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Impact of Movement Restrictions During COVID-19 on Jakarta's Air Quality: A Comparative Analysis

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Abstract: Amid the global COVID-19 pandemic, movement restrictions were implemented by various countries, Indonesia being among them. In this study, Jakarta, the capital city of Indonesia, serves as a focal point to elucidate the influence of such restrictions on air quality. Data, spanning from January to April 2020, were obtained from reputable sources including the Indonesian Meteorological Agency, Air Quality Index (AQI) platforms, IQAir, and Jakarta's open data repository. Upon meticulous analysis, it was observed that diminished human activities in Jakarta resulted in a notable enhancement of air quality, with a variance of 19 days of superior air quality compared to the previous year. For a comprehensive understanding, comparative analyses with neighbouring cities were undertaken. In Singapore, reductions ranging from 8% to 43% were discerned in PM10, PM2.5, CO_2, and SO_2 levels. Bangkok reported a decline of 22% in PM2.5 concentrations, whereas Kuala Lumpur exhibited reductions in PM2.5 levels, varying between 3% and 35%, with further reductions of 3% to 63% in NO_2 concentrations. Concurrently, SO_2 levels saw a decrease of 2% to 48%, and CO concentrations diminished by 1% to 27%. The findings underscore the dual benefits of mobility restrictions, addressing both the containment of COVID-19's proliferation and substantial improvements in environmental air quality.

Keywords: Air Quality Index (AQI); COVID-19; Environmental impact; Movement restrictions; Large-Scale social distancing

1 Introduction

In late 2019, global attention was captured by the emergence of a swiftly spreading epidemic in Wuhan, Hubei Province, China. By December 31, 2019, the World Health Organization (WHO) had announced an outbreak of a disease with, at that time, an unidentified etiology [1, 2]. It was not until February 11, 2020, that this virus was formally designated by the WHO as COVID-19, previously referred to as "2019 novel coronavirus" [3]. In Indonesia, the inaugural COVID-19 case was reported on March 2, 2020 [4], with the count escalating to 19 by March 8, 2020 [5]. Consequently, on March 13, 2020, a task force was established by the Indonesian government to expedite the response to COVID-19. A key recommendation from this task force was the implementation of a policy termed "large-Scale social restrictions," which centred on curtailing or eliminating direct human interactions, culminating in amplified work-from-home initiatives and concomitant reductions in vehicular movement [6].

It has been posited that human activities, particularly those requiring fossil fuels, are intricately tied to air quality [7–11]. Such a link suggests that diminished human endeavours could potentially lead to fewer emissions. Such an assertion finds support in studies highlighting the correlation between human activities and emissions released, for instance, human-induced forest fires in Nepal were observed to decrease by 4.54% during the COVID-19 pandemic, in comparison to prior periods [12]. Over the past decades, emissions – encompassing carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2) – have garnered global interest [13]. Emissions, which are broadly defined as particles and gases released from an array of sources, experience annual fluctuations in terms of both volume and composition, often attributable to diverse factors such as industrial progression, economic developments, technological advancements, and traffic patterns [14].

On a global scale, the directives put forth by the Indonesian government mirror those advised by the WHO, which urges member nations facing a surge in COVID-19 cases to impose lockdowns and restrict human interactions. This scenario presents a rare opportunity to analyse the profound relationship between human activity and air quality. Historically, the proposition of limiting global vehicular circulation was deemed challenging.

In essence, this study focuses on human activities encapsulating transportation, industrial operations, and traffic-related endeavours. It aims to discern the repercussions of the Large-Scale social restrictions policy, introduced by the Indonesian government in light of the COVID-19 pandemic, on environmental facets, notably air quality. Moreover, a comparative analysis with neighbouring nations has been embarked upon to gauge the efficacy of various governmental directives on air quality, utilizing the AQI as a benchmark.

2 Description of Indonesia

2.1 Geographical Context

Indonesia is strategically situated between two continents: Asia and Australia, and is bounded by two vast oceans, the Indian and Pacific. With a total expanse of 5,193,250 km^2, which includes both terrestrial and maritime domains, its terrestrial footprint is noted to be 1,916,862 km^2. As of current records, 13,466 islands within its territory have been recognized with official coordinates by the United Nations [15]. The nation stretches approximately 5,110 km from its eastern to western extents. The maritime territory encompasses 3,273,810 km^2, accounting for 63% of Indonesia's total area.

2.2 Demographics

Over a span of 67 years, from 1955 to 2022, a 254% surge in Indonesia's population was observed, with the numbers rising from 77,741,502 in 1955 to 275,501,339 in 2022 [16]. This populace forms 3.45% of the global headcount. Urban dwellers make up 59.1% of the nation's residents, with the median age at 29.9 years. A sustained growth in population could, inevitably, exert strains on various societal and economic sectors, with environmental degradation, particularly emissions, being a notable concern.

2.3 Capital: Jakarta

Jakarta, the Indonesian capital, was home to 10.56 million people in 2020, sprawled over a terrestrial region of 661.52 km^2 and a marine area of 6,977.5 km^2. The Seribu Islands further dot its maritime domain with approximately 110 islands. An impressive population density of 14,437 individuals per km^2 was recorded for Jakarta. Characterised by a tropical climate, it experiences an average annual temperature of $27^\circ\mathrm{C}$ and humidity levels fluctuating between 80 to 90 percent. Due to its equatorial location, monsoonal winds play a pivotal role in determining its wind patterns, with westerly monsoons prevalent from November to April and easterly monsoons from May to October. Average annual precipitation is approximately 2,000 mm, peaking in January and ebbing in September [17–21].

It was reported that Soekarno-Hatta Airport, in January 2022, had a commendable flight seat capacity, making it the 10th in rank globally. This indicated the significant inflow and outflow of both people and commodities. A notable improvement in its ranking from 15th in January 2019 was also highlighted. Predominantly driven by its extensive domestic market, the airport earned its position [22]. As per data from the Indonesian Central Bureau of Statistics, 26,370,535 vehicles were expected to be registered in Jakarta in 2022, with motorcycles comprising 66% of the total. The substantial vehicular activity, in conjunction with the dense population, accentuates the rationale behind selecting Jakarta as the focal point of this air quality analysis.

Emission simulations were conducted considering Jakarta's expansive profile. Utilising the ICAO Carbon Emissions Calculator [23], estimations were based on flights departing from Jakarta (Cengkareng-CGK) to Bandar Lampung (TKG), approximately 190 km away. Assumptions made include each aircraft carrying 100 passengers, leading to an emission rate of 32 kg of $\mathrm{CO_2}$ per passenger for a one-way journey. Consequently, the estimated $\mathrm{CO_2}$ emissions from the 66.7 million passengers in 2018 were approximately 2.14 million tons [24]. Additionally, vehicle contributions to emissions were evaluated, taking into consideration that all of the 21,897,192 registered vehicles in Jakarta in 2018 were in use. Using the Greenhouse Gas Equivalencies Calculator [25], the greenhouse gas emissions from these vehicles for that year amounted to approximately 111,725,258 tons ($\mathrm{CO_2e}$). With Jakarta's electricity consumption in 2017 noted to be 31,643 GWh [15], the resultant $\mathrm{CO_2}$ emissions stood at 24,661,865 tons ($\mathrm{CO_2e}$).

Air quality evaluations were further underscored by the average suspended PM in Jakarta in 2018, reported at 177.8 $\mu\mathrm{gr/m^3}$ from five monitoring stations [15]. North Jakarta registered the highest suspended PM concentrations. However, PM2.5 assessments from the initial trimester of 2019 revealed an average peak value of 159.8 $\mu\mathrm{gr/m^3}$, with a median value of 78 $\mu\mathrm{gr/m^3}$ [26]. It is vital to juxtapose these figures with global standards. The permissible ambient air concentration Threshold Value (TLV) for PM2.5 stands at 65 $\mu\mathrm{gr/m^3}$ [27]. Further, the WHO prescribes guideline values of 10 $\mu\mathrm{gr/m^3}$ (annual mean) and 25 $\mu\mathrm{gr/m^3}$ (24-hour mean) for fine PM2.5 [28]. Consequently, these statistics elucidate that Jakarta's air quality, in the period before the pandemic, remains suboptimal, ranking it amongst the ten most polluted cities globally.

3 Movement Restrictions Amidst the Global COVID-19 Pandemic

The following section concisely interprets the results drawn from data and provides possible conclusions.

3.1 Origins and Early Global Spread of COVID-19

Table 1 elucidates the timeline of the COVID-19 pandemic, charting its initial detection through to the implementation of multiple WHO travel advisories. The virus's transmission from human to human exhibited rapidity, a phenomenon attributed to the swift movement of people for both economic and tourism purposes [29–31]. By February 12, 2020, the COVID-19 virus had been identified in 23 countries, as depicted in Figure 1 and documented by a WHO situation report [32]. Such rapid dispersion is believed to be primarily facilitated through air travel or carriers using high-speed transport modes, such as aircraft [33]. Such conclusions are drawn from studies examining the role of aviation in disease or virus propagation [34–37].

Table 1. Chronological discoveries and announcements pertaining to COVID-19 and associated travel recommendations

Date	Findings / Announcements	Ref.
31 December 2019	Information on an outbreak of unknown etiology was officially received by WHO	[1, 2]
7 January 2020	A novel coronavirus was identified from a positive patient, displaying typical coronavirus morphology via electron microscopy	[38, 39]
9 January 2020	Chinese Authorities announced a "New type of Coronavirus" to the media	[38]
10 January 2020	WHO issued advice on international travel and trade related to the new coronavirus pneumonia outbreak in China	[40]
5 February 2020	Flights to and from China were suspended at Soekarno-Hatta Airport to prevent the spread of the virus	[41]
24 February 2020	WHO released updated advice for international travel in relation to the outbreak of the novel coronavirus 2019 − nCoV	[42]
27 February 2020	Updated WHO advice was given after the confirmation of human-to-human transmission largely in Wuhan city, as well as in other areas in China and abroad	[43]
11 February 2020	WHO provided key considerations for the repatriation and quarantine of travellers in light of the outbreak of the novel coronavirus 2019-nCoV	[44]
11 February 2020	The novel coronavirus was officially named "COVID-19" by WHO	[45]
29 February 2020	Updated recommendations for international traffic were released by WHO in relation to the COVID-19 outbreak	[46]
11 March 2020	A joint statement on COVID-19 was issued by ICAO and WHO	[47]

The rise and spread of the COVID-19 virus internationally led numerous countries to instate preventive measures, including restrictions on movement within communities.

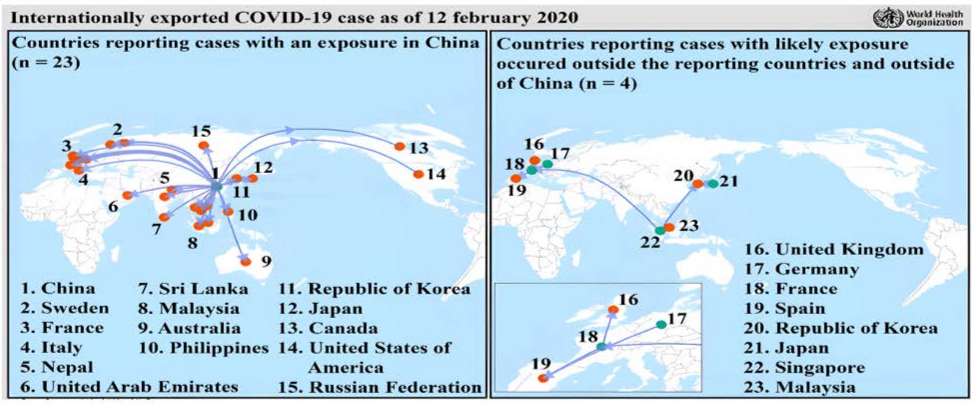

Figure 1. As of 12 February 2020, the global spread of COVID-19, posited to be largely attributed to international flights [32]

3.2 Movement Restriction Measures

To curb the transmission of the COVID-19 virus, numerous strategies have been employed globally, with the predominant measure being the limitation of human movement. This strategy was primarily intended to prevent viral transmission from one individual to another, necessitating significant modifications to social interactions. Social distancing measures were recommended, suggesting individuals maintain a safe distance during interactions [48]. Following China's precedent, numerous countries globally have enacted lockdowns as a decisive step to interrupt the viral transmission chain [49]. However, the structure and nomenclature of these lockdowns vary based on individual nation circumstances, with terms such as national and subnational lockdown being commonly employed [50–52].

European nations, recognising the imminent threat, promptly initiated lockdowns: Italy (March 13), Spain (March 15), Austria (March 16), France (March 17), Denmark (March 18), United Kingdom (March 23), and the Netherlands (March 24) [49]. Generally, whilst certain public spaces like schools, universities, colleges, restaurants, bars, and public transportation systems were closed, essential services, such as supermarkets and drug stores, remained operational. These establishments ensured adherence to distancing guidelines and mask mandates to mitigate viral spread [53].

For a comprehensive view of movement restriction implementations across various countries representing all seven continents, including the statuses of international flight operations as supportive measures, refer to Table 2. Notably, by June, some countries had begun to partially reinstate international flight routes, as depicted in Figure 2.

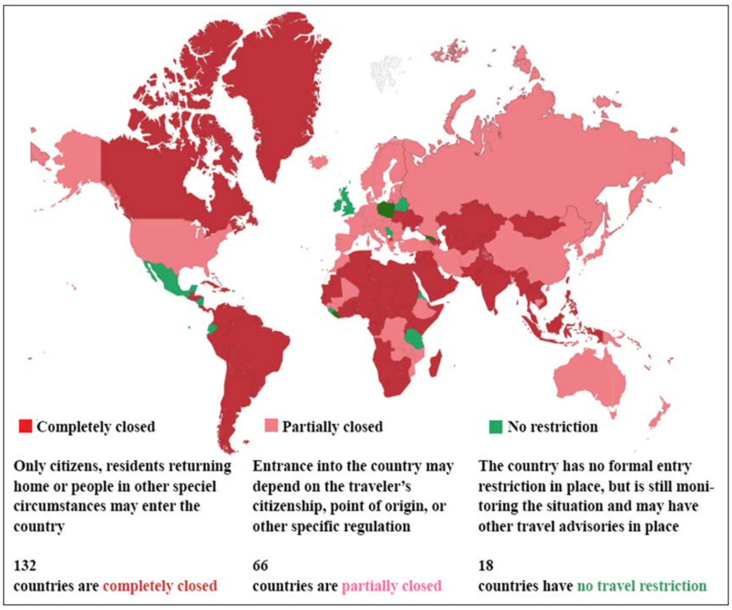

Figure 2. Depiction of countries with open, partially closed, or fully closed international flight operations as of June 2020 [54]

Table 2. Chronological discoveries and announcements pertaining to COVID-19 and associated travel recommendations

No.	Country	Type of Restrictions Movement	Sources
1	Indonesia	Large-Scale Social Restrictions	[41]
2	Singapore	Circuit Breaker	[55]
3	China	Lockdown	[56, 57]
4	Malaysia	The Movement Control Order (MCO)	[58]
5	Philippines	Enhanced Community Quarantine (ECQ)	[59]
6	Spanish	Lockdown	[60]
7	Italy	Lockdown	[60]
8	France	Lockdown	[61]
9	New Zealand	Lockdown	[62]
10	South African	Lockdown	[63, 64]
11	Brazil	Partial Lockdown	[65, 66]

4 Human Activities under Movement Restrictions in Indonesia

4.1 Large-Scale Social Restrictions Amidst the COVID-19 Pandemic

On April 10, 2020, Indonesia's government announced the initiation of the Large-Scale Social Restriction policy, which was later extended for an indefinite period. These restrictions encompassed various sectors, from educational institutions and workplaces to religious activities and public places. However, the imposition of such restrictions was contingent upon certain criteria as set by the Indonesian government. As per Regulation No. 21 of 2020, for any region to implement Large-Scale Social Restrictions, there needed to be a significant and rapid increase in the number of cases and/or deaths, with evident epidemiological links to similar incidents in other regions or countries [67].

It was observed that the government's flexible approach, allowing variations in restrictions based on regional needs, served as an effective strategy to prevent undue economic disruptions, especially in areas with fewer confirmed cases. A national implementation of the Large-Scale Social Restrictions was not announced, yet emphasis was laid on its rigorous enforcement in high-risk zones, including Jakarta and West Java, among others [68]. Although the framework for these restrictions was provided by the Minister of Health, its execution could be carried out by local governments upon the Minister's approval.

Further clarifications regarding the enforcement of these restrictions in Jakarta were provided by the Governor. According to the Governor's Regulation No. 47 of 2020, restrictions were placed on the mobility of Jakarta residents, prohibiting any ingress or egress from the region, save for individuals or business entities possessing requisite permissions [69]. The Ministry of Health of the Republic of Indonesia subsequently released detailed guidelines related to transportation under these restrictions:

(1) The passenger count was capped, ensuring a mandated distance between each individual.

(2) Specific measures for transportation to and from airports were also introduced, restricting the number of occupants in both private and public vehicles and maintaining the stipulated distance therein.

4.2 Flight Constraints During the Large-Scale Social Restrictions

Large-Scale Social Restrictions encapsulated a significant curtailment in both international and domestic flight operations. Consequently, a historic downturn in commercial flights, both inbound and outbound, was observed, contrasting the robust growth of the Indonesian aviation sector since 2010 [70]. This unusual downturn presented an opportunity to assess the environmental implications of reduced human activities during the COVID-19 spread.

Upon the execution of the Large-Scale Social Restrictions policy, an acute decline in aircraft movement across Indonesian airports was recorded. For instance, at the Soekarno Hatta Airport, previously ranked the 18th busiest globally with nearly 67 million passengers in 2019 [24], a notable decline in activity was evident. Following the commencement of restrictions on April 10, 2020, a palpable decline in flights, particularly in Jakarta, was observed. Gatherings and other crowd-related activities across Indonesia were subsequently prohibited due to an escalation in COVID-19 cases. This led the Ministry of Transportation to suspend commercial flights, passenger ships, and rail services. The airport ceased to operate scheduled and unscheduled commercial flights across all routes, relegating its operations to solely cargo and specialised aviation transportation, including medical and logistical services. Figure 3 illustrates the dwindling aircraft movements at Sukarno-Hatta airport from January to April 2020.

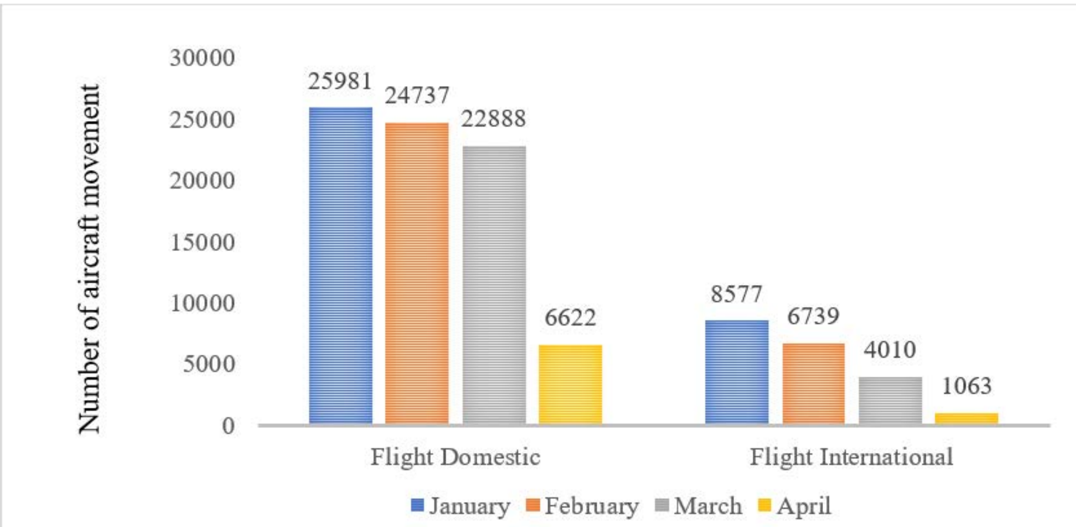

Figure 3. Aircraft Movement data in Sukarno-Hatta airport, 2020

Data suggests a significant downturn in air traffic by March 2020, exacerbated by global COVID-19 travel advisories issued by the WHO and a diminished demand for air travel. On March 24, 2020, the total number of recorded flights (Commercial flights + rest of business jet flights + private flights + gliders + most helicopter flights + most ambulance flights + government flights + some military flights + drones) tracked by the study [71] in March 24, 2020 was 4,294,685, witnessed a decrease of 21.6% from the previous year, with commercial flights being 27.7% lower than those in 2019 [72]. Such reductions, while hindering the economic agility of the aviation industry, bore environmental benefits. A salient by-product of aircraft activity is carbon dioxide (CO_2) emissions, which influence air quality and human health [57, 58]. A surge in emissions from 0 metric tons (tCO_2) to 700 million tCO_2 per annum was reported between 2004 and 2015 [73–75]. Notably, aircraft activities contribute 2-3 percent to the total human-induced global CO_2 emissions [76].

Combustion of fossil fuels in aircraft engines primarily releases CO_2 emissions. It has been postulated that the diminished flight activity could potentially result in a 70% decline in global jet fuel consumption in the second quarter of 2020, inevitably reducing the associated emissions [61]. Concurrently, a broader slump in global oil consumption and prices during the COVID-19 pandemic has been documented [77–79].

This reduction in flight frequency, although environmentally beneficial, levied economic pressures on the Indonesian economy. Economic and aviation experts within Indonesia have posited the need for extensive financial aid to the beleaguered airlines during this crisis. Such setbacks in the aviation domain would invariably ripple into associated sectors such as logistics, catering, hospitality, and travel, intensifying the economic repercussions of COVID-19, especially in industries hinging on human transportation.

4.3 Industrial Limitations Amidst Large-Scale Social Restrictions

In the spectrum of industrial operations in Jakarta, both small-to-medium enterprises and larger entities play a role. Over ten coal-fired power plants, situated within a 100-kilometer radius of Jakarta, have been identified as significant contributors to the capital's air pollution [80]. This proximity to coal-fired power plants is noteworthy in comparison to other global capitals [66]. However, the advent of the COVID-19 pandemic ushered in stringent adherence to the government's Large-Scale Social Restriction mandates. Consequently, it was reported by the Head of Jakarta's Manpower, Transmigration and Energy Agency that 1,376 businesses, employing 184,305 workers, ceased operations, while another 2,622 entities, with a workforce totalling 879,578 scaled down their activities during the restriction period [81].

Jakarta Governor Regulation No. 33 of 2020 delineated eleven sectors that were granted permission to operate amidst the restrictions. These sectors encompass healthcare, energy, communication services, media, food and beverages, hospitality, logistics, distribution, construction, financial services (including banking and the capital market), utilities, as well as groceries and essential services [82]. Despite these provisions, the shadow of economic recession looms over many nations, a crisis that the Indonesian government is striving to mitigate [83]. In light of these challenges, the Ministry of Industry of Indonesia, as of April 26, 2020, had granted operating licenses to 14,533 companies during the implementation of the Large-Scale Social Restriction [84]. It was observed that the majority of these companies stemmed from sectors like agro-industry, chemicals, pharmaceuticals, textiles, metal, machinery, transportation, electronics, small-to-medium enterprises, as well as industrial zones and services. Importantly, this policy was found to be congruent with the Minister of Health Regulation No. 9 of 2020, focusing on the guidelines for the Large-Scale Social Limitation [85].

Additionally, a Circular, designated as Number 4 of 2020, was released by the Ministry of Industry, highlighting protocols for factory operations during the COVID-19 public health emergency [85]. Manufacturing data from Indonesia subsequently revealed that although manufacturing activity witnessed contraction in June 2020, the rate of this decline was more moderate than what had been seen in the preceding two months. This trend was consistent with indicators suggesting a phased revival of the Indonesian economy in June 2020 [86].

4.4 Impacts on Transportation Amidst Large-Scale Social Restrictions

During a period extending nearly five months (March-July), restrictions on human activities led to a notable suspension of outdoor ventures. It was observed that both professional tasks and educational activities transitioned to home-based operations, commonly referred to as "work from home" (WFH) practices [87]. As a consequence, a significant reduction, amounting to 45%, was noted in the movement of private vehicles within Jakarta during the COVID-19 pandemic phase [87]. Motorised transport, encompassing both automobiles and motorbikes, were permitted operation contingent upon the adherence to prescribed health protocols. Public transportation, on the other hand, functioned at a diminished capacity, limited to 50%, with physical distancing measures in place.

Furthermore, a stark contrast in passenger numbers was discerned within the KRL Commuter line. Prior to the outbreak of COVID-19, daily passenger traffic stood at approximately 900,000. However, due to the imposition of Large-Scale Social Restrictions, this number plummeted to a mere 300,000 per day. Such restrictions dictated not only a reduced passenger count but also adjustments in the frequency of the KRL service. Pertaining to maritime transport, the passenger throughput at Tanjung Priok port witnessed a reduction of 50% during January-May 2020, equating to 85,355 individuals, in stark contrast to the 169,157 recorded in the previous year [88–90].

In a strategic move, the Indonesian government initiated the suspension of all passenger ship services from April 24 to June 8, 2020. As clarified by the Sea Transportation Director General at the Ministry of Transportation, while general passenger services were halted, certain exemptions were made. Vessels transporting returning migrant workers and citizens from overseas, including Indonesian crew members, cruise ships, and commercial maritime entities, both foreign and domestic, were still permitted operation. It was further noted that residents of islands, opting for shopping excursions to mainland metropolises using privately-owned boats, as well as fishermen setting sail, remained unaffected by these regulations [75, 76].

5 Jakarta's Air Quality: The Ramifications of Human Activity Curtailment Amidst Large-Scale Social Restrictions

Data utilised in this investigation were predominantly sourced from the AQI online site [26]. This platform also proffers historical data, crucial for gauging the environmental repercussions indirectly ascribed to COVID-19 [91]. Additionally, air quality data from IQAir were incorporated into the study [92]. Verification of air quality in Jakarta was further ascertained through open data available from the city's official repositories [93–95]. The examined dataset pertains to the timeframe spanning January through April 2020.

It is empirically noted that diminished human activity invariably results in decreased emissions of greenhouse gases, with concomitant reductions in environmental degradation [80, 81]. Amidst the COVID-19 pandemic, a conspicuous reduction in greenhouse gas emissions was observed in select European metropolises such as Paris, Rome, and Madrid, most notably manifested in a significant drop in NO_2 concentrations [96–98]. Analogously, by February 2020, a $20 - 30\%$ reduction in NO_2 concentrations was recorded in China compared to averages from the previous three years for the analogous month [97].

5.1 The NO_2 Landscape in Jakarta

Jakarta, Indonesia's bustling capital, serves as a case in point. Historically, the city's compromised air quality can be attributed to myriad factors: accelerated urbanisation, seasonal agricultural land combustion, reliance on coal-fired power plants, and an influx of fuel-inefficient vehicles [99–101]. Encompassing an expansive 6,392 km^2, the Jakarta metropolitan region accommodates over 30 million inhabitants, a number that continues to burgeon. Projections indicate that by 2030, Jakarta could potentially emerge as the world's most populous megacity, housing an estimated 35.6 million residents. This anticipated urban sprawl augments concerns surrounding deteriorating air quality, a predicament exacerbated by dust-producing construction activities and a burgeoning vehicular populace, with its attendant energy demands [102].

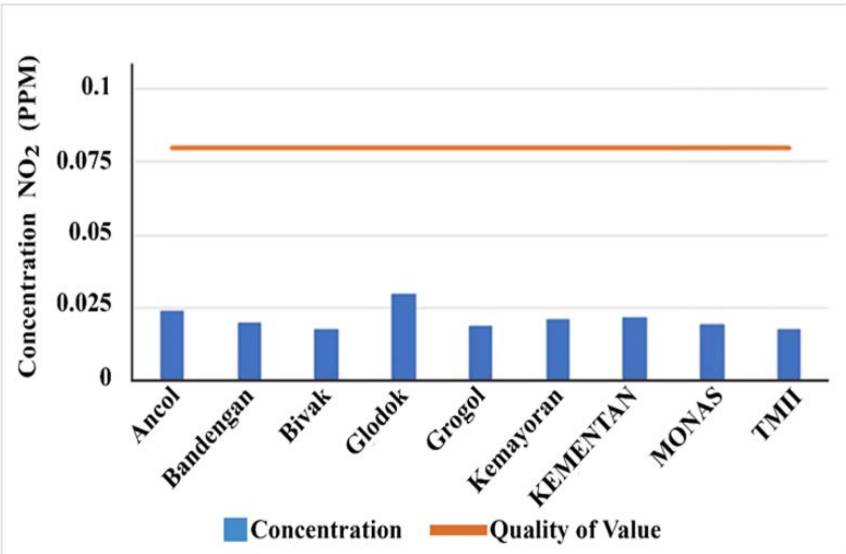

Figure 4. NO_2 monitoring in march 2020

To elucidate the intricacies of the air quality components, the initial focus lies on NO_2. A substantial fraction of NO_2 emissions is derived from anthropogenic activities, prominently stemming from the combustion of petroleum products such as coal, gas, and oil, with vehicles being the primary contributors. Additional sources include welding, petroleum refinement, metallurgical processes, and food manufacturing [103]. Within the Jakarta precinct, NO_2 levels are monitored across nine pivotal locations, namely: Ancol, Bandengan (Delta), Bivouac, Glodok, Grogol, Kemayoran, Ministry of Agriculture, TMII, and Monas. Passive gas methodology is employed for these measurements, and subsequent analyses are conducted at the BMKG air quality laboratory using spectrophotometric techniques. In the month of March 2020, GLODOK-West Jakarta registered the highest NO_2 concentration, clocking in at 0.0316 ppm (Figure 4), though this figure remains comfortably beneath the stipulated Quality Standard Value of 0.08 ppm [104].

Corroborating the aforementioned data, imagery from the Sentinel-5P satellite delineates comparative NO_2 air quality indices for Jakarta for the months of March and April in 2019 and 2020, as depicted in Figure 5. The mapping showcases monthly averaged values of the total vertical column of NO_2 over the Java island, gleaned from the Sentinel-5P satellite, which scans NO_2 concentrations spanning from the Earth's surface up to the troposphere's upper echelons [105]. Given Jakarta's proximity to multiple airports, including one of the globe's most frequented, discernible peaks in NO_2 levels, oscillating between moderate to unhealthy ranges, were identified in March and April 2019 (Figure 5) [106].

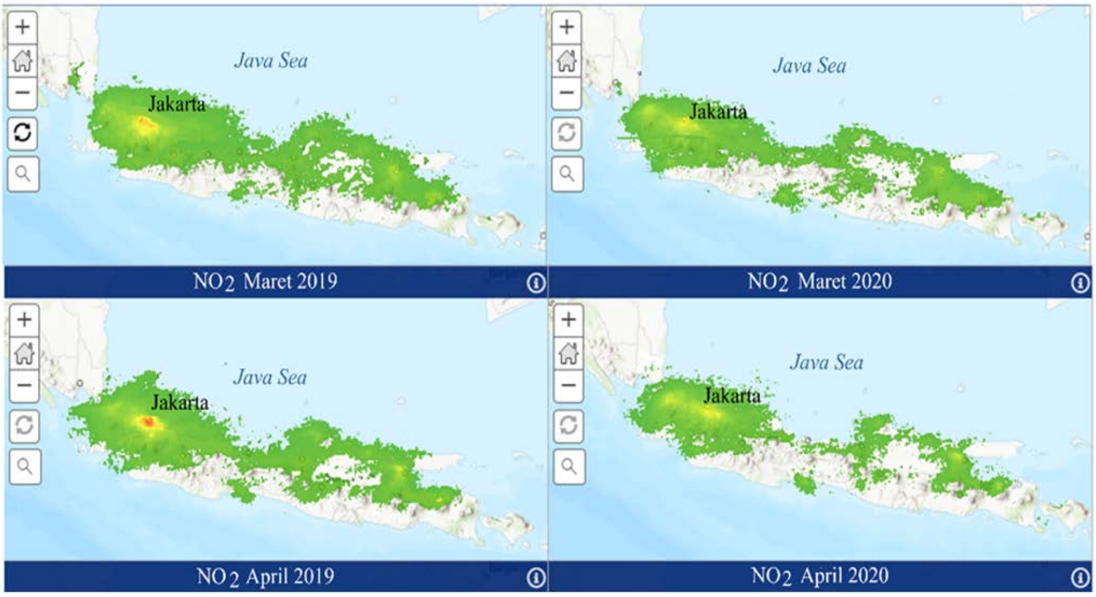

Figure 5. Comparative analysis: NO_2 concentrations in Jakarta (March-April 2019 vs March-April 2020)

5.2 PM2.5 and PM10 Concentrations in Jakarta

Beyond NO_2, the assessment of Jakarta's air quality notably encompasses the concentrations of PM: PM2.5 and PM10. Distinct categories have been identified for PM2.5, namely outdoor and indoor concentrations [107, 108].

In outdoor environments, PM2.5 arises chiefly from vehicular emissions, encompassing cars, trucks, buses, and other motorised conveyances. Combustion of organic materials, evident in the burning of wood, oil, or coal, further contributes to these levels. Forest and grassland fires, along with emissions from industrial chimneys, also represent notable sources. Conversely, indoor environments are marked by PM2.5 emanating from sources such as cigarette smoke, cooking (especially frying), burning candles or lamp oils, and fireplace emissions.

Prior to the pandemic's onset, the adoption of green masks had become a quotidian practice amongst Jakarta's populace, especially during commutes. Despite this precaution, PM2.5 particles, by virtue of their minuscule dimensions, were found to infiltrate through mask gaps, subsequently entering the respiratory system. Upon accumulation within pulmonary structures and other organs, these particles have been linked to a spectrum of ailments, ranging from respiratory disorders to cardiac complications. Given that their size equates to a mere three percent of a human hair's diameter, they have colloquially been dubbed "the Silent Killer", attributed to their insidious health repercussions and potential lethality [109]. Their diminutive size facilitates their suspension in the atmosphere, rendering them ubiquitously present [110].

Online data collated by the study [91] offer a comprehensive depiction of PM2.5 distributions across Jakarta, as delineated in Figure 6, capturing the months of January, February, March, and April for the years spanning 2016 to 2020. Building upon this AQI distribution, subsequent analyses were conducted. A commendable AQI score for PM2.5 falls within the 0-50 range, indicating optimal health conditions devoid of associated health risks [97, 98]. The encapsulated data in Figure 6 predominantly centres on AQI values bracketed between 0-25 and 26-50. Annual AQI values within these brackets are subsequently tabulated, the summative outcomes of which are presented in Figure 7.

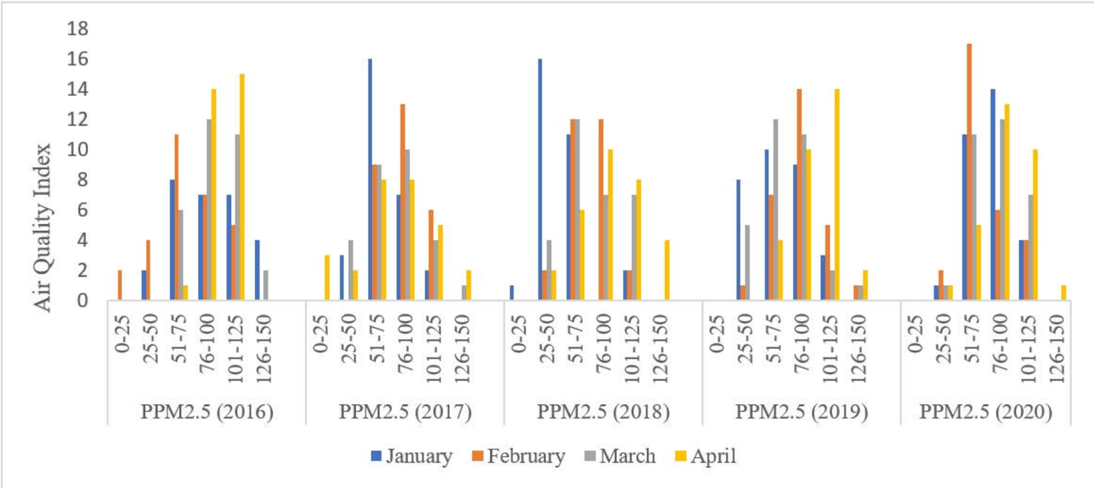

Figure 6. Consolidation of AQI measurements in Jakarta from January to April (2016-2020)

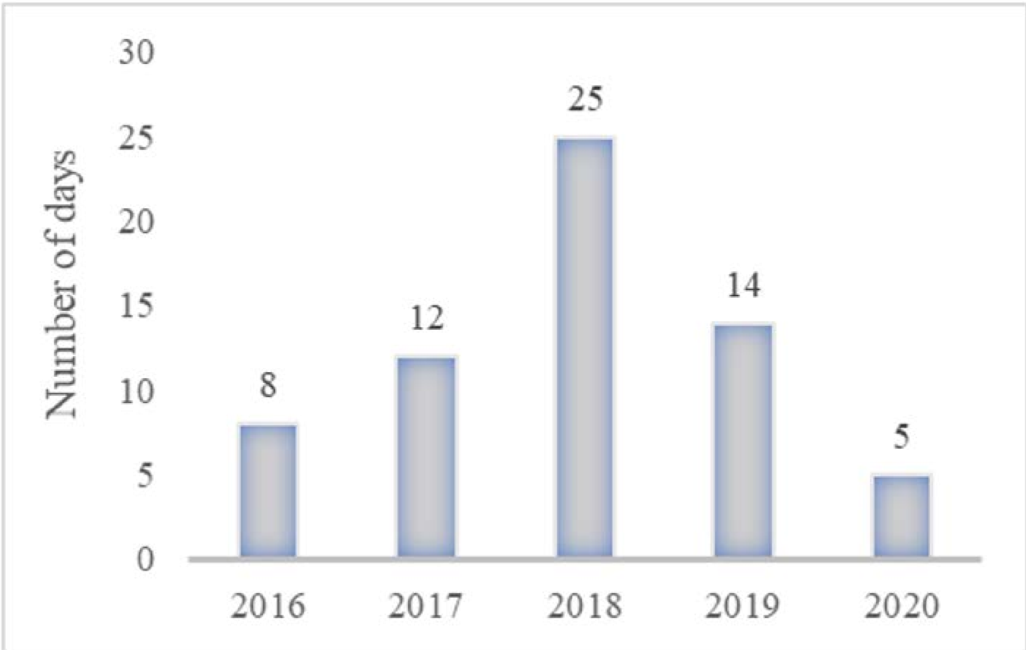

Figure 7. Aggregated PM2.5 data: January to April (2016-2020)

From the AQI data presented in Figure 7, it was observed that the months of January to April in 2018 recorded the healthiest air quality, with 25 days falling within the 'good' AQI level. Conversely, 2020 witnessed only 5 days within the 'good' PM2.5 level during the same period from a 121-day measurement. A point of contention arises considering the global prevalence of COVID-19 during this period, which, theoretically, should have led to a reduction in PM2.5 values. Such deductions can be attributed to the Large-Scale Social Restrictions enforced by the Indonesian government, limiting vehicular movements. Nevertheless, the proximity of Jakarta to at least ten coal-fired power plants is noteworthy. It is speculated that the amplified demand for electricity during the Large-Scale Social Restrictions might have augmented PM2.5 values, particularly from indoor activities. Supporting this supposition, data from PLN (State Electricity Company) indicates a 6% year-on-year surge in domestic electricity consumption in April 2020, primarily due to these restrictions compelling citizens to work from home [111–113].

Comparatively, a 35% decline in 'healthy' AQI days (by standard metrics) was recorded in the initial four months of 2020 relative to 2019, implying an uptick in PM2.5 concentrations during the COVID-19 pandemic in Jakarta. Concurrently, PM10 AQI data, solely available for January to April in 2018 and 2020 [91], exhibited different patterns. The primary sources of PM10, as identified by the study [114], include long-distance transportation emissions, vehicle exhaust, tyre wear, and natural origins like soil particles.

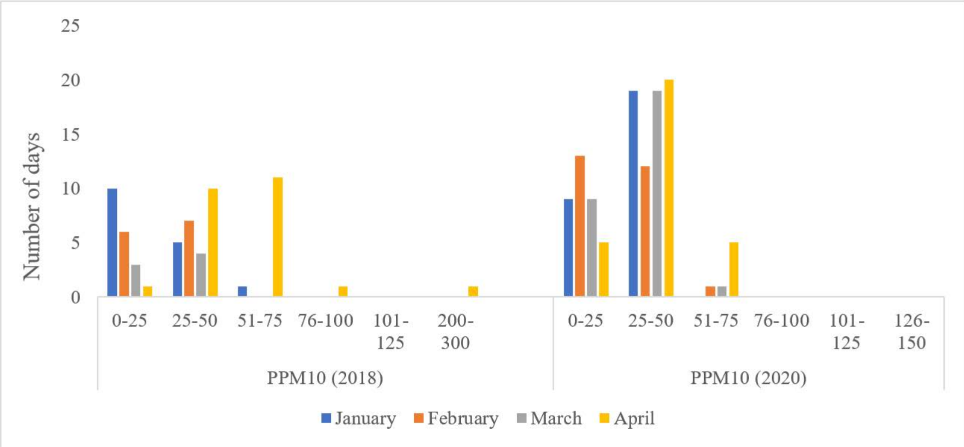

Figure 8. Consolidation of PM10 AQI measurements: January to April (2018 & 2020)

Figure 9. Summary of PM10 levels adhering to AQI value of 0-50: January-April (2018 & 2020)

Utilising AQI data from Figure 8 and benchmarking against the healthy AQI level of 0-50 for PM10 [111], it was discerned that, of the 120 days spanning January to April in 2018, 46 days were classified as having good air quality. In stark contrast, 2020 boasted 106 such days (Figure 9), predominantly in March and April. For a more comprehensive understanding, AirVisual Data was consulted, illuminating PM10 and PM2.5 levels across the ASEAN region (Figure 10). According to April 2020 data, the island of Java, encompassing Jakarta, exhibited an extensive spread of PM2.5 in the atmosphere, whereas PM10 values had diminished. Such findings corroborate the relationship between the discussed data and satellite imagery.

AQI computations traditionally factor in six primary pollutants: PM2.5, PM10, CO, SO_2, NO_2, and O_3. Published data from the environmental department of Jakarta [93] illustrates that during the January-April stretch in 2019, only one day met the ‘good’ AQI criterion. However, an increment to seven days was noted in 2020. These measurements were ascertained from five strategic points in Jakarta: Hotel-Indonesia roundabout (Central Jakarta), Kelapa Gading (North Jakarta), Jagakarsa (South Jakarta), Lubang Buaya (East Jakarta), and Kebun Jeruk (West Jakarta).

From the insights presented in Figure 11, a discernible shift towards improved AQI scores was observed during January-April 2020 relative to 2019. Specifically, an enhancement of 19 days was recorded, a development ostensibly linked to the COVID-19 pandemic and the consequential Large-Scale Social Restrictions implemented by the Indonesian government, resulting in diminished transportation, industrial activities, and traffic.

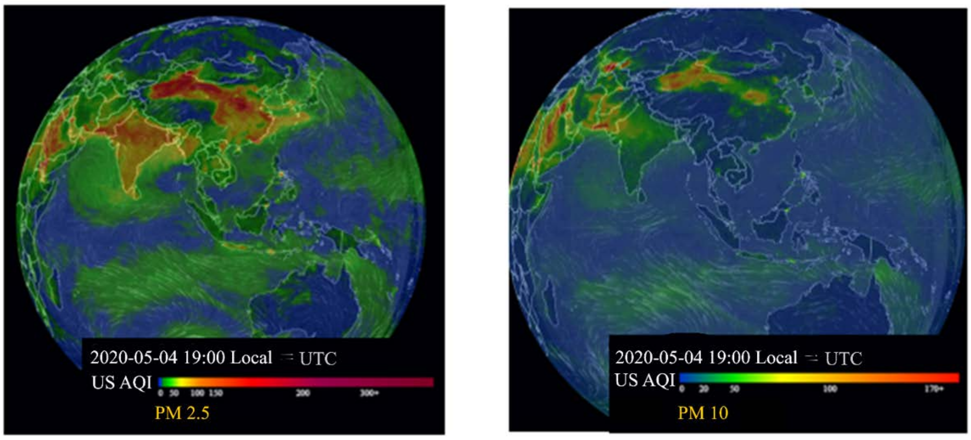

Figure 10. IQAir earth depicting PM2.5 and PM10 distributions across ASEAN

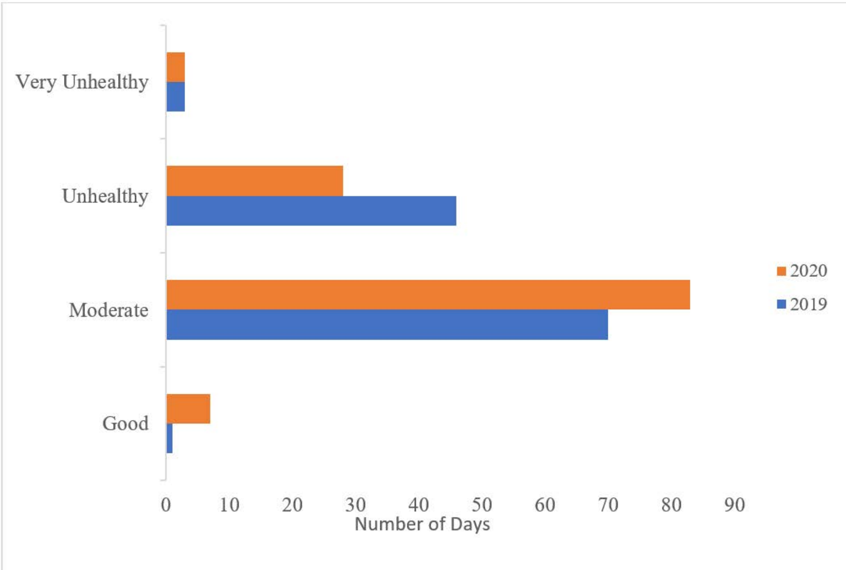

Figure 11. Comparative analysis of AQI classifications: 2019 & 2020

5.3 Ground-Level O_3 Levels in Jakarta

In the assessment of air quality concerning good and moderate categorisations, specific critical parameters within the AQI components were observed to reach maximal values. It was observed that in Jakarta, ground-level O_3 achieved critical readings on approximately 86 days in 2019, and on 78 days in 2020 (as indicated in Figure 12). This ground-level O_3, responsible for haze formation, is known to adversely affect both lung and cardiac functions. It is formed when volatile organic compounds undergo chemical reactions with methane and nitrogen oxide, with sunlight acting as the catalyst. Such reactions are accentuated by sunlight and elevated temperatures.

A pronounced surge in the utilisation of vehicles powered by fossil fuels, combined with an insufficient monitoring system of their emissions, has positioned Jakarta as a representation of inadequate environmental supervision. This issue is not exclusive to the capital; indeed, multiple urban areas on Java Island in Indonesia grapple with similar challenges. Consequently, elevated O_3 levels in such densely populated regions have a marked influence on human health. Studies indicate that an 8-hour exposure to an O_3 concentration of 0.3 ppm might result in ocular irritation. Moreover, exposure periods ranging from 3 minutes to 2 hours, with O_3 levels oscillating between 0.3 and 1 ppm, were associated with symptoms like choking, coughing, and a pronounced sense of fatigue. More worryingly, an exposure of 2 hours at concentrations between 1.5–2 ppm manifested in symptoms including chest discomfort, coughing, headaches, and challenges in both coordination and expression. In summary, O_3 concentrations at 0.3 ppm have been linked with irritation in the nasal passages and throat. Interactions with O_3 levels between 1.0-3.0 ppm over two hours were observed to lead to severe disorientation and coordination loss in specific sensitive populations. Extended exposure to a concentration nearing 9.0 ppm is purported to induce pulmonary edema in a majority of the populace.

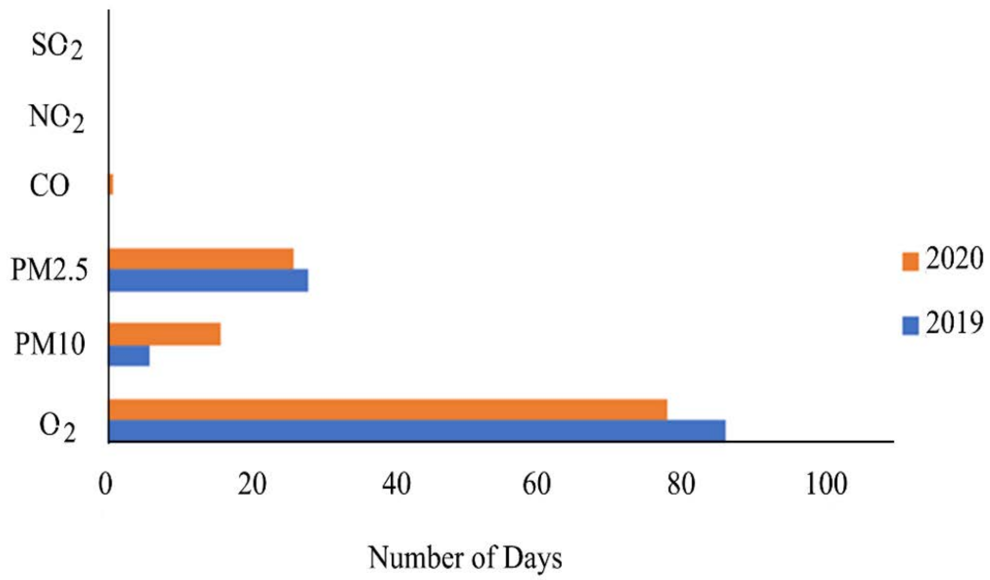

Figure 12. Critical AQI parameters in Jakarta: 2019 & 2020

6 Comparison of Air Quality Alterations Due to Human Activities Amidst the COVID-19 Pandemic in Indonesia and Neighbouring Countries

Many countries neighbouring Indonesia have endeavoured to curtail the spread of COVID-19 without entirely stalling their economies due to stringent lockdown measures. These varied policies, largely shaped to stem the virus's spread, were predominantly informed by travel advisories issued by the WHO. This study examines the AQI data until May 4, 2020, with a particular emphasis on the span between January and April.

6.1 Kuala Lumpur, Malaysia

In Malaysia, the initial COVID-19 case was recorded on January 25, 2020 [115]. By March 2020, an upward trajectory in case numbers was discerned. In response, the Malaysian Government sanctioned the MCO on March 18, aiming to curtail the contagion's source [116].

Throughout the MCO's imposition, several activities, encompassing business operations, were restricted, with exceptions granted only to essential services [117]. A decline in traffic density and industrial emissions was noted, as working from home became mandated, and several industries faced temporary suspensions. Evidently, major contributors to air pollution in Malaysia have been identified as vehicular emissions, industrial outputs, and open burning activities. Thus, the country's air quality status is largely gauged using the Air Pollution Index (API), focusing on specific pollutant criteria like PM2.5. During this period, a significant transition towards finer air pollutant particles was observed in Malaysia [118].

Hourly API data retrieved from the Air Pollutant Index of Malaysia portal [119] indicated an enhancement in Kuala Lumpur's air quality, with readings on May 4, 2020, registering below 50, thus being categorised as "Good." The Malaysian API Index classifies readings into five distinct categories: 0-50 (Good), 51-100 (Moderate), 101-200 (Unhealthy), 201-300 (Very Unhealthy), and those exceeding 300 (Hazardous) [120]. The implementation of the MCO had a discernible impact on pollutant concentrations, manifesting in reductions of PM2.5 (ranging from 3% to 35%), NO_2 (between 43% and 63%), SO_2 (from 2% to 48%), and CO (spanning 1% to 27%). This data delineation was drawn from a comparison before and during the third phase of the MCO [121]. Concurrently, daily PM2.5 concentrations oscillated between 5.3–42.5 $\mu g/m^3$ and 3.9-69.2 $\mu g/m^3$. Besides environmental considerations, the MCO's encompassing directives also extended to prohibiting mass gatherings, international travel by residents, entry of international tourists, and the suspension of educational institutions and public-private governmental agencies.

6.2 Bangkok, Thailand

In Bangkok, the capital of Thailand, an examination of air quality data revealed a pronounced decrease in hazardous pollution levels by approximately 20% following the enactment of rigorous social distancing measures. A marked decline of at least 22% was observed in the average PM2.5 concentrations—fine PM predominantly resulting from vehicular emissions, refineries, and other significant industrial processes within the urban confines of the city [122].

Analyses of governmental datasets by leading air quality specialists in Thailand have further highlighted a substantial reduction in PM10 concentrations, commonly attributed to agricultural and construction undertakings, and a nearly halved presence of CO within urban locales [123]. Emissions from urban vehicles, biomass combustion coupled with cross-border haze in rural and peripheral zones, and industrial discharge in dense industrial sectors are identified as the principal contributors to Bangkok's air pollution [124].

In a bid to curtail the spread of COVID-19, the Thai government inaugurated stringent measures. A 'soft' lockdown was initiated in Bangkok on March 21, 2020, transitioning to a full lockdown by March 26 of the same year. On April 30, 2020, the Centre for the COVID-19 Situation Administration (CCSA) elected to moderate certain policies in Bangkok, scheduling the easing to commence on May 3, 2020. Concessions were granted to vendors and traders, permitting the operation of cafes, restaurants, and marketplaces, albeit under stringent guidelines aimed at thwarting a potential resurgence of COVID-19 infections [125].

Moreover, from April 4, 2020, the Kingdom of Thailand enforced a restriction on commercial flight entries to Bangkok, a measure intended to attenuate COVID-19 transmission, particularly from imported cases. However, according to details procured from the Indonesian Embassy in Bangkok, flights executing specific mandates, inclusive of repatriation missions, retained their entry privileges.

6.3 Singapore

The inaugural case of COVID-19 in Singapore was confirmed at Singapore General Hospital (SGH) on January 23, 2020 [126]. By February 7, 2020, an escalation to an orange alert level was declared within the Disease Outbreak Response System Condition (DORSCON), indicating the worsening of respiratory conditions and a disease transmission potential from person to person, albeit without widespread contagion [126].

It is posited that the diminution of economic and social activities, consequential to the COVID-19 outbreak, has led to a marked enhancement in Singapore's air quality. Data provided by the National Environment Agency (NEA) elucidates that reductions in pollutant levels were discernible even prior to the April 2020 circuit breaker's enforcement [127]. On April 3, 2020, a nationwide mitigation strategy, colloquially known as the 'circuit breaker', was announced by Prime Minister Lee Hsien Loong to impede the viral spread in Singapore. This intervention was precipitated by a discerned increase in unlinked infections over the previous month, and the looming threat of a significant infection escalation [127]. Post the circuit breaker's implementation, an even more pronounced decrease in pollutants was observed.

According to records from the NEA, in the fortnight leading up to the circuit breaker's activation, $\mathrm{NO_2}$ levels, which averaged at 17 $\mu\mathrm{g/m^3}$, witnessed a reduction to 13 $\mu\mathrm{g/m^3}$. Such reductions are attributed to a myriad of factors, including decreased vehicular activity, suspension of select business operations, and deceleration of industrial undertakings, synchronous with global economic dynamics [127]. Concurrently, average concentrations of PM10, PM2.5, $\mathrm{CO_2}$, and $\mathrm{SO_2}$ were observed to decrease by between 8 and 43 percent. Subsequent to the circuit breaker's activation, though reductions in pollutant levels persisted, the decrease magnitude was marginal, registering at less than 1 percent. As per current evaluations, Singapore holds the 38th global position for air pollution, but boasts commendable air quality standards [127, 128].

The government's circuit breaker policy, which commenced in April 2020, mandated residents to largely confine themselves to their homes, venturing out only for essential or emergency undertakings, such as procuring provisions or medications. Singular or household-based recreational activities were permitted, contingent on the adherence to a minimum interpersonal distance of one meter.

Historical data underscores Singapore's superior air quality metrics relative to its ASEAN contemporaries, inclusive of Thailand, Malaysia, and Indonesia. The aftermath of the pandemic has amplified this distinction, reinforcing the conjecture that both the Singaporean populace and the administrative echelons evince heightened environmental consciousness and equilibrium, especially in juxtaposition with neighboring nations.

7 Conclusions

The pervasive propagation of the COVID-19 pandemic resulted in the imposition of stringent restrictions on human mobility and activity across several afflicted nations. In Jakarta, Indonesia, a discernible amelioration in air quality has been observed. Compared to the previous year, days characterised by good and moderate air quality experienced an increment of 19 days. This enhancement was underscored by a marked 126% reduction in the mean concentrations of PM2.5, PM10, $\mathrm{NO_2}$, $\mathrm{SO_2}$ and CO [126]. Parallel observations were made in proximate regions; in Singapore, concentrations of PM10, PM2.5, $\mathrm{CO_2}$, and $\mathrm{SO_2}$ diminished between 8% and 43%. Concurrently, Bangkok registered a 22% contraction in PM2.5 levels. Kuala Lumpur documented variances in PM2.5 concentrations ranging from 3% to 35%, inducing an overall decrease in levels from 3% to 63%. Subsequent observations revealed contractions in $\mathrm{NO_2}$ (43% to 63%), $\mathrm{SO_2}$ (2% to 48%), and CO (1% to 27%) concentrations.

It has been discerned that the mandates curtailing human activity in sectors such as transportation, industrial operations, and vehicular movement not only contained the virus's transmission but inadvertently contributed to the enhancement of atmospheric conditions. Such findings highlight a paradoxical, yet lasting environmental impact arising from the pandemic's repercussions.

Nevertheless, the scope for future exploration persists. The probability of external dynamics, like vigorous atmospheric movements facilitating the dispersion of pollutants from Jakarta, cannot be overlooked. Thus, an in-depth examination into the role of atmospheric dynamics, which was not encapsulated in this initial inquiry, is imperative for a holistic understanding of the observed phenomena.

Author Contributions

Conceptualization, R.P.; formal analysis, H.V.; investigation, R.P.; data curation, R.P.; writing—original draft preparation, R.P.; writing—review and editing, H.V. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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