Impact of COVID-19 on Air Quality in Hanoi and Ho Chi Minh City, Vietnam

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***Abstract* — Vietnam has had one of the fastest growing economies in Asia over the years. However, the COVID-19 pandemic has proven to be a major hindrance to this growth as the country's GDP plummeted significantly. Air pollution can further amplify the impact of the pandemic since residents exposed to high levels of pollution are likely to increasingly suffer from respiratory illnesses, such as asthma. This paper investigates the impact of COVID-19 on air quality and how air quality can influence the spread of the virus. Finally, the paper proposes suitable machine learning practices for predicting air quality, based on historical trends, using spatial and temporal data.**

Keywords* — *SARS-CoV-2, Coronavirus. Environmental Health, Air Quality.

I. INTRODUCTION

In 2019, 99% of the world population were exposed to air pollution (AP) levels that exceeded the World Health Organization's (WHO) air quality (AQ) guidelines. Outdoor AP in cities and rural areas caused approximately 4.2 million premature deaths in 2016. Of these deaths, 91% occurred in low- and middle-income countries, with most of these occurring in the WHO's South-East Asian and Western Pacific regions. According to the WHO's mortality data, approximately 58% outdoor AP-related premature deaths were linked to heart disease and stroke, 18% were linked to chronic obstructive pulmonary disease and acute lower respiratory infections, and 6% were due to lung cancer [1].

There is a range of different pollutants that are hazardous to the population, including particulate matter (PM), ozone (O_3), carbon monoxide and dioxide (CO and CO_2), sulfur oxides (SO_x), nitrogen oxides (NO_x), and lead (Pb). Particulate matter (PM) has three classifications: PM_{10} (coarse), $PM_{2.5}$ (fine), and $PM_{0.1}$ (ultra-fine) [2]. Of the three categories, $PM_{2.5}$ is thought to pose the greatest risk to health as it can get deep into the lungs, causing lung cancer, and may enter the blood stream [3], which can lead to stroke and heart disease. In terms of the sources of PM, some are emitted directly from a source (construction sites, road dust, fields, fires), while most particles are the product of complex chemical reactions in the atmosphere, mainly emanating from power plants, industrial sites and vehicle emissions.

This paper investigates recent $PM_{2.5}$ levels in Vietnam and how the prevailing COVID-19 outbreak affected the country's air quality. Furthermore, the application of an artificial intelligence paradigm is proposed in this context, which could assist with the provision of accurate AQ predictions. For such system to work effectively, large volumes of diverse data are required, such as data on AP, population and population density, underlying health conditions, GDP, and meteorological data.

AP is highly relevant to the recent pandemic as exposure to higher levels of $PM_{2.5}$ can stimulate ACE-2 receptors, which act as cellular doorways and are thought to favour SARS-CoV-2 viral entry and infectivity [4]. Additionally, pollution is thought to extend the longevity of viral particles, which presents a compounded problem when attempting to mitigate transmission [5].

II. METHODS

A. *Study Area - Vietnam*

This study focuses on the two major cities in Vietnam: Hanoi, the cultural centre and capital city of the country, and Ho Chi Minh City, the country's largest city. In 2020, the population of Hanoi was 8,246,600 with a population density of 2,455 person/km^2, while Ho Chi Minh City had a population of 9,227,600 with a density of 4,476 person/km^2 [6]. Of the two cities, Ho Chi Minh City had the highest Gross Regional Domestic Product (GRDP) in 2019, reaching $57.3

billion (approximately 21% of the country's GDP), while Hanoi had a GRDP of $39.6 billion [7].

According to the most recently published data, the dominating economic sectors in the country were Services (41.63%), Industry (33.72%, including construction) and Agriculture, Forestry and Fishing (14.85%) [8]. Interestingly, despite the pandemic, the Services sector (which includes tourism) only dropped by 0.01% from 2019. However, the GDP growth stagnated due to the pandemic; in 2019 the growth rate was 7.16%, while in 2020, it dropped to 2.31% and the growth is currently being estimated to be around 1.42% in 2021. Investments have also shown an overall decline over the past 12 months.

B. Hanoi

The city of Hanoi is located within the Red River Delta. The climate is monsoon-influenced humid subtropical with high precipitation. Between May and August, the climate is hot and humid with high precipitation and only a few dry days. From September to November the temperature and precipitation decrease, and in December and January there is little sunshine and there are many frequent occurrences of drizzle rain [9]. In addition to being the capital city, Hanoi is also considered to be the cultural centre of the country, which makes it one of the most popular tourist destinations in the whole of Asia.

C. Ho Chi Minh City

Vietnam's largest city, Ho Chi Minh City, is located in the Southeast Region, and is built around the Saigon River. The climate in Ho Chi Minh City is different from that of Hanoi's; while in Hanoi four different seasons can be observed, based on temperature and precipitation, in Ho Chi Minh City, there are only two distinct seasons: dry and wet. The climate is a tropical savannah with the rainy season starting in May and ending in November, while the dry season is between December and April. The temperature, relative humidity levels, and monthly sunshine hours vary little throughout the year. The key identifiers for the seasons are the average rainfall per month and the number of rainy days [10]. Ho Chi Minh City is also a popular tourist attraction.

AQ Data Collection, Categorisation, and Selection

The air quality indicators analysed in this study were measured by air quality monitors (AQMs) set up by the U.S. State Department and U.S. Environmental Protection Agency (EPA). The devices used provide hourly $PM_{2.5}$ concentration levels in $\mu g/m^3$, from which an EPA-derived air quality index (AQI) informs health-related decisions, according to the criteria in the next section.

For the purposes of this research, the data was acquired and wrangled from the air quality data repository, AirNow [11]. First, the data was drilled down; instead of using the hourly records, 6-hourly snapshots were used, meaning that measurements taken at 00:00, 06:00, 12:00 and 18:00 were considered. Excess data categories with corresponding data were also erased. To visualise the data, bar charts and line graphs were used allowing a simple identification of trends for each city. However, because the raw data (for example, face value of $PM_{2.5}$ concentration levels) of the two cities cannot be readily compared in terms of AQ, it was normalised for both cities, which revealed comparative insights.

It should be noted that, in Hanoi's case, data from 2016 to 2021 was used for the analysis; the 2019 data was not complete at the time of carrying out the study and was therefore precluded. Equally, it should be noted that 2021 has no full annual data available yet and was thus partially used in the analysis. Ho Chi Minh City's data ranges, uninterrupted, from 2017 to 2020, in addition to a few months in 2021.

The NowCast concentration level, quoted in AirNow, reflects the concentration of $PM_{2.5}$, and its value is indicative of the air quality. The reason why this category is highlighted is because it is the best data to use to visualise the fluctuations in air pollution over time.

III. AIR QUALITY DATA ANALYSIS

A. EPA's AQI Categorisation

As mentioned earlier, the AQI values determine the category of air quality, as outlined in Table I [12].

B. AQ in Hanoi

As seen in Fig. 1, significant number of Very Unhealthy AQI instances occurred over the period of analysis; the worst month was February with a total count of 26 such instances. Unhealthy instances occurred the most during January, with a total count of 238. There was a total of 204 Unhealthy for Sensitive Groups AQI instances in April. There was an

increase of Unhealthy for Sensitive Groups instances in March and April, while the number of Unhealthy instances dropped – this means that AQ tends to start improving around this time as Unhealthy instances are replaced by Unhealthy for Sensitive Groups instances. No instances of Very Unhealthy classification occurred in the months of April, May, August, and September throughout the years.

According to the NowCast measurements, the air was the cleanest in July on average, while December and January had the highest $PM_{2.5}$ concentration levels.

C. AQ in Ho Chi Minh City

With reference to Fig. 2, only two Very Unhealthy instances occurred in Ho Chi Minh City: one in January 2017, and the other in June 2021. There was an increase in Unhealthy and Unhealthy for Sensitive Groups instances (meaning a general worsening in AQ) in May – this did not occur in Hanoi. However, air quality subsequently improved. Generally, AQ starts to get worse from September, slightly later than in Hanoi, and the counts of Unhealthy instances continue to rise until January.

D. Intracity Comparison & Covid-19 Impact

Following the normalisation of the data for the two cities, each of the three AQI categories of interest (Very Unhealthy, Unhealthy and Unhealthy for Sensitive Groups) for each city was plotted on a single line chart (Fig. 3). From this chart, it is noticed that an improvement in AQ incurred between the months of January and April in Ho Chi Minh City; the region however saw higher concentrations of $PM_{2.5}$ May. Hanoi's AQ worsened between September and February, started to improve in March, and steadily improved until September, except for the month of June, when there was an increase in counts of Unhealthy instances.

Table I. EPA's AQI Categorisation

AQI Range	Classification	Interpretation
0-50	Good	Air pollution poses little or no risk.
51-100	Moderate	Acceptable level of AQ, people with underlying health conditions my experience some symptoms.
101-150	Unhealthy for Sensitive Groups	Healthy individuals won't be affected by this range, however, individuals with respiratory or heart disease are at a greater risk.
151-200	Unhealthy	The general public may begin to experience adverse health effects.
201-300	Very Unhealthy	The health effects are more serious.
301-500	Hazardous	The entire population is likely to be greatly affected, health warning of emergency conditions would trigger.

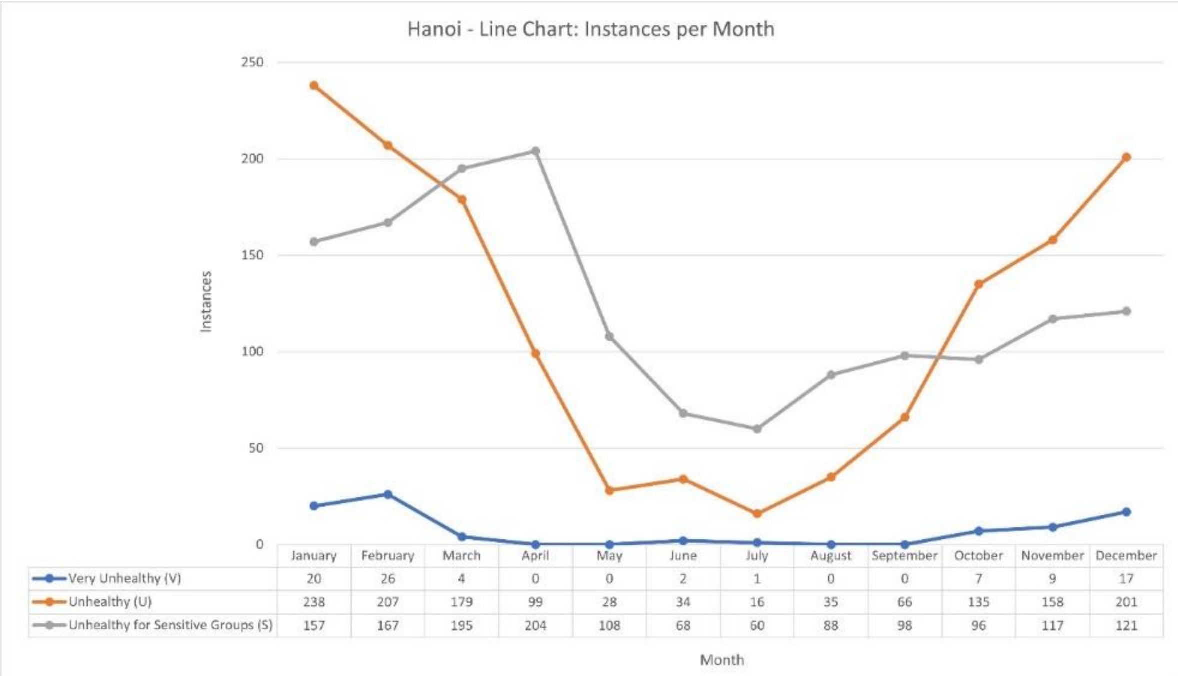

Fig. 1. Hanoi AQI Instances

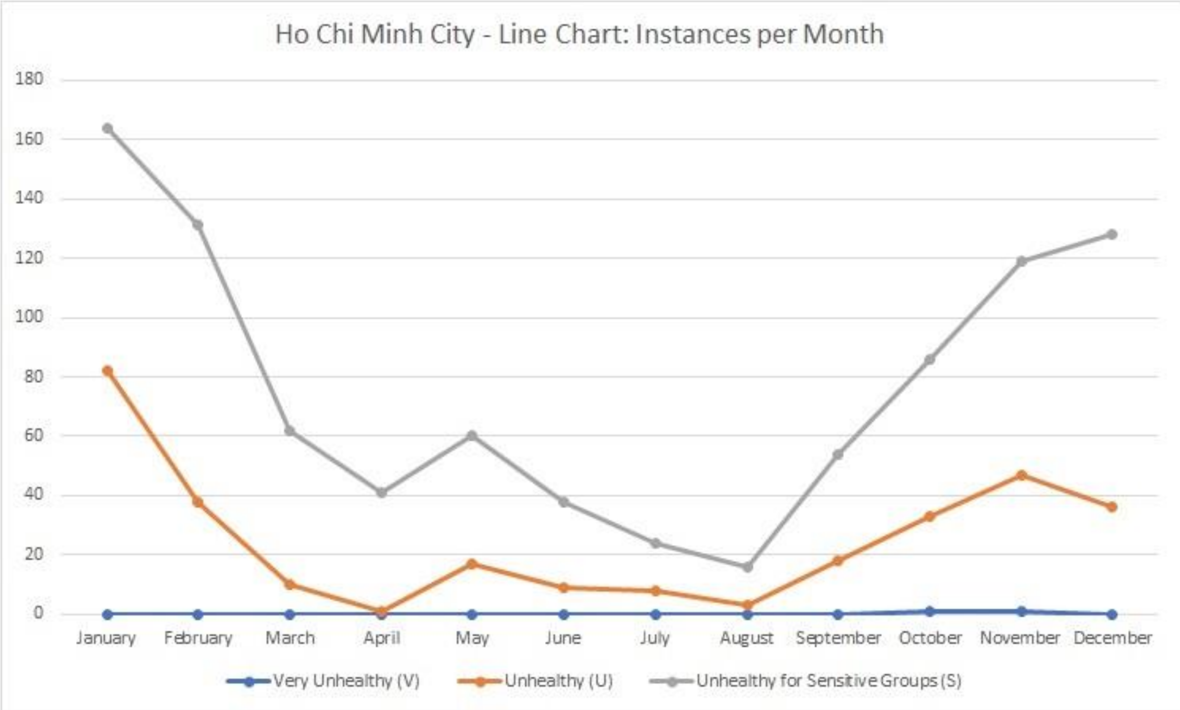

Fig. 2. Ho Chi Minh City AQI Instances

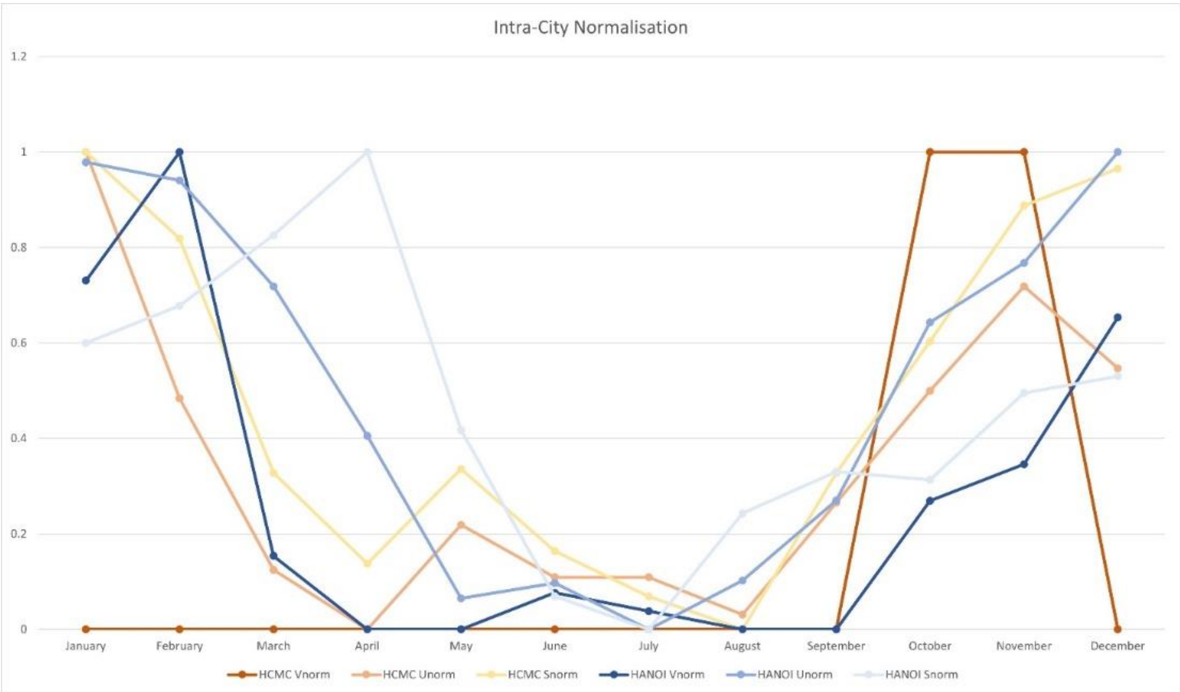

Fig. 3. Intra-city Normalised Values

Notes on the Intra-City Normalisation chart: HCMC is the abbreviation of Ho Chi Minh City; V_{norm} = Very Unhealthy instances normalised, U_{norm} = Unhealthy instances normalised, S_{norm} = Unhealthy for Sensitive Groups instances normalised.

Data suggests that AQ is heavily influenced by seasons. In Hanoi, AQ continuously improves from the end of the winter and throughout the summer season and it steadily deteriorates from fall and during the winter seasons. Ho Chi Minh City's AQ follows a slightly different trend – since there are two observable seasons in the region where the city is located, the more humid and rainy months cause an increase in $PM_{2.5}$ concentration levels. Despite having the highest population, being the most densely populated and having the highest GRPD in Vietnam, Ho Chi Minh City's AQ fares much better than that of Hanoi's. This could be due to climate – $PM_{2.5}$ concentration levels can equally be enhanced by natural conditions. With regard to the impact of COVID-19, Vietnam faced significant periods of lockdown to help prevent the spread of the disease. This, in turn, significantly impacted GDP – certain sectors either completely ceased activity or continued to operate at a minimum level. Industrial activity was also impacted, therefore there was less air pollution during lockdown periods. To confirm this, the NowCast concentration levels were plotted (see Fig. 4 and Fig. 5). As per Fig. 4, Ho Chi Minh City's NowCast levels increased in January every year, except for 2020. Furthermore, in May 2021, the AQ improved – previously, in every year, concentration levels rose in that month. Interestingly, there was no significant improvement in AQ in Hanoi despite the lockdown (Fig. 5). January 2021 had an exceptionally high NowCast concentration level, but this dropped significantly and followed previous trends.

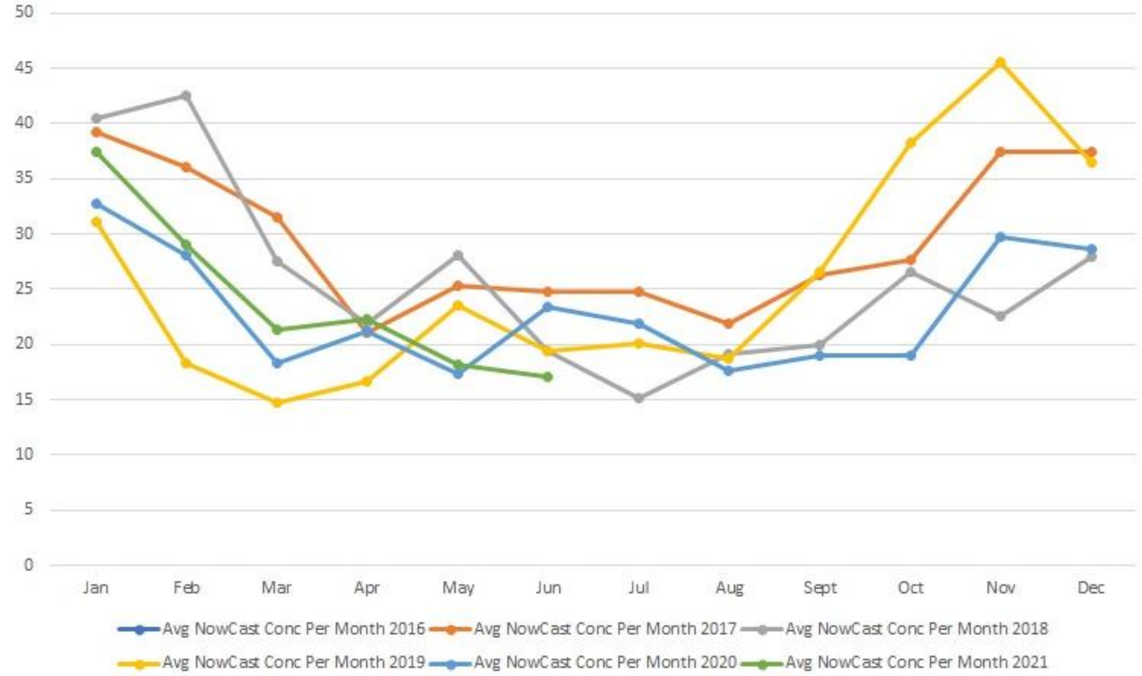

Fig. 4. Average NowCast Levels – Ho Chi Minh City

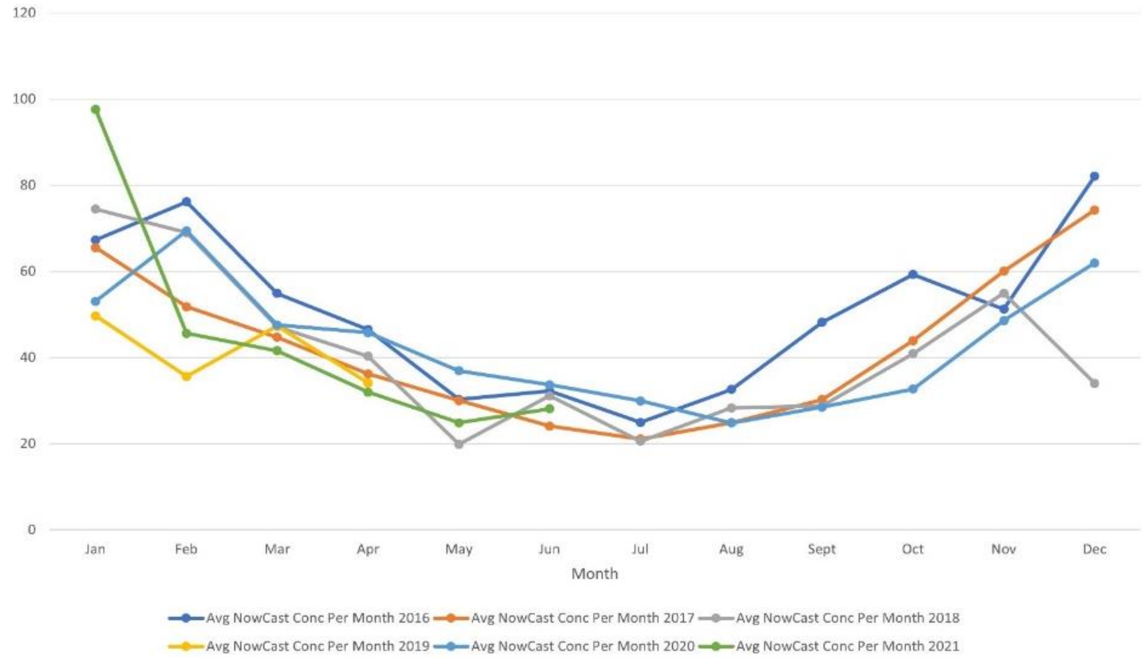

Fig. 5. Average NowCast Levels – Hanoi

IV. CONCLUSION AND DISCUSSION

The lockdown response to the COVID-19 pandemic has shown that air pollution can be heavily influenced by either human activity or as a result of natural events. In Ho Chi Minh City, a drastic improvement in air quality incurred when a lockdown was imposed. However, in Hanoi, AP seems to have been influenced by precipitation rather than as a result of human undertakings (such as industrial emissions and/or urbanisation activities).

Previous studies have suggested that $PM_{2.5}$ presence can extend the longevity of viral particles in the air and that particulate matter stimulates ACE-2 receptors, increasing the uptake of the virus [4]. The case of the COVID-19 impact in Hanoi and Ho Chi Minh City suggests that population density, as a contributing factor to viral transmission, outweighs AP by far; at the time of our study Ho Chi Minh City had over 400,000 cumulative COVID-19 cases, while Hanoi had only approximately 4,200 confirmed cases [13]. This is not to say that AP is not an important variable in the context of a pandemic where a virus attacks the respiratory system. On the contrary, AP is responsible for the development of certain diseases and the weakening of the immune and respiratory systems, making it more difficult for those afflicted by it to recover from the virus [4]. This also means that AP may not promote the longevity of viral particles to a high degree.

Models can be developed that allow the prediction of the future impact of AP and COVID-19-like pandemics. For example, a multilayer perceptron (MLP) model can be implemented and trained on historical data to predict potential outcomes. Furthermore, to assist in making a more accurate prediction and reduce computational costs, create an index for the city or region can be devised. This will take into account several variables, such as population density, GRDP, contributing sectors to GRDP, and average industrial activity in hours per day. When making an AI or neural network-based prediction, the output can be encoded through a formula that utilises this index, instead of performing calculations on all the data, thus resulting in significant reduction in dimensionality and complexity.

A more intricate model can also be designed which would make predictions based on the impact of any viral disease that attacks the respiratory system. The data used in this study was temporal; however, with Hanoi's AQ having been barely influenced by the lockdown, it became evident that the supplementary consideration of geographical and meteorological factors is of significant importance, so is the collection of additional data and the design of a more versatile neural network. For example, while recurrent neural networks could be used in conjunction with temporal data and convolutional neural networks may be better suited for spatial data, in general, spatiotemporal prediction and analysis using deep learning remains a challenge [14]. This is currently being investigated by our group.

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