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Analisis Dampak Lockdown pada Polutan Udara Utama di Era Pandemi COVID-19: Literature Review

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ABSTRACT

Lockdown applied in big cities around the world as an effort to prevent the spreading of COVID-19. Lockdown has shown a major impact on the air quality. The decline of pollution happened because of the reduction of anthropogenic activities, especially in transportation and industry. This research method examines various articles about the impact of the COVID-19 lockdown on air quality and aims to describe changes in pollutants in the atmosphere. This study used several search engines (Scopus, Science direct, springer, PubMed, and google scholar). The results of the lockdown were proven to reduce the concentration of pollutants PM_{2.5} (21.8% - 39%), PM₁₀ (22.9% - 75%), NO₂ (54.3% - 96%), SO₂ (7.6% - 215.5%), CO (35% - 64.8%). The decreasing NO₂ concentration causes the O₃ concentration to increasing (15% - 525%) in the atmosphere. This is due to the limitation of titration process of O₃ by NO especially in the urban areas. The COVID-19 pandemic lockdown shows restriction on number of motor vehicles as transportation and industrial activities could become a strategy in air pollution control. The appropriate sources of pollution control will increase the quality of air and improve the lives of the community.

Keywords: Air Quality, COVID-19, Lockdown, Major Cities

ABSTRAK

Lockdown diterapkan di kota-kota besar di dunia sebagai upaya pencegahan penyebaran COVID-19. Penguncian telah menunjukkan dampak besar pada kualitas udara. Penurunan pencemaran terjadi karena berkurangnya aktivitas antropogenik, terutama di bidang transportasi dan industri. Metode penelitian ini mengkaji berbagai artikel tentang dampak penguncian COVID-19 terhadap kualitas udara dan bertujuan untuk mendeskripsikan perubahan polutan di atmosfer. Penelitian ini menggunakan beberapa mesin pencari (Scopus, Science direct, springer, PubMed, dan google scholar). Hasil lockdown terbukti menurunkan konsentrasi pencemar PM_{2.5} (21.8% - 39%), PM₁₀ (22.9% - 75%), NO₂ (54.3% - 96%), SO₂ (7.6% - 215.5%), CO (35% - 64.8%). Penurunan konsentrasi NO₂ menyebabkan peningkatan konsentrasi O₃ (15% - 525%) di atmosfer. Hal ini dikarenakan keterbatasan proses titrasi O₃ oleh NO khususnya di wilayah perkotaan. Penguncian pandemi COVID-19 menunjukkan adanya pembatasan jumlah kendaraan bermotor karena transportasi dan kegiatan industri dapat menjadi salah satu strategi pengendalian pencemaran udara. Sumber pengendalian pencemaran yang tepat akan meningkatkan kualitas udara dan meningkatkan taraf hidup masyarakat.

Kata Kunci: Kualitas Udara, COVID-19, Lockdown, Kota Besar

PENDAHULUAN

Penyakit Coronavirus Disease 2019 (COVID-19) adalah jenis penyakit baru yang sebelumnya tidak pernah teridentifikasi pada manusia. Virus penyebab COVID-19 adalah Sars-CoV-2⁽¹⁾. Pada 30 Januari 2020 World Health Organization (WHO) telah menetapkan COVID-19 sebagai *Public Health Emergency of International Concern* (PHEIC)⁽²⁾. Kasus COVID-19 meningkat pesat dan telah menyebar antar negara⁽³⁾. WHO kemudian menyatakan wabah COVID-19 sebagai pandemi global pada 11 Maret 2020⁽⁴⁾. Jumlah kasus dan kematian akibat COVID-19 semakin meningkat, dan mengharuskan pemerintah menetapkan kebijakan lockdown untuk mengurangi kasus COVID-19⁽⁵⁾. Mobilitas komunitas dihilangkan untuk mengurangi penyebaran COVID-19. Akibatnya, kegiatan komersial⁽⁶⁾, industri⁽⁷⁾, transportasi⁽⁸⁾, dan hiburan⁽⁹⁾ ditutup selama pandemi COVID-19.

Pada prinsipnya, COVID-19 ditularkan melalui kontak orang ke orang^(10,11). Kebijakan paling efektif yang diterapkan untuk mengurangi penyebaran COVID-19 adalah social distancing dan lockdown^(12,13). Dampak positif dari penguncian adalah terhadap lingkungan ketika ada aktivitas terbatas yang menghasilkan polutan.

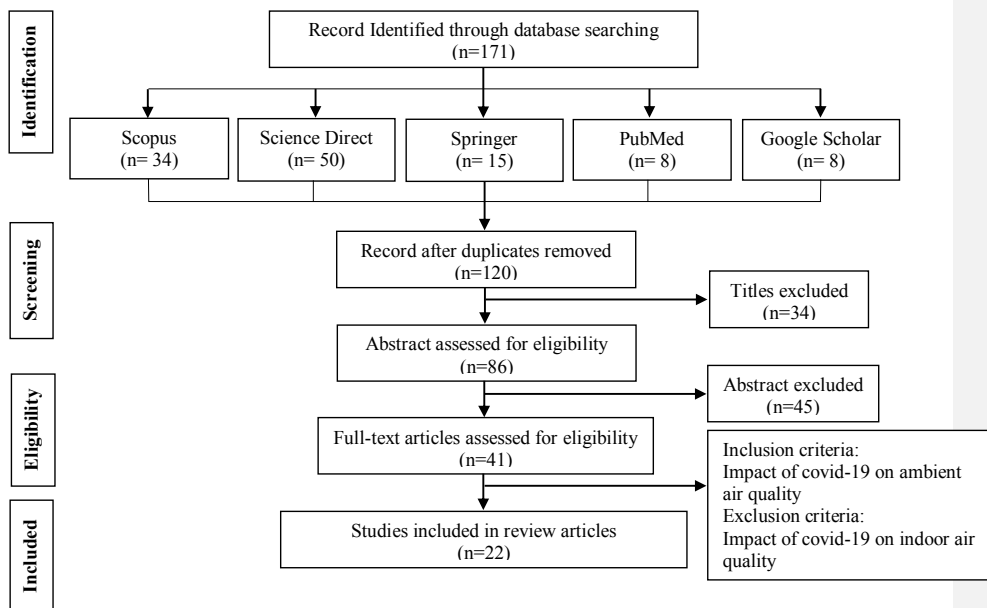
Banyak penelitian yang menemukan bahwa kualitas udara di kota-kota besar membaik akibat menurunnya jumlah kendaraan bermotor dalam kegiatan transportasi dan industri selama lockdown^(5,14,15,16). Meskipun demikian, lockdown yang dilakukan di seluruh dunia berdampak negatif terhadap perekonomian, kehidupan sosial dan budaya⁽¹⁷⁾.

Polusi udara ambien menyebabkan 4,2 juta kematian setiap tahun di kota-kota besar⁽¹⁸⁾. Kegiatan antropogenik industri, sektor energi, dan lalu lintas kendaraan merupakan penyumbang terbesar gas pencemar^(19,20,21). Penerapan penguncian nasional akibat pandemi COVID-19 telah mengakibatkan perubahan yang cukup besar pada polusi udara di seluruh dunia⁽²²⁾. Perubahan konsentrasi polutan di atmosfer (PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃) telah dilaporkan di India⁽²³⁾, Italia⁽²⁴⁾, China⁽²⁵⁾, United State⁽²⁶⁾, Korea⁽²⁷⁾, Spanyol⁽²⁸⁾. Penelitian ini bertujuan untuk mendeskripsikan perubahan parameter kualitas udara (PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃) di kota-kota besar di dunia. Kami menyajikan persentase perubahan parameter kualitas udara selama periode lockdown COVID-19 dan membahas kemungkinan kontributor perubahan kualitas udara.

METODE

Studi literature dilakukan untuk mempelajari, memahami, dan menafsirkan studi yang ada tentang topik yang sama. Penelitian ini menggunakan beberapa database, seperti Scopus, Science Direct, Springer, PubMed dan Google Scholar. Pencarian artikel dilakukan mulai Agustus hingga Desember 2020. Kata kunci yang digunakan dalam pencarian adalah “kualitas udara”, “COVID-19”, dan “Lockdown”. Studi dimasukkan dalam ulasan kami jika memenuhi kriteria inklusi: (1) Artikel diterbitkan hanya dalam bahasa Inggris; (2) Studi diterbitkan pada 2020; (3) Kajian meliputi perubahan parameter kualitas ambien udara. Untuk kriteria eksklusi: (1) Studi yang meneliti perubahan kualitas udara dalam ruangan, dikeluarkan; (2) Duplikasi publikasi. Proses pemilihan artikel yang relevan disajikan pada Gambar 1.

Comment [HP1]: Sebaiknya dipaparkan strategi pencarian literatur (misalnya PICOS) Apakah dalam penelitian, peneliti melakukan penilaian kualitas artikel?



Gambar 1. Temuan artikel mengenai perubahan konsentrasi polutan di udara akibat lockdown di era pandemi COVID-19

HASIL

Dampak Lockdown terhadap Polutan Udara di Era Pandemi COVID-19

Rincian penelitian yang meneliti dampak lockdown terhadap kualitas udara di berbagai kota disajikan pada Tabel 1. Dari 22 manuskrip yang digunakan untuk kajian ini, satu penelitian mencatat kualitas udara di Bangladesh⁽²⁹⁾, dua penelitian dilakukan di Brasil^(30,31), empat studi yang dilakukan di China^(32,33,34,35), tiga studi

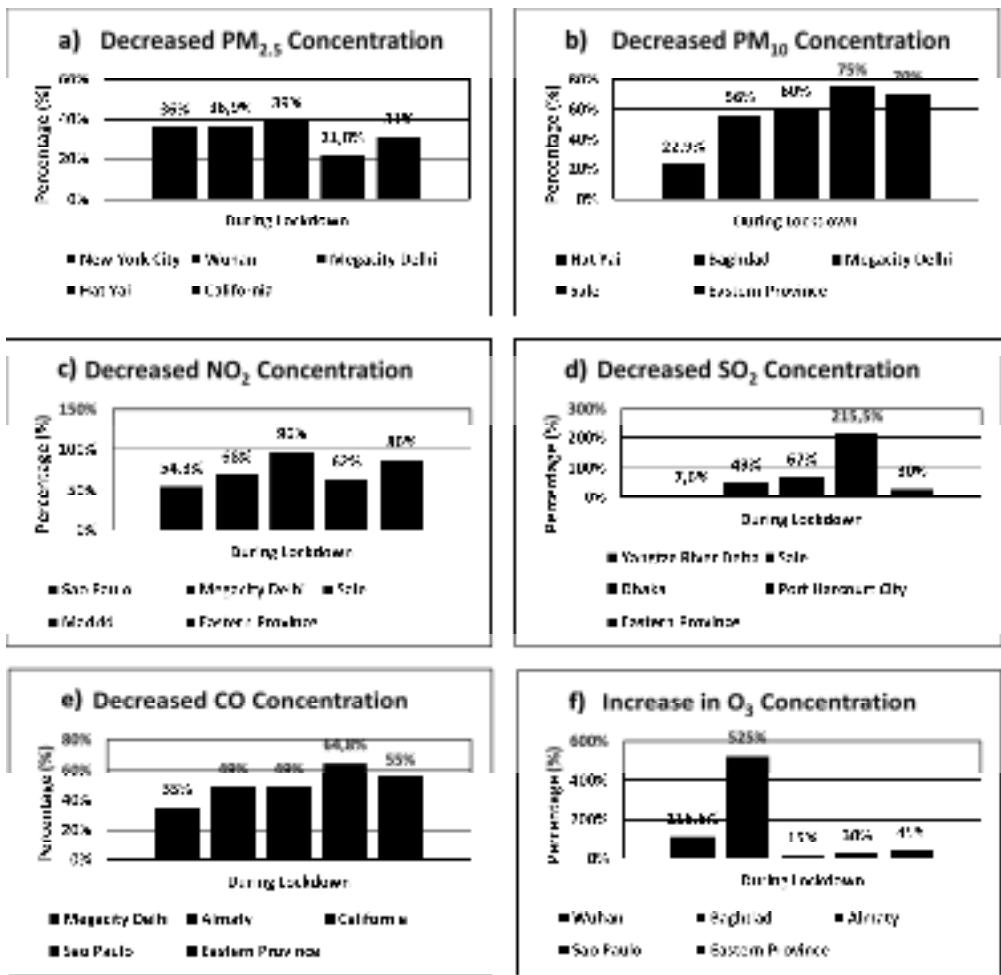
yang dilakukan di India^(6,36,37), tiga studi yang dilakukan di Amerika Serikat^(38,39,40), dan masing-masing satu studi di Irak⁽⁴¹⁾, Kazakhstan⁽⁴²⁾, Maroko⁽⁴³⁾, Spanyol⁽⁴⁴⁾, Korea Selatan⁽⁴⁵⁾, Amerika Selatan Utara (NSA)⁽⁷⁾, Nigeria⁽⁴⁶⁾, Arab Saudi⁽⁴⁷⁾ dan Thailand⁽⁸⁾. Telah banyak penelitian yang membahas dampak lockdown terhadap parameter udara diantaranya PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃.

Tabel 1. Ringkasan lokasi penelitian yang dilaporkan dalam literatur

Author, Year	Country	Research Title	Location	Pollutant
Islam et al., 2020	Bangladesh	Impacts of nationwide lockdown due to COVID-19 outbreak on air quality in Bangladesh: a spatiotemporal analysis	Dhaka, Gazipur, Chattogram, and Narayanganj	NO ₂ SO ₂ CO O ₃
Dantas et al., 2020	Brazil	The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil	Rio de Janeiro	NO ₂ CO PM ₁₀
Kondoet al., 2020	Brazil	COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil	Sao Paulo	NO ₂ CO O ₃
Chu et., 2021	China	Significant concurrent decrease in PM _{2.5} and NO ₂ concentrations in China during COVID-19 epidemic	Wuhan	PM _{2.5} NO ₂
Li et al., 2020	China	Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation	Yangtze River Delta	NO ₂ SO ₂ PM _{2.5} O ₃
Filonchik et al., 2020	China	Impact Assessment of COVID-19 on Variations of SO ₂ , NO ₂ , CO and AOD over East China	East China	NO ₂ CO
Lian et al., 2020	China	Impact of city lockdown on the air quality of COVID-19-hit of Wuhan city	Wuhan	PM _{2.5} NO ₂ O ₃
Sharma et al., 2020	India	Effect of restricted emissions during COVID-19 on air quality in India	(north, south, east, central and western) India	NO ₂ SO ₂ CO PM _{2.5} PM ₁₀ O ₃
Mor et al, 2021	India	Impact of COVID-19 lockdown on air quality in Chandigarh, India: Understanding the emission sources during controlled anthropogenic activities	Chandigarh	PM ₁₀ PM _{2.5}
Mahato et al., 2020	India	Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India	Megacity Delhi	PM _{2.5} PM ₁₀ NO ₂ CO
Zangari et al., 2020	United State	Air quality changes in New York City during the COVID-19 pandemic	New York City	PM _{2.5} NO ₂
Son et al., 2020	United State	Reductions in mortality resulting from reduced air pollution levels due to COVID-19 mitigation measures	10 US states and the District of Columbia	PM _{2.5}
Liu et al., 2021	United State	Spatiotemporal impacts of COVID-19 on air pollution in California, USA	California	CO PM _{2.5} NO ₂
Hashim et al., 2021	Iraq	Impact of COVID-19 lockdown on NO ₂ , O ₃ , PM _{2.5} and PM ₁₀ concentrations and assessing air quality changes in Baghdad, Iraq	Baghdad	NO ₂ O ₃ PM _{2.5} PM ₁₀
Kerimray et al., 2020	Kazakhstan	Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan	Almaty	NO ₂ PM _{2.5} O ₃ CO
Otmani et al., 2020	Marocco	Impact of Covid-19 lockdown on PM ₁₀ , SO ₂ and NO ₂ concentrations in Sale City (Morocco)	Sale	PM ₁₀ SO ₂ NO ₂
Baldasano., 2020	Spain	COVID-19 lockdown effects on air quality by NO ₂ in the cities of Barcelona and Madrid (Spain)	Barcelona and Madrid	NO ₂
Han et al., 2020	South Korea	Air Quality Change in Seoul, South Korea under COVID-19 Social Distancing: Focusing on PM _{2.5}	Seoul	PM _{2.5} CO NO ₂
Mendez-Espinosa et al., 2020	Northern South America (NSA)	Air quality variations in Northern South America during the COVID-19 lockdown	Bogota and Medellin	NO ₂ PM _{2.5} PM ₁₀

Fuwape et al., 2020	Nigeria	Impact of COVID -19 pandemic lockdown on distribution of inorganic pollutants in selected cities of Nigeria	Lagos, Kaduna	NO ₂ SO ₂ O ₃
Anil and Alagha, 2020	Saudi Arabia	The impact of COVID-19 lockdown on the air quality of Eastern Province, Saudi Arabia	Eastern Province	PM ₁₀ NO ₂ SO ₂ O ₃
Stratoulis et al., 2020	Thailand	Air quality development during the COVID-19 pandemic over a medium-sized urban area in Thailand	Hat Yai	NO ₂ PM _{2.5} PM ₁₀ O ₃

Kebijakan lockdown di era pandemi COVID-19 mengurangi aktivitas industri, transportasi dan sosial. Kondisi ini mengakibatkan terjadinya perubahan konsentrasi PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃ di beberapa kota selama periode lockdown. Data yang disajikan berupa penurunan konsentrasi pencemar di lima kota yang mengalami perubahan signifikan untuk setiap pencemar selama lockdown period. Persentase perubahan konsentrasi pencemar PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃ disajikan pada Gambar 2.



Gambar 2. Persen perubahan konsentrasi polutan. a) Penurunan konsentrasi PM_{2.5}, b) Penurunan konsentrasi PM₁₀, c) Penurunan konsentrasi NO₂, d) Penurunan konsentrasi SO₂, e) Penurunan konsentrasi CO, dan f) Peningkatan konsentrasi O₃ selama periode lockdown COVID-19

DISKUSI

PM_{2.5} merupakan partikel dengan diameter <2.5 µm yang berupa partikel hasil pembakaran, senyawa organik, dan logam⁽⁴⁸⁾. Gambar 2 (a) menunjukkan penurunan konsentrasi PM_{2.5} selama periode lockdown di lima kota, yaitu Megacity Delhi, Wuhan, New York City, California, dan Hat Yai. Persentase penurunan konsentrasi PM_{2.5} yang tinggi ditemukan di Megacity Delhi yaitu 39% selama fase lockdown. Ini meningkatkan kualitas udara sekitar 40% hingga 50%⁽³⁷⁾. Penerapan lockdown di Wuhan, konsentrasi PM_{2.5} mengalami penurunan sebesar 36.9% dan tetap menjadi pencemar utama⁽³⁵⁾. Penurunan konsentrasi PM_{2.5} dengan persentase 36% diamati di New York City setelah penguncian terjadi⁽³⁸⁾. Pengamatan yang dilakukan di California menunjukkan penurunan 31% konsentrasi PM_{2.5} selama lockdown (19 Maret - 7 Mei 2020)⁽⁴⁰⁾. Konsentrasi PM_{2.5} juga menurun sebesar 21,8% di Hat Yai⁽⁸⁾. Penelitian lain juga melaporkan penurunan PM_{2.5} di Delta Sungai Yangtze⁽³³⁾, Chandigarh⁽³⁶⁾, Seoul⁽⁴⁵⁾ dan Baghdad⁽⁴¹⁾. Adanya lockdown policy selama pandemi COVID-19 terbukti menurunkan konsentrasi PM_{2.5}.

PM₁₀ adalah partikel berdiameter <10 µm yang berupa debu, serbuk, dan kapang⁽⁴⁸⁾. Gambar 2 (b) menunjukkan bahwa konsentrasi PM₁₀ menurun selama periode lockdown di lima kota, yaitu Sale, Eastern Province, Megacity Delhi, Baghdad, dan Chandigarh. Pengurangan aktivitas kendaraan selama lockdown mengakibatkan penurunan 75% konsentrasi PM₁₀ tertinggi di Sale, Maroko⁽⁴³⁾. Provinsi Timur juga mengalami penurunan konsentrasi yang signifikan pada berbagai tingkat PM₁₀ (21-70%)⁽⁴⁷⁾. Kondisi ini juga terjadi pada fase lockdown di Megacity Delhi, konsentrasi PM₁₀ menurun sekitar 60%⁽³⁷⁾. Penguncian parsial yang diterapkan di Baghdad mengurangi konsentrasi PM₁₀ sebesar 56%⁽⁴¹⁾. Konsentrasi PM₁₀ menurun sebesar 22,9% dalam 3 minggu pertama penutupan di Hat Yai, Thailand⁽⁸⁾. Penelitian lain juga melaporkan penurunan konsentrasi PM₁₀ selama periode lockdown, masing-masing 36,8%, 22,8% dan 2,4% di Chandigarh⁽³⁶⁾. Hal ini menunjukkan bahwa selama pelaksanaan lockdown konsentrasi PM₁₀ menurun.

NO₂ adalah gas yang sangat reaktif yang dikenal sebagai nitrogen oksida (NO_x). NO₂ terbentuk dari emisi kendaraan bermotor, pembangkit listrik, dan peralatan off-road⁽⁴⁹⁾. Gambar 2 (c) menunjukkan bahwa konsentrasi NO₂ telah menurun secara signifikan di lima kota, yaitu Sale, Eastern Province, Megacity Delhi, Madrid, dan Sao Paulo. Penurunan emisi karena berkurangnya aktivitas antropogenik, terutama di bidang transportasi dan industri selama lockdown COVID-19. Penurunan konsentrasi NO₂ sebesar 96% di Sale, Maroko⁽⁴³⁾. NO₂ sebagai penanda polutan yang merespon tindakan lockdown karena konsentrasinya mengalami penurunan, berkisar antara 12-86% di Provinsi Bagian Timur⁽⁴⁷⁾. Penurunan terjadi pada konsentrasi NO₂ sekitar 68% selama fase lockdown di Megacity Delhi, India⁽³⁷⁾. Konsentrasi NO₂ juga menurun di Madrid selama lockdown sebesar 62%⁽⁴⁴⁾. Penurunan konsentrasi NO₂ sebesar 54,3% diamati di daerah perkotaan selama penutupan sebagian (31). Penelitian lain juga melaporkan penurunan konsentrasi NO₂ di Wuhan⁽³⁵⁾, New York City⁽³⁸⁾, Yangtze River Delta⁽³³⁾, California⁽⁴⁰⁾, Almaty⁽⁴²⁾, dan Hat Yai⁽⁸⁾. Kebijakan lockdown menyebabkan penurunan konsentrasi NO₂ selama pandemi COVID-19.

SO₂ adalah indikator kelompok gas sulfur oksida (SO_x). Sumber SO₂ di atmosfer adalah hasil pembakaran bahan bakar fosil oleh pembangkit listrik dan fasilitas industri lainnya⁽⁵⁰⁾. Gambar 2 (d) menunjukkan penurunan konsentrasi SO₂ selama fase lockdown COVID-19 di lima kota, yaitu Port Harcourt City, Dhaka, Sale, Eastern Province, dan Yangtze River Delta. Penurunan konsentrasi SO₂ tertinggi terjadi di Port Harcourt City sebesar 215,5%⁽⁴⁶⁾. Di Dhaka, konsentrasi SO₂ menurun sekitar 67%⁽²⁹⁾. Hasil yang diperoleh di Sale menunjukkan bahwa konsentrasi SO₂ menurun sebesar 49% (Otmami et al., 2020). Provinsi Timur juga mengalami penurunan konsentrasi yang signifikan pada tingkat variasi SO₂ antara 8,7 dan 30%⁽⁴⁷⁾. Konsentrasi SO₂ menurun 7,6% selama penguncian di Delta Sungai Yangtze⁽³³⁾. Kebijakan lockdown selama pandemi COVID-19 menurunkan konsentrasi SO₂.

CO merupakan gas yang tidak berwarna, tidak berbau, dan sangat berbahaya jika terhirup dalam jumlah banyak. Sumber CO berasal dari kendaraan bermotor yang menggunakan bahan bakar fosil, cerobong asap⁽⁵¹⁾. Gambar 2 (e) menunjukkan bahwa konsentrasi CO mengalami penurunan selama lockdown COVID-19 di lima kota, yaitu Sao Paulo, Eastern Province, Almaty, California, dan Megacity Delhi. Penurunan drastis konsentrasi CO sebesar 64,8% di daerah perkotaan selama penguncian parsial⁽³¹⁾. Selama periode lockdown, konsentrasi CO menurun 55% di Provinsi Timur⁽⁴⁷⁾. Konsentrasi CO telah menurun di Almaty dan California sebesar 49% (14,25), Sekitar 35% penurunan CO selama fase penguncian di Megacity Delhi⁽³⁷⁾. Penelitian lain juga melaporkan penurunan konsentrasi CO di Rio De Janeiro⁽³⁰⁾, China Timur⁽³⁴⁾, dan Seoul⁽⁴⁵⁾. Selama lockdown COVID-19, konsentrasi CO menurun.

O₃ atau ozon merupakan salah satu jenis polutan udara yang merupakan oksidator kuat dan berdampak negatif bagi kesehatan⁽⁵²⁾. Gambar 2 (f) menunjukkan bahwa O₃ tidak mengalami penurunan tetapi mengalami peningkatan konsentrasinya di lima kota yaitu Wuhan, Provinsi Bagian Timur, Sao Paulo, Almaty, dan Baghdad. Peningkatan konsentrasi O₃ tertinggi ditemukan di Baghdad sebesar 525%⁽⁴¹⁾. Konsentrasi O₃ telah meningkat di Wuhan sebesar 116,6%⁽³⁵⁾. Provinsi Timur juga mengalami penurunan konsentrasi yang signifikan pada berbagai tingkat O₃ sebesar 45%⁽⁴⁷⁾. Peningkatan sekitar 30% konsentrasi O₃ diamati di daerah perkotaan Sao Paulo, Brazil. Hal ini dipengaruhi oleh kondisi lalu lintas kendaraan, karena nitrogen monoksida mengalami

Comment [HP2]: Sebaiknya dijelaskan bagaimana lockdown menyebabkan perubahan konsentrasi polutan kaitannya dengan kehidupan (termasuk kesehatan)

penurunan⁽³¹⁾. Konsentrasi O₃ meningkat sebesar 15% selama periode penguncian di Almaty⁽⁴²⁾. Pembentukan O₃ dipengaruhi oleh reaksi fotokimia. Konsentrasi NO dan NO₂ menurun karena lockdown yang membatasi aktivitas kendaraan bermotor. Penurunan konsentrasi NO mengurangi proses tritiasi O₃ yang biasanya menurunkan konsentrasi O₃ terutama di wilayah kota. Proses titrasi yang lebih rendah sekaligus meningkatkan konsentrasi O₃ di udara ambien⁽⁵³⁾.

KESIMPULAN

Lockdown yang dilakukan di kota-kota besar di dunia telah mengakibatkan perubahan konsentrasi polutan di atmosfer. Penurunan konsentrasi PM_{2.5}, PM₁₀, NO₂, SO₂, CO terjadi di Megacity Delhi, Wuhan, New York City, California, Hat Yai, Sale, Eastern Province, Baghdad, Chandigarh, Madrid, Sao Paulo, Port Harcourt City, Dhaka, Sungai Delta Yangtze dan Almaty. Berkurangnya konsentrasi pencemar sebagian besar disebabkan oleh berkurangnya jumlah kendaraan bermotor dan berkurangnya kegiatan industri. Konsentrasi NO₂ yang rendah yang biasanya disebabkan oleh konsentrasi NO yang lebih rendah seperti yang ditunjukkan di beberapa kota seperti Wuhan, Provinsi Timur, Sao Paulo, Almaty, dan Baghdad menurunkan proses titrasi O₃ dan pada saat yang sama meningkatkan konsentrasi di udara ambien.

Comment [HP3]: sebaiknya dijelaskan apa dampak lockdown yang menyebabkan penurunan konsentrasi polutan, jadi tidak hanya sampai pada penurunan polutan.

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Analisis Dampak Lockdown pada Polutan Udara Utama di Era Pandemi COVID-19: Literature Review

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ABSTRACT

Lockdown applied in big cities around the world as an effort to prevent the spreading of COVID-19. Lockdown has shown a major impact on the air quality. The decline of pollution happened because of the reduction of anthropogenic activities, especially in transportation and industry. This research method examines various articles about the impact of the COVID-19 lockdown on air quality and aims to describe changes in pollutants in the atmosphere. This study used several search engines (Scopus, Science direct, springer, PubMed, and google scholar). The results of the lockdown were proven to reduce the concentration of pollutants PM_{2.5} (21.8% - 39%), PM₁₀ (22.9% - 75%), NO₂ (54.3% - 96%), SO₂ (7.6% - 215.5%), CO (35% - 64.8%). The decreasing NO₂ concentration causes the O₃ concentration to increasing (15% - 525%) in the atmosphere. This is due to the limitation of titration process of O₃ by NO especially in the urban areas. Limiting transportation activities and industrial activities can be one of the strategies for controlling COVID-19 and air pollution. The right source of pollution control will improve air quality and improve people's lives.

Keywords: Air Quality, COVID-19, Lockdown, Major Cities

ABSTRAK

Lockdown diterapkan di kota-kota besar di dunia sebagai upaya pencegahan penyebaran COVID-19. Penguncian telah menunjukkan dampak besar pada kualitas udara. Penurunan pencemaran terjadi karena berkurangnya aktivitas antropogenik, terutama di bidang transportasi dan industri. Metode penelitian ini mengkaji berbagai artikel tentang dampak lockdown COVID-19 terhadap kualitas udara dan bertujuan untuk mendeskripsikan perubahan polutan di atmosfer. Penelitian ini menggunakan beberapa mesin pencari (Scopus, Science direct, springer, PubMed, dan google scholar). Hasil lockdown terbukti menurunkan konsentrasi pencemar PM_{2.5} (21.8% - 39%), PM₁₀ (22.9% - 75%), NO₂ (54.3% - 96%), SO₂ (7.6% - 215.5%), CO (35% - 64,8%). Penurunan konsentrasi NO₂ menyebabkan peningkatan konsentrasi O₃ (15% - 525%) di atmosfer. Hal ini dikarenakan keterbatasan proses titrasi O₃ oleh NO khususnya di wilayah perkotaan. Pembatasan kegiatan transportasi dan kegiatan industri dapat menjadi salah satu strategi pengendalian COVID-19 dan pencemaran udara. Sumber pengendalian pencemaran yang tepat akan meningkatkan kualitas udara dan meningkatkan taraf hidup masyarakat.

Kata Kunci: Kualitas Udara, COVID-19, Lockdown, Kota Besar

PENDAHULUAN

Penyakit Coronavirus Disease 2019 (COVID-19) adalah jenis penyakit baru yang sebelumnya tidak pernah teridentifikasi pada manusia. Virus penyebab COVID-19 adalah Sars-CoV-2⁽¹⁾. Pada 30 Januari 2020, *World Health Organization* (WHO) telah menetapkan COVID-19 sebagai *Public Health Emergency of International Concern* (PHEIC)⁽²⁾. Kasus COVID-19 meningkat pesat dan telah menyebar antar negara⁽³⁾. WHO kemudian menyatakan wabah COVID-19 sebagai pandemi global pada 11 Maret 2020⁽⁴⁾. Jumlah kasus dan kematian akibat COVID-19 semakin meningkat, mengharuskan pemerintah menetapkan kebijakan lockdown untuk mengurangi kasus COVID-19⁽⁵⁾. Mobilitas masyarakat dibatasi untuk mengurangi penyebaran COVID-19. Akibatnya, kegiatan komersial⁽⁶⁾, industri⁽⁷⁾, transportasi⁽⁸⁾, dan hiburan⁽⁹⁾ ditutup selama pandemi COVID-19.

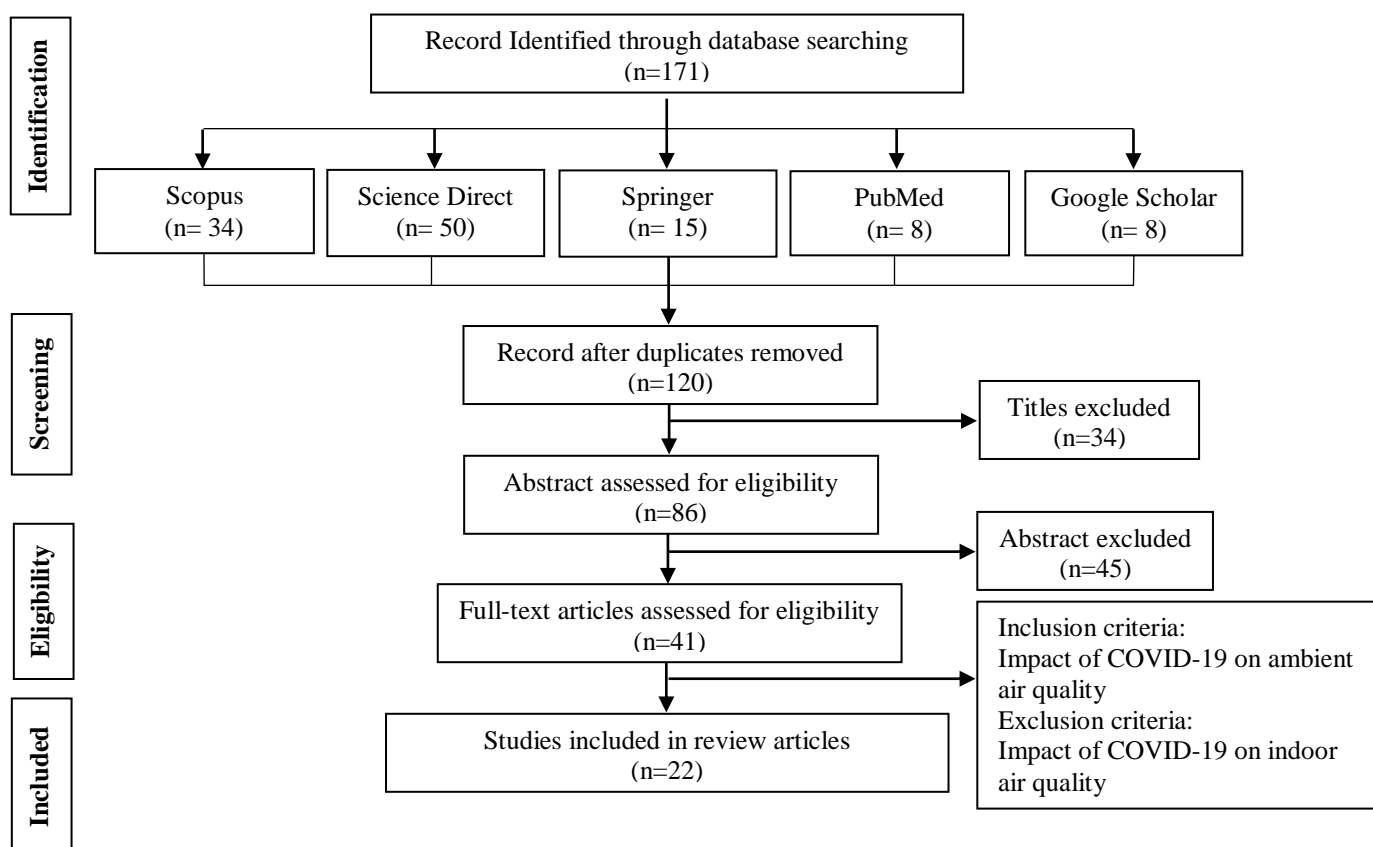
Prinsipnya COVID-19 ditularkan melalui kontak orang ke orang^(10,11). Kebijakan paling efektif yang diterapkan untuk mengurangi penyebaran COVID-19 adalah social distancing dan lockdown^(12,13). Dampak positif lockdown terhadap lingkungan, pembatasan aktivitas yang menghasilkan polutan. Banyak penelitian yang menemukan bahwa kualitas udara di kota-kota besar membaik akibat menurunnya jumlah kendaraan

bermotor dalam kegiatan transportasi dan industri selama lockdown^(5,14,15,16). Meskipun demikian, lockdown yang dilakukan di seluruh dunia berdampak negatif terhadap perekonomian, kehidupan sosial dan budaya⁽¹⁷⁾.

Polusi udara ambien menyebabkan 4,2 juta kematian setiap tahun di kota-kota besar⁽¹⁸⁾. Kegiatan antropogenik industri, sektor energi, dan lalu lintas kendaraan merupakan penyumbang terbesar gas pencemar^(19,20,21). Penerapan lockdown akibat pandemi COVID-19 telah mengakibatkan perubahan yang cukup besar pada polusi udara di seluruh dunia⁽²²⁾. Perubahan konsentrasi polutan di atmosfer (PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃) telah dilaporkan di India⁽²³⁾, Italia⁽²⁴⁾, China⁽²⁵⁾, United State⁽²⁶⁾, Korea⁽²⁷⁾, Spanyol⁽²⁸⁾. Penelitian ini bertujuan untuk mendeskripsikan perubahan konsentrasi parameter kualitas udara (PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃) di kota-kota besar di dunia. Kami menyajikan persentase perubahan parameter kualitas udara selama periode lockdown COVID-19 dan membahas kemungkinan kontributor perubahan kualitas udara.

METODE

Studi literature dilakukan untuk mempelajari, memahami, dan menafsirkan studi yang ada tentang topik yang sama. Penelitian ini menggunakan beberapa database, seperti Scopus, Science Direct, Springer, PubMed dan Google Scholar. Pencarian artikel dilakukan mulai Agustus hingga Desember 2020. Kata kunci yang digunakan dalam pencarian adalah “*air quality*”, “*COVID-19*”, dan “*lockdown*”. Ekstrasi data dilakukan dengan mempertimbangkan pendekatan Population, Intervention, Control, Outcome, Study Design (PICOS)⁽²⁹⁾. Studi dimasukkan dalam ulasan kami jika memenuhi kriteria inklusi: (1) Kajian perubahan parameter kualitas ambien udara selama periode lockdown COVID-19 di kota besar; (2) Study menyajikan data persentase perubahan parameter kualitas udara; (3) Artikel diterbitkan dalam bahasa Inggris. Untuk kriteria eksklusi: (1) Studi yang meneliti perubahan kualitas udara dalam ruangan; (2) Tidak menyajikan data persentase perubahan parameter kualitas udara ambien.



Gambar 1. Temuan artikel mengenai perubahan konsentrasi polutan di udara akibat lockdown di era pandemi COVID-19

HASIL

Dampak Lockdown terhadap Polutan Udara di Era Pandemi COVID-19

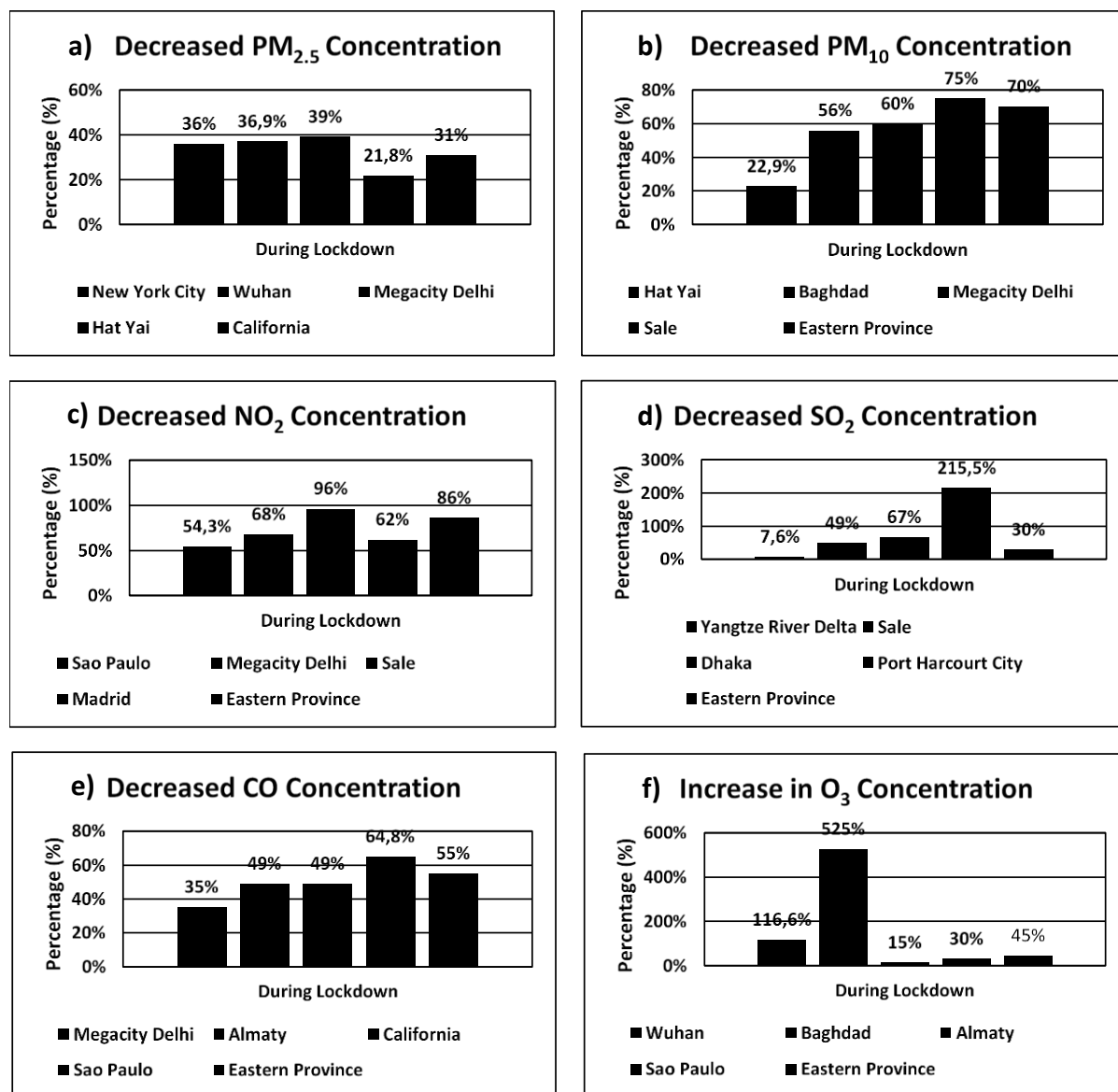
Rincian penelitian yang meneliti dampak lockdown terhadap kualitas udara di berbagai kota disajikan pada Tabel 1. Dari 22 manuskrip yang digunakan untuk kajian ini, satu penelitian mencatat kualitas udara di Bangladesh⁽³⁰⁾, dua penelitian dilakukan di Brasil^(31,32), empat studi yang dilakukan di China^(33,34,35,36), tiga studi yang dilakukan di India^(6,37,38), tiga studi yang dilakukan di Amerika Serikat^(39,40,41); dan masing-masing satu studi di Irak⁽⁴²⁾, Kazakhstan⁽⁴³⁾, Maroko⁽⁴⁴⁾, Spanyol⁽⁴⁵⁾, Korea Selatan⁽⁴⁶⁾, Amerika Selatan Utara (NSA)⁽⁷⁾, Nigeria⁽⁴⁷⁾, Arab Saudi⁽⁴⁸⁾ dan Thailand⁽⁸⁾. Telah banyak penelitian yang membahas dampak lockdown terhadap parameter udara diantaranya PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃.

Tabel 1. Ringkasan lokasi penelitian yang dilaporkan dalam literatur

Author, Year	Country	Research Title	Location	Pollutant
Islam et al., 2020	Bangladesh	Impacts of nationwide lockdown due to COVID-19 outbreak on air quality in Bangladesh: a spatiotemporal analysis	Dhaka, Gazipur, Chattogram, and Narayanganj	NO ₂ , SO ₂ , CO, O ₃
Dantas et al., 2020	Brazil	The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil	Rio de Janeiro	NO ₂ , CO, PM ₁₀
Kondoet al., 2020	Brazil	COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil	Sao Paulo	NO ₂ , CO, O ₃
Chu et., 2021	China	Significant concurrent decrease in PM _{2.5} and NO ₂ concentrations in China during COVID-19 epidemic	Wuhan	PM _{2.5} , NO ₂
Li et al., 2020	China	Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation	Yangtze River Delta	NO ₂ , SO ₂ , PM _{2.5} , O ₃
Filonchik et al., 2020	China	Impact Assessment of COVID-19 on Variations of SO ₂ , NO ₂ , CO and AOD over East China	East China	NO ₂ , CO
Lian et al., 2020	China	Impact of city lockdown on the air quality of COVID-19-hit of Wuhan city	Wuhan	PM _{2.5} , NO ₂ , O ₃
Sharma et al., 2020	India	Effect of restricted emissions during COVID-19 on air quality in India	India	NO ₂ , SO ₂ , CO, PM _{2.5} , PM ₁₀ , O ₃
Mor et al, 2021	India	Impact of COVID-19 lockdown on air quality in Chandigarh, India: Understanding the emission sources during controlled anthropogenic activities	Chandigarh	PM ₁₀ , PM _{2.5}
Mahato et al., 2020	India	Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India	Megacity Delhi	PM _{2.5} , PM ₁₀ , NO ₂ , CO
Zangari et al., 2020	United State	Air quality changes in New York City during the COVID-19 pandemic	New York City	PM _{2.5} , NO ₂
Son et al., 2020	United State	Reductions in mortality resulting from reduced air pollution levels due to COVID-19 mitigation measures	10 US states and the District of Columbia	PM _{2.5}
Liu et al., 2021	United State	Spatiotemporal impacts of COVID-19 on air pollution in California, USA	California	CO, PM _{2.5} , NO ₂
Hashim et al., 2021	Iraq	Impact of COVID-19 lockdown on NO ₂ , O ₃ , PM _{2.5} and PM ₁₀ concentrations and assessing air quality changes in Baghdad, Iraq	Baghdad	NO ₂ , O ₃ , PM _{2.5} , PM ₁₀
Kerimray et al., 2020	Kazakhstan	Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan	Almaty	NO ₂ , PM _{2.5} , O ₃ , CO
Otmani et al., 2020	Marocco	Impact of Covid-19 lockdown on PM ₁₀ , SO ₂ and NO ₂ concentrations in Sale City (Morocco)	Sale	PM ₁₀ , SO ₂ , NO ₂
Baldasano., 2020	Spain	COVID-19 lockdown effects on air quality by NO ₂ in the cities of Barcelona and Madrid (Spain)	Barcelona and Madrid	NO ₂
Han et al., 2020	South Korea	Air Quality Change in Seoul, South Korea under COVID-19 Social Distancing: Focusing on PM _{2.5}	Seoul	PM _{2.5} , CO, NO ₂
Mendez-Espinosa et al., 2020	Northern South America (NSA)	Air quality variations in Northern South America during the COVID-19 lockdown	Bogota and Medellin	NO ₂ , PM _{2.5} , PM ₁₀
Fuwape et al., 2020	Nigeria	Impact of COVID -19 pandemic lockdown on distribution of inorganic pollutants in selected cities of Nigeria	Lagos, Kaduna	NO ₂ , SO ₂ , O ₃
Anil and Alagha, 2020	Saudi Arabia	The impact of COVID-19 lockdown on the air quality of Eastern Province, Saudi Arabia	Eastern Province	PM ₁₀ , NO ₂ , SO ₂ , O ₃
Stratoulis et al., 2020	Thailand	Air quality development during the COVID-19 pandemic over a medium-sized urban area in Thailand	Hat Yai	NO ₂ , PM _{2.5} , PM ₁₀ , O ₃

Kebijakan lockdown di era pandemi COVID-19 mengurangi aktivitas industri, transportasi dan sosial. Kondisi ini mengakibatkan terjadinya perubahan konsentrasi PM_{2.5}, PM₁₀, NO₂, SO₂, CO, dan O₃ di beberapa kota selama periode lockdown. Data yang disajikan berupa penurunan konsentrasi pencemar di lima kota yang

mengalami perubahan signifikan untuk setiap pencemar selama periode lockdown. Persentase perubahan konsentrasi pencemar PM_{2,5}, PM₁₀, NO₂, SO₂, CO, dan O₃ disajikan pada Gambar 2.



Gambar 2. Persentase perubahan konsentrasi polutan. a) Penurunan konsentrasi PM_{2,5}, b) Penurunan konsentrasi PM₁₀, c) Penurunan konsentrasi NO₂, d) Penurunan konsentrasi SO₂, e) Penurunan konsentrasi CO, dan f) Peningkatan konsentrasi O₃ selama periode lockdown COVID-19

DISKUSI

COVID-19 adalah penyakit pernapasan akut yang dapat menyebabkan pneumonia dengan gejala seperti demam, batuk, dan dispnea⁽⁴⁹⁾ dan memiliki perkiraan tingkat kematian 2-3%⁽⁵⁰⁾. COVID-19 memiliki tingkat keagresifan yang lebih tinggi ketika udara tercemar. Paparan jangka panjang PM_{2,5} mengarah pada peningkatan tingkat kematian COVID-19, dengan besaran peningkatan yang 20 kali lebih besar⁽⁵¹⁾. Penelitian 120 kota di China menunjukkan bahwa terdapat hubungan yang signifikan antara polusi udara dan infeksi COVID-19⁽⁵²⁾.

Sars-CoV-2 menyebar dengan cepat pada manusia yang memiliki kontak dekat dengan orang yang sudah terinfeksi⁽⁵³⁾. Sebagian besar negara menerapkan pembatasan pada transportasi, perdagangan dan kegiatan budaya, sekolah dan universitas ditutup, dan jarak sosial diberlakukan⁽³⁰⁾. Efek lockdown cukup jelas dalam hal penurunan yang cukup besar pada tingkat pertumbuhan penyakit⁽⁵⁴⁾. Efeknya juga terlihat pada faktor lingkungan di seluruh dunia dalam hal penurunan kabut asap, peningkatan kualitas udara dan air. Akibat aktivitas antropogenik yang terbatas di sektor transportasi, industri dan domestik⁽⁵⁾.

Kegiatan antropogenik merupakan penyebab utama terjadinya pencemaran udara ambien, karena banyaknya emisi polutan berbahaya dalam konsentrasi tinggi yang merugikan kesehatan^(55,56). Penyebab utama pencemaran udara antara lain pembangunan ekonomi, urbanisasi, konsumsi energi, transportasi dan motorisasi, serta penambahan penduduk perkotaan yang pesat⁽⁵⁷⁾. Udara merupakan elemen penting untuk kelangsungan hidup semua makhluk hidup. Oleh karena itu, perlu dijaga kebersihan dan keamanannya.

PM_{2.5} merupakan partikel dengan diameter <2.5 µm yang berupa partikel hasil pembakaran, senyawa organik, dan logam⁽⁵⁸⁾. Gambar 2 (a) menunjukkan penurunan konsentrasi PM_{2.5} selama periode lockdown di lima kota, yaitu Megacity Delhi, Wuhan, New York City, California, dan Hat Yai. Persentase penurunan konsentrasi PM_{2.5} yang tinggi ditemukan di Megacity Delhi yaitu 39% selama fase lockdown. Ini meningkatkan kualitas udara sekitar 40% hingga 50%⁽³⁸⁾. Penerapan lockdown di Wuhan, konsentrasi PM_{2.5} mengalami penurunan sebesar 36,9% dan tetap menjadi pencemar utama⁽³⁶⁾. Penurunan konsentrasi PM_{2.5} dengan persentase 36% diamati di New York City setelah penguncian terjadi⁽³⁹⁾. Pengamatan yang dilakukan di California menunjukkan penurunan 31% konsentrasi PM_{2.5} selama lockdown (19 Maret - 7 Mei 2020)⁽⁴¹⁾. Konsentrasi PM_{2.5} juga menurun sebesar 21,8% di Hat Yai⁽⁸⁾. Penelitian lain juga melaporkan penurunan PM_{2.5} di Delta Sungai Yangtze⁽³⁴⁾, Chandigarh⁽³⁷⁾, Seoul⁽⁴⁶⁾ dan Baghdad⁽⁴²⁾.

PM₁₀ adalah partikel berdiameter <10 µm yang berupa debu, serbuk, dan kapang⁽⁵⁸⁾. Gambar 2 (b) menunjukkan bahwa konsentrasi PM₁₀ menurun selama periode lockdown di lima kota, yaitu Sale, Eastern Province, Megacity Delhi, Baghdad, dan Chandigarh. Pengurangan aktivitas kendaraan selama lockdown mengakibatkan penurunan 75% konsentrasi PM₁₀ tertinggi di Sale, Maroko⁽⁴⁴⁾. Provinsi Timur juga mengalami penurunan konsentrasi yang signifikan pada berbagai tingkat PM₁₀ (21-70%)⁽⁴⁸⁾. Kondisi ini juga terjadi pada fase lockdown di Megacity Delhi, konsentrasi PM₁₀ menurun sekitar 60%⁽³⁸⁾. Penguncian parsial yang diterapkan di Baghdad mengurangi konsentrasi PM₁₀ sebesar 56%⁽⁴²⁾. Konsentrasi PM₁₀ menurun sebesar 22,9% dalam 3 minggu pertama penutupan di Hat Yai, Thailand⁽⁸⁾. Penelitian lain juga melaporkan penurunan konsentrasi PM₁₀ selama periode lockdown, masing-masing 36,8%, 22,8% dan 2,4% di Chandigarh⁽³⁷⁾.

NO₂ adalah gas yang sangat reaktif yang dikenal sebagai nitrogen oksida (NOx). NO₂ terbentuk dari emisi kendaraan bermotor, pembangkit listrik, dan peralatan off-road⁽⁵⁹⁾. Gambar 2 (c) menunjukkan bahwa konsentrasi NO₂ telah menurun secara signifikan di lima kota, yaitu Sale, Eastern Province, Megacity Delhi, Madrid, dan Sao Paulo. Penurunan emisi karena berkurangnya aktivitas antropogenik, terutama di bidang transportasi dan industri selama lockdown COVID-19. Penurunan konsentrasi NO₂ sebesar 96% di Sale, Maroko⁽⁴⁴⁾. NO₂ sebagai penanda polutan yang merespon tindakan lockdown karena konsentrasinya mengalami penurunan, berkisar antara 12-86% di Provinsi Bagian Timur⁽⁴⁸⁾. Penurunan terjadi pada konsentrasi NO₂ sekitar 68% selama fase lockdown di Megacity Delhi, India⁽³⁸⁾. Konsentrasi NO₂ juga menurun di Madrid selama lockdown sebesar 62%⁽⁴⁵⁾. Penurunan konsentrasi NO₂ sebesar 54,3% diamati di daerah perkotaan selama penutupan sebagian⁽³²⁾. Penelitian lain juga melaporkan penurunan konsentrasi NO₂ di Wuhan⁽³⁶⁾, New York City⁽³⁹⁾, Yangtze River Delta⁽³⁴⁾, California⁽⁴¹⁾, Almaty⁽⁴³⁾, dan Hat Yai⁽⁸⁾. Adanya pembatasan kegiatan transportasi telah menurunkan konsentrasi NO₂.

SO₂ adalah indikator kelompok gas sulfur oksida (SO_x). Sumber SO₂ di atmosfer adalah hasil pembakaran bahan bakar fosil oleh pembangkit listrik dan fasilitas industri lainnya⁽⁶⁰⁾. Gambar 2 (d) menunjukkan penurunan konsentrasi SO₂ selama fase lockdown COVID-19 di lima kota, yaitu Port Harcourt City, Dhaka, Sale, Eastern Province, dan Yangtze River Delta. Penurunan konsentrasi SO₂ tertinggi terjadi di Port Harcourt City sebesar 215,5%⁽⁴⁷⁾. Di Dhaka, konsentrasi SO₂ menurun sekitar 67%⁽³⁰⁾. Hasil yang diperoleh di Sale menunjukkan bahwa konsentrasi SO₂ menurun sebesar 49%⁽⁴⁴⁾. Provinsi Timur juga mengalami penurunan konsentrasi yang signifikan pada tingkat variasi SO₂ antara 8,7 dan 30%⁽⁴⁸⁾. Konsentrasi SO₂ menurun 7,6% selama penguncian di Delta Sungai Yangtze⁽³⁴⁾.

CO merupakan gas yang tidak berwarna, tidak berbau, dan sangat berbahaya jika terhirup dalam jumlah banyak. Sumber CO berasal dari kendaraan bermotor yang menggunakan bahan bakar fosil, cerobong asap⁽⁶¹⁾. Gambar 2 (e) menunjukkan bahwa konsentrasi CO mengalami penurunan selama lockdown COVID-19 di lima kota, yaitu Sao Paulo, Eastern Province, Almaty, California, dan Megacity Delhi. Penurunan drastis konsentrasi CO sebesar 64,8% di daerah perkotaan selama penguncian parsial⁽³¹⁾. Selama periode lockdown, konsentrasi CO menurun 55% di Provinsi Timur⁽⁴⁸⁾. Konsentrasi CO telah menurun di Almaty dan California sebesar 49% (14,25), Sekitar 35% penurunan CO selama fase penguncian di Megacity Delhi⁽³⁸⁾. Penelitian lain juga melaporkan penurunan konsentrasi CO di Rio De Janeiro⁽⁵¹⁾, China Timur⁽³⁵⁾, dan Seoul⁽⁴⁶⁾.

O₃ atau ozon merupakan salah satu jenis polutan udara yang merupakan oksidator kuat dan berdampak negatif bagi kesehatan⁽⁶²⁾. Gambar 2 (f) menunjukkan bahwa O₃ tidak mengalami penurunan tetapi mengalami peningkatan konsentrasinya di lima kota yaitu Wuhan, Provinsi Bagian Timur, Sao Paulo, Almaty, dan Baghdad. Peningkatan konsentrasi O₃ tertinggi ditemukan di Baghdad sebesar 525%⁽⁴²⁾. Konsentrasi O₃ telah meningkat di Wuhan sebesar 116,6%⁽³⁶⁾. Provinsi Timur juga mengalami peningkatan konsentrasi yang signifikan pada berbagai tingkat O₃ sebesar 45%⁽⁴⁸⁾. Peningkatan sekitar 30% konsentrasi O₃ diamati di daerah perkotaan Sao Paulo, Brazil. Hal ini dipengaruhi oleh kondisi lalu lintas kendaraan, karena nitrogen monoksida mengalami penurunan⁽³²⁾. Konsentrasi O₃ meningkat sebesar 15% selama periode penguncian di Almaty⁽⁴³⁾.

Pembentukan O₃ dipengaruhi oleh reaksi fotokimia. Konsentrasi NO dan NO₂ menurun karena lockdown yang membatasi aktivitas kendaraan bermotor. Penurunan konsentrasi NO mengurangi proses titrasi O₃ yang biasanya menurunkan konsentrasi O₃ terutama di wilayah kota. Proses titrasi yang lebih rendah sekaligus meningkatkan konsentrasi O₃ di udara ambien⁽⁶³⁾.

KESIMPULAN

Kebijakan lockdown sebagai upaya mencegah penyebaran COVID-19. Pembatasan kegiatan industri, transportasi, pendidikan, dan rutinitas masyarakat ditutup selama pandemi COVID-19. Penurunan konsentrasi polutan terlihat jelas, karena pembatasan aktivitas antropogenik. Penurunan konsentrasi PM_{2.5}, PM₁₀, NO₂, SO₂, CO terjadi di Megacity Delhi, Wuhan, New York City, California, Hat Yai, Sale, Eastern Province, Baghdad, Chandigarh, Madrid, Sao Paulo, Port Harcourt City, Dhaka, Sungai Delta Yangtze dan Almaty. Berkurangnya konsentrasi pencemar sebagian besar disebabkan oleh berkurangnya jumlah kendaraan bermotor dan berkurangnya kegiatan industri. Konsentrasi NO₂ yang rendah yang biasanya disebabkan oleh konsentrasi NO yang lebih rendah seperti yang ditunjukkan di beberapa kota seperti Wuhan, Provinsi Timur, Sao Paulo, Almaty, dan Baghdad menurunkan proses titrasi O₃ dan pada saat yang sama meningkatkan konsentrasi di udara ambien. Kebijakan lockdown menjadi opsi terbaik dalam menekan penyebaran COVID-19. Selain itu, perilaku memakai masker, mencuci tangan, dan menjaga jarak perlu diterapkan.

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