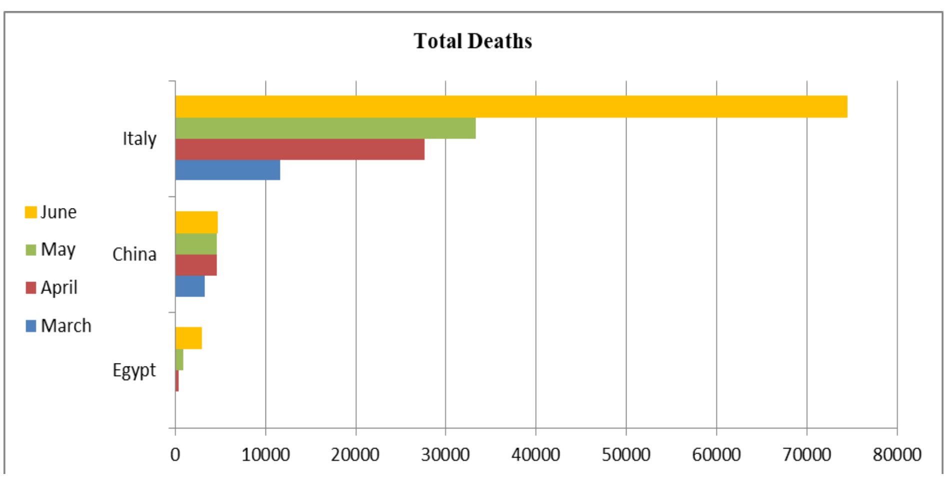


Figure 3.(a) COVID-19 infection cases reported from March to June 2020, and (b) COVID-19 infection deaths reported from March to June 2020.

IV.PEARSON CORRELATION COEFFICIENT (PCC)

The PCC is a measure to assess the linear association between two variables X, and Y. The PCC is calculated using equation (1). The function COV (X, Y) is the covariance of X and Y. σ_X and σ_Y are the standard deviations of X and Y. The PCC varies from -1 to +1. The value (+1) indicates that X is linearly (directly) correlated entirely positively with Y. whereas a value of 0 indicates that X has no linear relationship with Y at all. On the other hand, the value of -1 indicates that X is a completely negative linear relationship with Y. It can be assumed that X and Y are strongly related to each other when ρ (X, Y) is greater than 0.6 and medium related when the value of ρ (X, Y) is greater than 0.4[26].

ρ_(X,Y)=(COV(X,Y))/(σ_X σ_Y)(1)

Degrees of PCC relationship:

a. Perfect: If ρ_(X,Y)value is near ± 1. Then it was stated that there was a perfect correlation.This implies that when one variable increases, the other tends to increase as well, and vice versa.
b. High degree: ρ_(X,Y) the coefficient value lies between ± 0.50 and ± 1.
c. Moderate degree: ρ_(X,Y)value lies between ± 0.30 and ± 0.49.
d. Low degree: ρ_(X,Y)value lies below + 0.3.
e. No correlation: When ρ_(X,Y)value is equal to zero.

V.RESULTS AND DISCUSSION

A. *The impact of No2 concentration on the COVID-19 pandemic*

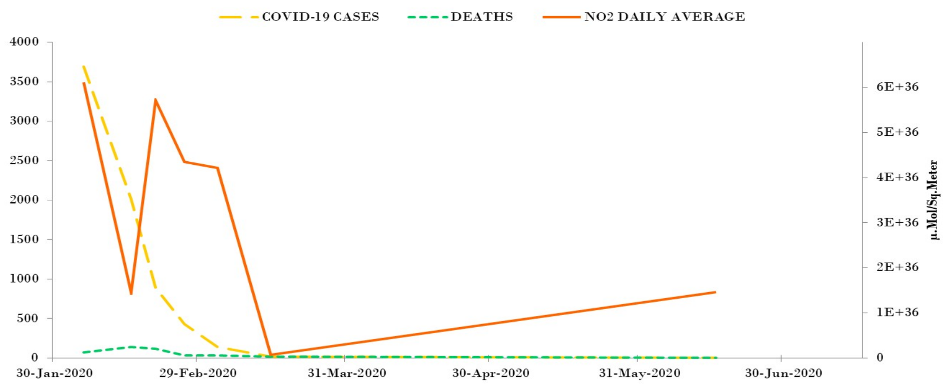
To investigate the relationship between the number of COVID-19 cases and deaths and the level of NO2 air pollution measured between January 2020 and June 2020. Because each country's COVID-19 cases began at a different time, the time series for each country is different. We included only mean values from daily measurements because this was the most consistent type of aggregation reported for air pollutants.

In this paper, the PCC test was utilized to evaluate the NO2 gas pollutant effect on COVID-19 infections and deaths. PCC applies to measure the strength of the association between the two variables. Figure (4) shows the association between NO2 emissions and COVID-19 cases and deaths in China, Egypt, and Italy. These graphs show the positive linear relationship between the two variables, the NO2 daily average and the number of cases and deaths from COVID-19 in the period from 30th of Jan to 30th of June 2020. Table (1) shows the PCC values for the previously mentioned cities.It is clear from Fig. (4) that the curve of the state of China has a noticeable rise at the beginning of the epidemic and as a result of the rise in the air pollution index with NO2. It is also shown that the curve has decreased significantly due to the situation reflects China's remarkable work and progress in preparedness, response, availability of services, and as a result of the lockdown, which had a positive impact on the decrease in NO2 (Fig. 5), which had a positive impact on the number of cases and deaths of Covid-19. It is caused that the NO2 emissionshave a moderate degree associated with the number of COVID-19 infections and a low degree with the number of deaths. This has been verified at the local level in China and Tehran by applying to more than one of the air pollutants [27, 28].

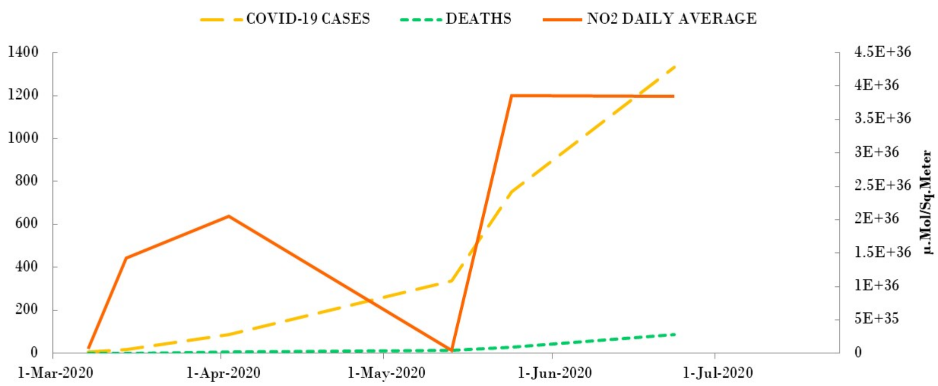
Similarly, Italy has a moderate degree with the number of infections and a low degree of deaths. Italy is the only country to have announced a nationwide shutdown since the COVID-19 outbreak.Which had a significant impact on the concentration of nitrogen dioxide, which affected the number of Covid cases and deaths. On the other hand, Egypt has a high degree (substantial) relationship between the NO2 and the number of coronavirus infections and deaths. Because the shutdown was not com, which did not affect the concentration of NO2.

Table 1. PCC between NO2 and COVID-19 Variables (cases and deaths)

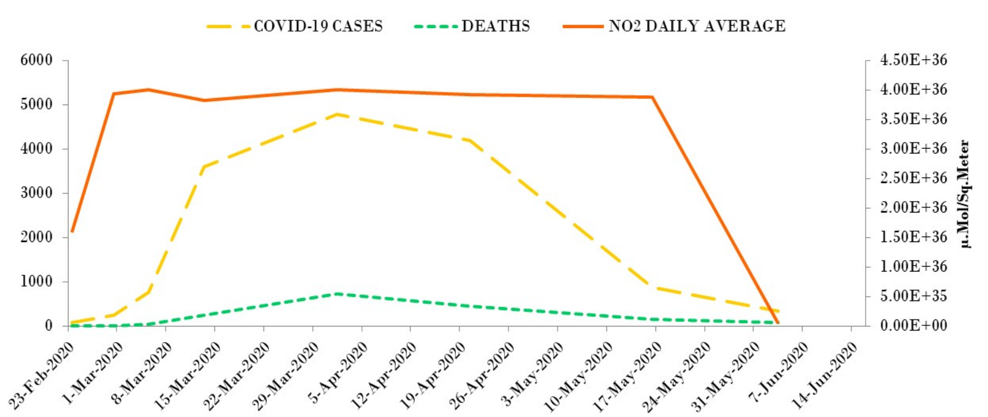
Period: November–June 2020			
Pearson Values	China	Egypt	Italy
COVID-19 Cases	0.4701615626	0.7678804382	0.4857104706
Deaths	0.2950762559	0.7219621881	0.3958650694



(a)



(b)



(c)

Figure4: Temporal variation of NO2 concerning COVID-19 infections and deaths in a) China b) Egypt, and c) Italy.

The lockdown of COVID-19 has affected many sectors and activities. Lockdown has decreased transport activities, resulting in lower oil demand and energy consumption. These changes have exerted a notable impact on environmental quality. This section discusses the implications of lockdown on NO2 emission concentration. The reductions in complete NO2 emission concentration can be visualized using S5p/TROPOMI ESA satellitemeasurements of background tropospheric NO2 emission concentrations [29]. Figure 5 (a), shows NO2 concentrations in China in the periods November 2019 and March 2020 after lockdown. NO2 emission concentration is observed to be high during Nov. 2019 In contrast, during March 2020, the effect of lockdown is observed in the average NO2 emission concentrations in most parts of China. NO2 concentrations are significantly reduced from 400-500 to 200-350 100 µ.Mol/Sq.Meter after lockdown. On the other hand, Fig. (b) showed the NO2 concentration in Egypt between Nov.2019 and March 2020. It shows that NO2 emissions concentrationreduced due to the lockdown of COVID-19 from 100-200 to 50-100 µ.Mol/Sq.Meter. It is noted that the decrease in the concentration of nitrogen dioxide emissions in Egypt is small because the lockdown was not complete. Finally, Fig 5(c) showed the NO2 in Italy during the same period. NO2 emissions concentrationreduced from 200-400 to 50-100 µ.Mol/Sq.Meter after lockdown. Because Italy is one of the countries that has implemented a complete lockdown in response to the significant spread of the COVID-19 epidemic.

The overall assessment of NO2 emission concentrations indicates That lockdown is more effective in Europe and Asia than it is in Africa, resulting in improved air quality. Additionally, European countries have a higher rate of confirmed cases and deaths than African and Asian countries. Such variations can arise from various causes, such as European and Asian countries' precautionary measuresagainst the COVID-19 pandemic and putting travel constraints almost early. Advances in technology in various sectors, including the health sector.

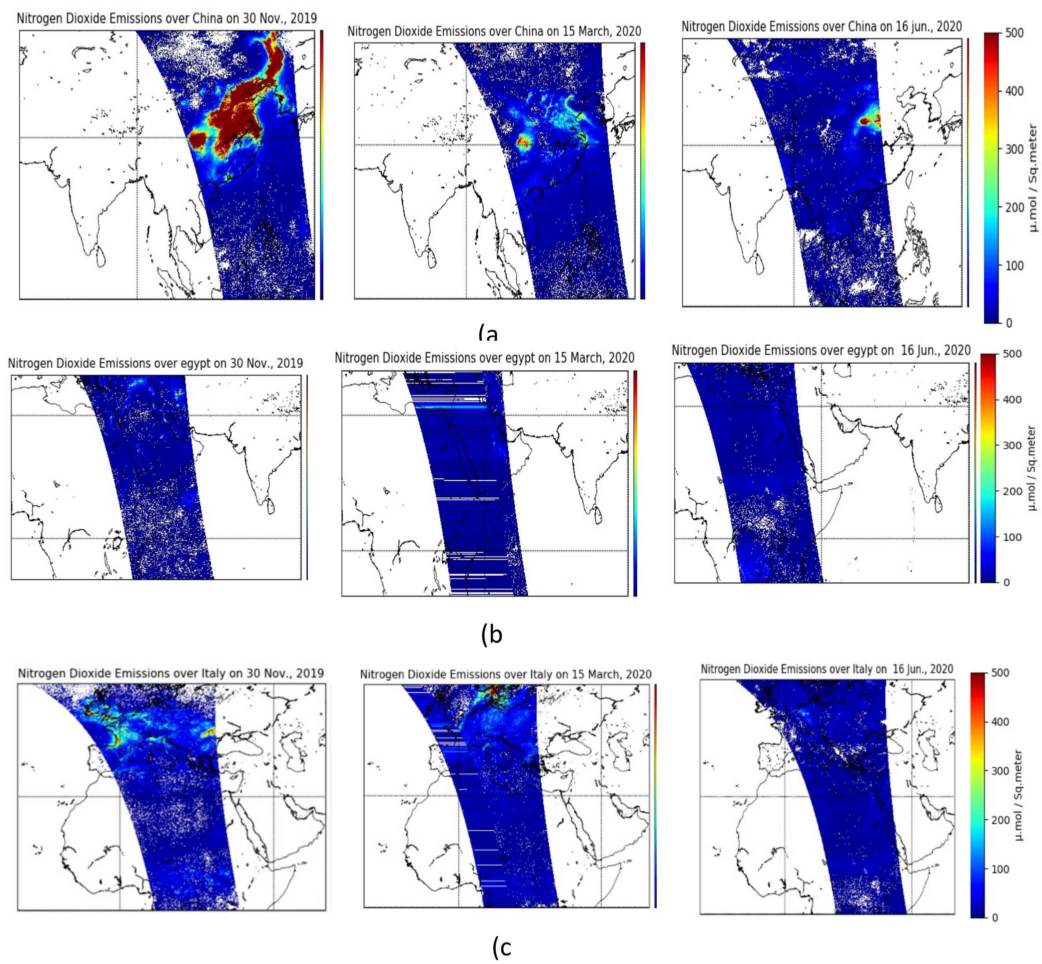


Figure5: NO2 emissions measurements a) China, b) Egypt and c) Italy

VI.Conclusion

This paper used the NO2 concentrations measured by the Sentinel-5P satellite to demonstrate the significant reduction in NO2 levels in Asia, Africa, and Europe as a result of COVID-19 lockdowns, and the

Coronavirus is viewed as a blessing in disguise, according to the findings.While the current state of air quality is temporary, the opportunities are immense.

The obtained results present evidence that measured air pollution NO2 emissions have decreased in Italy, China, and Egypt during the COVID-19 pandemic lockdown. China's reduction is more significant than Egypt's estimates but less than Italy's decline. NO2 decreases are expected to be incorporated with reduced vehicular traffic and with limited domestic travel. Additionally, studying this link between individuals would enable us to more precisely eliminate the influence of age and health conditions. However, until now, conclusive evidence of a link between pollution and COVID-19 has never been established.If the COVID-19 pandemic has a positive side, it's likely the fact that for a while, at least, the smog view is not seen. Warnings of the environmental disaster have been replaced by markedphotographs showing the apparent difference in air quality raised by a few weeks of drastically reduced fossil fuel consumption and NO2 emissions, everywhere over Asia, Africa, and E. Given that transportation is one of the most significant origins of air pollution re-establishment of crossing in a post-COVID world is a critical step to reducing emissions in long-term Europe. But how is it preserved that progress as life gradually begins returning to normal? Already, pollution is rising again in countries where people have gone back to everyday life. Here are three main ways sustainable transit can prolong COVID-19's effect on reducing air pollution. A) Cities for people, not cars, b) Public transportation remains an essential service, and c) Electric buses: Complex but critical.

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