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Measuring The Spatio-Temporal Distribution of Sulfur Dioxide (SO2) with Copernicus Sentinel-5P Near Real Time in Medan City

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ABSTRACT
This study aims to monitor the impact of sulfur dioxide (SO2), a significant contributor to atmospheric corrosion and associated with air pollution, in urban and industrial areas through empirical models of spatial distribution and temporal estimation in Medan. Datasets of Sentinel 5P NRTI are worth using to monitor the formation of sulfate aerosols or SO2 emissions from natural sources and anthropogenic origin in near real-time from 2019 until 2023 on the local scale, Medan. The source dataset covers 1,11 km of spatial image resolution on orbital in daily revisit time with a spectral bound between the ultraviolet and the shortwave infrared. The measurement of atmospheric SO2 concentrations is generated by enumerating the SO2 vertical column density technique at the soil surface with the cloud-based platform The Earth Engine (EE) Code Editor to handle large data sizes and produce interactive mapping. Based on the availability of auxiliary results, the number of spreading SO2 concentrations fell from 0,92 mmol/m2 in 2019 to 0,41 mmol/m2 in 2023, a reduction of 49.98 percent. The average of SO2 concentrations has decreased substantially over the years. Consequently, these pollutants have recorded long-term health and meteorological parameters impact that substances can rise or reduce acid rain.

INTRODUCTION

Over the last few years, increases in air impurities have been treated by natural or human- made sources of pollution. The atmosphere's sulfur dioxide (SO2) is a fugacious residual gas produced from anthropogenic (environmental change originating in human activity) and natural substances. Anthropogenic sources of primary SO2 include industrial and combustion processes. The nature of industrial particles depends on the process, but combustion particles are generally dominated by black carbon or heavy organic elements and materials such as polycyclic aromatic hydrocarbons (Ridwana et al., 2023). High concentrations of atmospheric sulfur dioxide at the surface can increase awareness of human physical conditions and the environment concrete hazardous. When SO2 oxidizes, it can affect direct radiative forcing on climate and indirectly affect the hydrologic cycle in local or global coverage (Zhang et al., 2023).

Currently, Air pollution has been a significant environmental carcinogen for all residents in recent decades. Increased pollution airing out affects human able-bodied outcomes directly and indirectly. Air quality alert is generally calculated depending on the weight of Sulfur Dioxide (SO2), Nitrogen Dioxide (NO2), Carbon Monoxide (CO), particulate matter (PM2.5 and PM10), and Ozone (O3). As a consequence, climate impact, visibility, biogeochemical cycling, atmospheric reactivity, and carcinogens are hit by exposure to SO2 (Shikwambana et al., 2020).

Traditionally, the government considered various measures, including plying odd and even-numbered industries until pioneering green industrial manufactures (David et al., 2022). Consequently, growth industrial pays more limitation of ground-based measurements impacts in the long-term. This study aims to measure SO2 emission significantly changing in 5 years, 2019 to 2023, over Medan city, generated by characteristics of SO2 imagery from the Ozone Monitoring Instrument (OMI) instrument. Due to recent technological advances, satellite SO2 provides the measurement and acquisition of emissions used in sophisticated technology processing. Remote sensing technology supports satellite tracking of SO2 concentrations in the atmosphere or without field observing (In Situ). Accordingly, the field of satellite data has widely applied this technology. A fair reason was also found between the sustained emission rates, which perfectly fit for more substantial and continuous issues.

Air global sustainability at an urban scale concern faced by air pollutant components (SO2 emission) in the troposphere layers of the Earth. Medan City, an urban area in North Sumatra Province, is one of Indonesia's metropolis cities, with more than 15.115.206 people in 2019 and a recent increase of 179.058 (Statistics Indonesia of Berau, 2023). With population growth, population explosion is responsible for the natural increase in industrialization (Supriyatin et al., 2020). The manufacturing sector attracts many industry opportunities in Indonesia. Medan City's role as an engine of economic growth intricates the relationship that exists between manufacturing and industrial companies. According to the 2023 BMKG AQI, the Medan air pollution range has consistently been harmful, with range levels rising 150,4 μgr/m3 for several days (Meteorological, Climatological, and Geophysical Agency, 2023). This condition is far from the established standard pollution level value of over 100 and is considered unhealthy and hazardous for human health.

In this context, SO2 concentrations are extracted and calculated using algorithmic and simplified analytical approaches from long-term Sentinel-5P of 0.34 microns and 0.380 microns wavelengths. Projection of high-temporal-resolution imagery plays a more critical role in determining the changes in light interacting with air pollutants in the atmosphere from 2019 to 2023. Ialongo et al. (2018) detected satellite-based sulfur dioxide emission to support the cleantech sector to reduction from copper smelters (Ialongo et al., 2018). Similar studies by Salgueiro et al. (2023) and Esse et al. (2022) evaluate and compare satellite observations and ground-based SO2 emissions rates based on volcanic plume eruption (Esse et al., 2023; Salgueiro et al., 2023). On the other hand, the manufacturing and industrial sectors are also primary emission sources of SO2. Schmidt et al. (2022) showed a positive correlation between the number of employees in the metal industry and local SO2 concentrations (Schmidt et al., 2022). In Indonesia, the anomaly of air pollutants (NO2) from Sentinel 5 integrated during COVID-19 and aerosol estimation indicate that the seasonal and location-specific would exacerbate serious problems over Medan (Faisal & Jaelani, 2023; Tampubolon et al., 2023). Nonetheless, most studies have estimated air pollutants spatiotemporally from a larger coverage area. Therefore, the main objective of our study was to estimate SO2 density and investigate long-term changes of SO2 using Sentinel 5 datasets, particularly in metropolises in Medan City, and their phenomenon during heat waves during the summer season.

RESEARCH METHODS

The study area is located in Medan city. It belongs to the North Sumatra in Sumatra Island of Indonesia archipelago. It has 265, 10 km2 and cover 21 districs and 151 subdistric on geographical coordinate 3°27' to 3°47' North and 98°35' to 98°44' East on 2.5 to 37.5 meters above sea level. For the past century, Medan City has been most diversity city in Indonesia with more than 2,4 millions people, and it continues grew by 1,54 percent annually and as well as the third largest city of population after its competitors Jakarta and Surabaya. This clearly indicates Medan city is impressively increase its population in transmitting industries, economics and evironmental factors changing quickly (Statistics Indonesia of Berau, 2023).

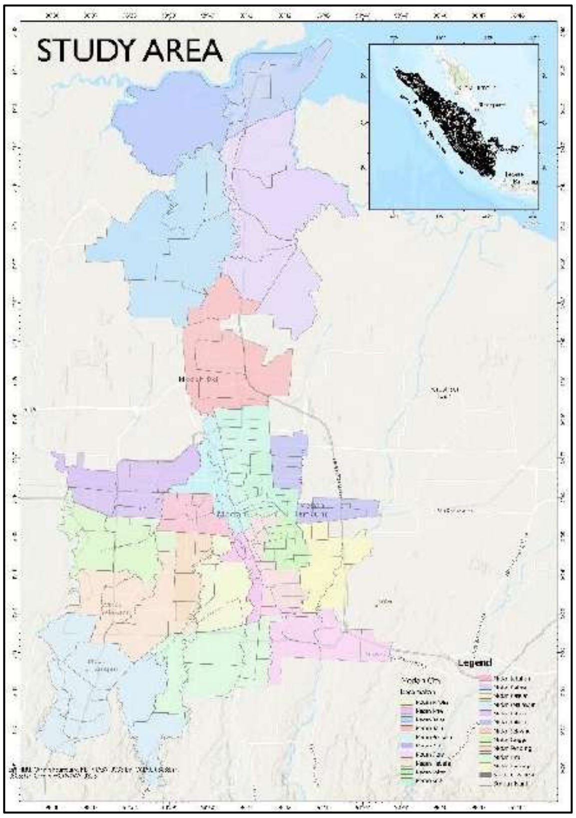

Figure 1. Medan administrative map (Source: Statistics Indonesia of Berau, 2023).

This study focuses on the spatio-temporal measurement of SO2 emission by the TROPOMI instrument onboard ESA's Sentinel-5P satellite (S5P). Sulfur dioxide (SO2) is a monatomic gas with a strong and sharp smell that transforms into liquid under pressure and is very soluble in water. The molecular compound of SO2 is represented in Figure 2. Sulfur dioxide in the air mostly comes from burning coal and oil in power plants or smelting copper. Naturally, sulfur dioxide can be released through volcanic ash. With Google Earth Engine (GEE) algorithmic and simplified analytical development, SO2 emission datasets have been extracted from 0.34 and 0.380 bands of Sentinel-5P (Mejía C. et al., 2023). Sentinel 5P SO2 characteristics has been available since 2018 by the European Space Agency (ESA), continuously monitoring air contaminants (Shaygan & Mokarram, 2023). Sentinel5P products have two variations on temporal resolution in near real-time (NRT) and offline versions, where the NRT dataset has larger spatial resolution coverage and less revisit time resolution (Han et al., 2022). Data were available at GEE cloud assets with 1113.2 meters of spatial resolution with bin spatial operation, and the data were upgraded to level 3 to allow the data to process statistical algorithms in the cloud platform (Matondang, 2022).

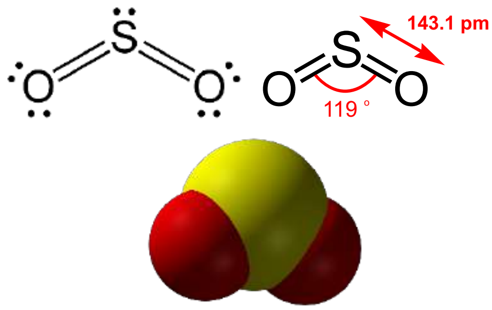

Figure 2. Mollecular compounds of SO2 structure and conformer (Source: National Library of Medicine, 2019).

The original product is ingested as two GEE assets on suffixes first ver and upgrade. When QA values are less than 80 percent for AER AI, 75 percent for NO2 band count density, and 50 percent for the entire data, spatial filtering removes pixels. The characteristics of SO2 index Sentinel 5P NRTI can be seen in Table 1.

This study collects datasets from Sentinel-5P NRTI SO2: Near Real-Time Sulfur Dioxide, extracts the dataset from hdf to bin data, processes data using Google Earth Engine, and analyzes the trend in time series. Building and developing datasets on GEE can define SO2 emissions based on their number density in the column dataset (Gonzalez Abad et al., 2019; Kumari et al., 2022). Acquisition and presenting data SO2 emission from Sentinel 5P in line can be seen on this code below.

```
Harpconve
rt --format hdf5 --hdf5-compression 9
var collection = ee.ImageCollection('COPERNICUS/S5P/NRTI/L3_SO2')
.select('SO2_column_number_density')
.filterDate('2023-06-01', '2023-06-30');
var band_viz = { min: 0.0,
max: 0.0005,
palette: ['black', 'blue', 'purple', 'cyan', 'green', 'yellow', 'red']
};

Map.addLayer(collection.mean(), band_viz, 'S5P SO2'); Map.setCenter(0.0, 0.0, 0);
SO2_column_number_density,                           SO2_column_number_density_amf,
SO2_slant_column_number_density, cloud_fraction,

sensor_altitude, sensor_azimuth_angle, sensor_zenith_angle, solar_azimuth_angle,
solar_zenith_angle;
S5P_NRTI_L2 SO2_output.h5
```

Figure 3. Compilation code of SO2 emission from Sentinel 5P NRTI

Tabel 1. The characteristics of SO2 index Sentinel 5P NRTI

No	Name	Function	Scale	Units
1	SO_2 column number density	Estimated SO2 on vertical layer at ground level applied DOAS technique	-48* - 0.24*	mol/m²
2	SO_2 column number density air mass factor	Improve the accuracy of the retrieval by intensity-weighted cloud fraction	0.1* - 3.397*	mol/m²
3	SO_2 slant column number density	Optimized for each trace gas separately	-0.147* - 0.162*	mol/m²
4	SO_2 column number density 15 km	Present the best SO2 profile estimate according to the newest emissions inventories, atmospheric transport, photochemistry, and seasonal elimination		mol/m²
5	Cloud fraction	Effective cloud fraction	0* - 1*	Fraction

(Source: Copernicus EU, 2023)

RESULTS AND DISCUSSION

Overall, emission of pollutants in metropolitan cities finds the largest sources of SO2 emission from the summer season 2019 to 2023 in 21 districts of Medan city (Figure 4). Sulfur dioxide (SO2), produced in natural or anthropogenic mechanisms, is decided as a pollutant point of reference by the Indonesian Air Pollutant Index (ISPU or API) owing to its adverse effects on public health and the environment (Commane & Schiferl, 2022; Liu et al., 2023).

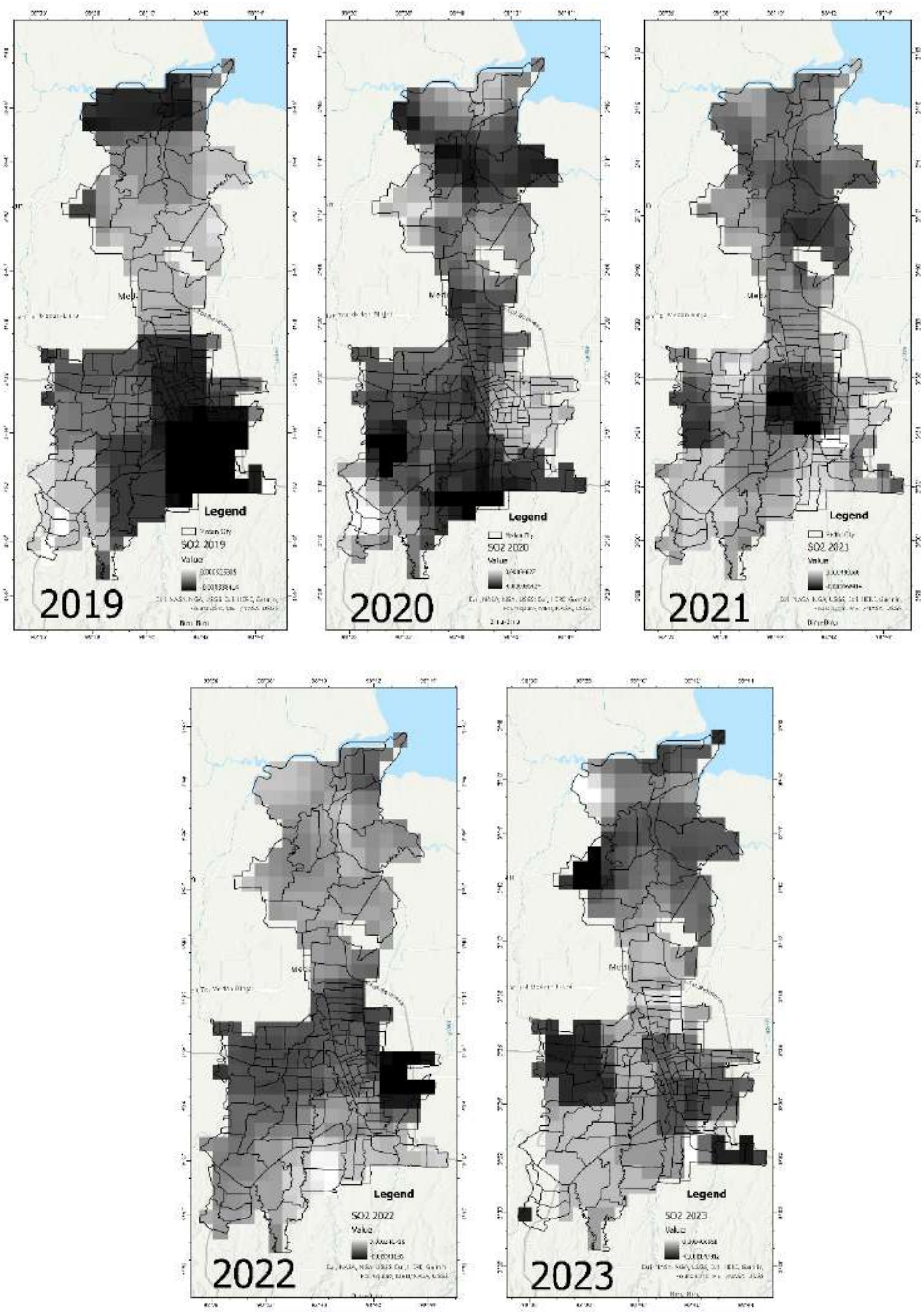

Figure 4. Local spatial distribution of SO2 from summer season 2019 to 2023 over Medan city (Source: Research Results, 2023).

Monitoring SO2 concentrations is essential to track air quality, collect information continuously, and provide a consistent long-term database. Spatial interpolation and interpretation of SO2 observation over Medan are calculated by SO2 column from NIR and IR Sentinel 5P in near real-time. A comprehensive statistical value of SO2 is shown in Table 2, including information about the distribution of a particular statistic over five years in Medan City (Filippini et al., 2020).

From 21 districts over Medan City, Medan Belawan has the prominent role of the highest SO2 values from 2019 until 2023. This district is more dependent on exchanges, the largest industrial area in Indonesia (Huyen et al., 2022). Therefore, this results in many emission distributions confirmed in this area (Martín et al., 2023). The decrease in SO2 emission in recent years, with Medan emission falling by 56 percent between 2019 and 2023, was mainly due to the closure of coal-fired power industries to biomass fuel (Figure 5). Annual emissions of SO2 from the summer season 2019 to 2023 in Medan city decreased. However, it still refers to the predominantly produced SO2 from the combustion in manufacturing and industrial facilities. Levels and trends in emission from specific sources indeed contribute to future research in advanced statistical analysis (Kaloni et al., 2022).

Table 2. Descriptive statistics of SO_2 from summer season 2019 to 2023 over Medan city

*mmol/m²	Year				
	2019	2020	2021	2022	2023
min	-0.338	-0.395	-0.168	-0.401	-0.147
max	0.925	0.366	0.498	0.341	0.406
mean	0.15	-0.07	0.21	0.01	0.01
StdDev	0.31	0.16	0.12	0.13	0.1

(Source: Research Results, 2023)

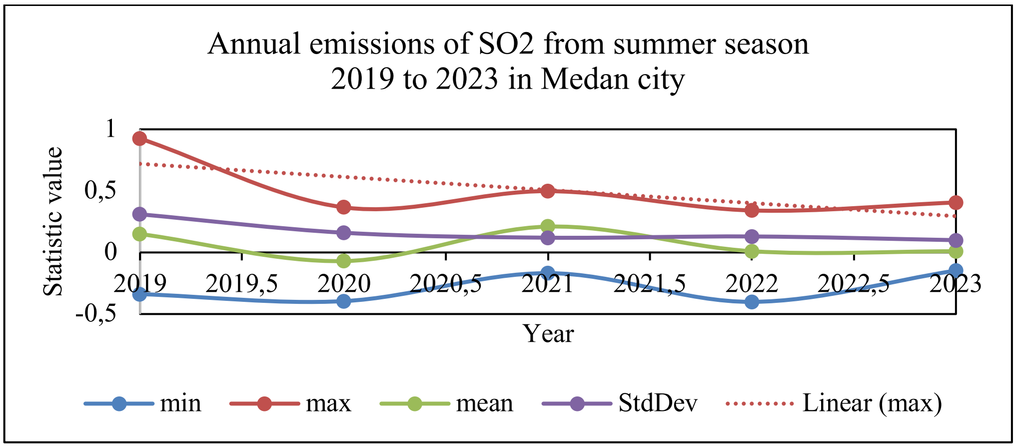

Figure 5. Annual emissions of SO2 from summer season 2019 to 2023 in Medan city (Source: Research Results, 2023).

According to the changing variable, SO2 concentrate shows a partial start from a negative to a positive value. Positive change is simultaneously centered in Medan City, with more than ten districts (Cao et al., 2023). The area of SO2 emission must fall under the surrounding of Medan city that shows adverse value (Figure 6). The relative differences of SO2 emission from 2019 until 2023, Δ SO2, (a) spatial distribution on compute change method difference in mas of cell size type and intersection of as extent type (b) total number of pixels (per mol of Δ SO2 values) throughout the time series. Interpreting SO2 characteristics in spectral, spatial, and temporal moves to identify the transmission structure of the spreading air pollution as chemical compounds such as SO2, PM2.5, PM10, NO2, and Aerosol Index (Domingo & Rovira, 2020; Tampubolon et al., 2023).

SO2 relativity changes found that higher exposure to concentrate in significant associations between overrun manufacturing sites and greenery zones clearly identifiable on the SO2 emission spreading map. Heavy industrial areas stand out as the degrading environment and severely polluted contributors. Furthermore, aggravated damages surprisingly occur on very few precipitation days in risky heatwaves in the summer (from December to March) annually. Hence, the existence of open space and sustainability in the urban areas is vital (Fahreza et al., 2022).

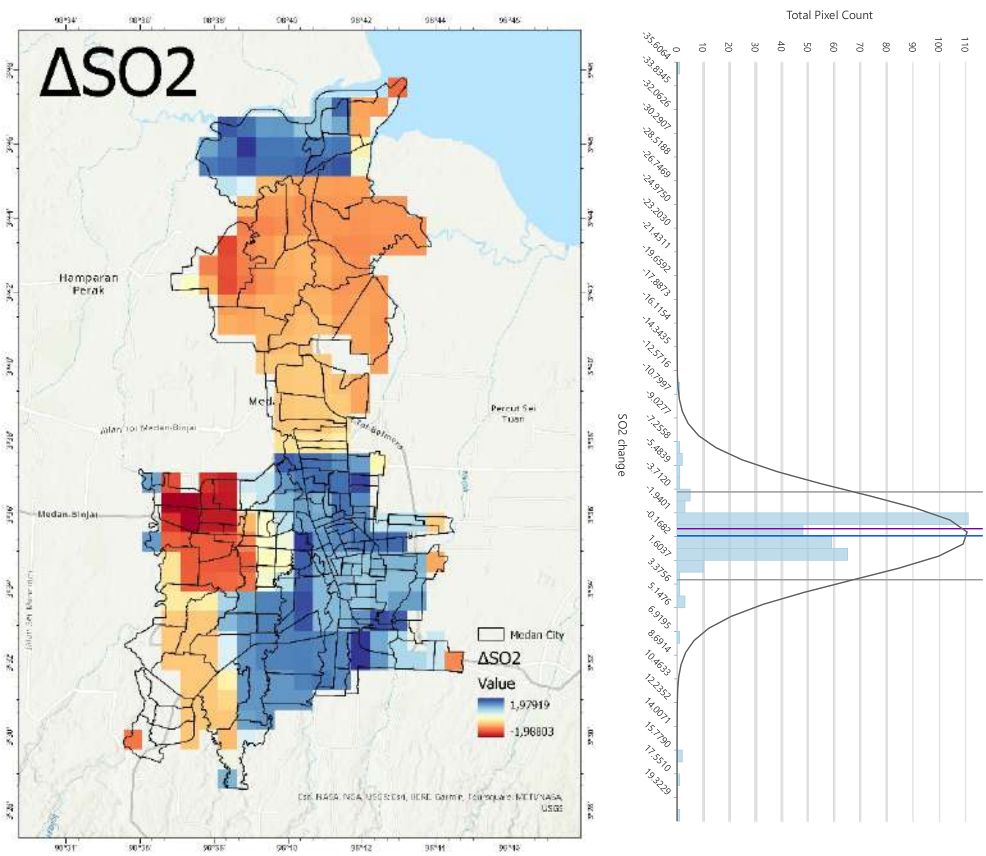

Figure 6. The relative differences of SO2 emission since 2019 until 2023, ΔSO2, (a) spatial distribution on compute change methode difference in mas of cellsize type and intersection of as extent type (b) total number of pixels (per mol of ΔSO2 values) throughout the time series (Source: Research Results, 2023).

CONCLUSION

The number of spreading SO2 concentrations fell from 0,92 mmol/m2 in 2019 to 0,41 mmol/m2 in 2023, a reduction of 49.98 per cent. The average of SO2 concentrations has decreased substantially over the years. Medan City emissions fell by 56 per cent between 2019 and 2023. Medan Belawan district, the centre of the manufacturing industry are in Medan City, has the prominent role of the highest SO2 values from 2019 until 2023. Medan's manufacturing industry significantly contributes to global air pollution, with industrial emissions emitting hazardous waste fumes that pose severe risks to human health and the environment. Besides, aggravated damages surprisingly occur on very few precipitation days in risky heatwaves in the summer (from December to March) annually. Consequently, these pollutants have recorded long-term health and meteorological parameters impact that substances can also rise or reduce acid rain. Interpreting SO2 characteristics in spectral, spatial, and temporal moves to identify the transmission structure of the spreading air pollution and monitoring the emission concentrate. Therefore, the existence of open space and sustainability in the urban areas is vital

REFERENCE LIST

Cao, D., Sun, Y., Chai, J., Xue, J. J., & Sun, Q. (2023). An assessment of China's joint prevention and control policy on sulfur dioxide emissions reduction: A spatial econometric analysis. Journal of Management Science and Engineering, 8(4), 498–511. https://doi.org/10.1016/j.jmse.2023.03.003

Commane, R., & Schiferl, L. D. (2022). Climate mitigation policies for cities must consider air quality impacts. Chem, 8(4), 910–923. https://doi.org/10.1016/j.chempr.2022.02.006

David, J. C., Rauf, A., & Harahap, H. (2022). Gap Analysis in Deli Watershed Management Measured By Stakeholders' Social Factors Deli North Sumatera. Jurnal Geografi, 14(1), 1. https://doi.org/10.24114/jg.v14i1.24851

Domingo, J. L., & Rovira, J. (2020). Effects of air pollutants on the transmission and severity of respiratory viral infections. Environmental Research, 187(May), 109650. https://doi.org/10.1016/j.envres.2020.109650

Esse, B., Burton, M., Hayer, C., Pfeffer, M. A., Barsotti, S., Theys, N., Barnie, T., & Titos, M. (2023). Satellite derived SO2 emissions from the relatively low-intensity, effusive 2021 eruption of Fagradalsfjall, Iceland. Earth and Planetary Science Letters, 619, 118325. https://doi.org/10.1016/j.epsl.2023.118325

Fahreza, W., Slamet, B., & Delvian, D. (2022). Analysis of the Need for Green Open Space Based on Oxygen Requirement in Medan City. Jurnal Geografi, 14(2). https://doi.org/10.24114/jg.v14i2.33363

Faisal, M., & Jaelani, L. M. (2023). Spatio-temporal analysis of nitrogen dioxide (NO2) from Sentinel-5P imageries using Google Earth Engine changes during the COVID-19 social restriction policy in jakarta. Natural Hazards Research, 3(2), 344–352. https://doi.org/10.1016/j.nhres.2023.02.006

Filippini, T., Rothman, K. J., Goffi, A., Ferrari, F., Maffeis, G., Orsini, N., & Vinceti, M. (2020). Satellite-detected tropospheric nitrogen dioxide and spread of SARS-CoV-2 infection in Northern Italy. Science of the Total Environment, 739. https://doi.org/10.1016/j.scitotenv.2020.140278

Gonzalez Abad, G., Souri, A. H., Bak, J., Chance, K., Flynn, L. E., Krotkov, N. A., Lamsal, L., Li, C., Liu, X., Miller, C. C., Nowlan, C. R., Suleiman, R., & Wang, H. (2019). Five decades observing Earth's atmospheric trace gases using ultraviolet and visible backscatter solar radiation from space. Journal of Quantitative Spectroscopy and Radiative Transfer, 238, 106478. https://doi.org/10.1016/j.jqsrt.2019.04.030

Han, Y., Zhao, W., & Pereira, P. (2022). Global COVID-19 pandemic trends and their relationship with meteorological variables, air pollutants and socioeconomic aspects. Environmental Research, 204(PC), 112249. https://doi.org/10.1016/j.envres.2021.112249

Huyen, T. T., Oanh, N. T. K., Huy, L. N., Winijkul, E., & Chi, N. N. H. (2022). Impact of lowering fuel sulfur content on atmospheric emissions from shipping activities in a World Heritage Bay in Vietnam. Environmental Technology and Innovation, 27, 102507. https://doi.org/10.1016/j.eti.2022.102507

Ialongo, I., Fioletov, V., McLinden, C., Jåfs, M., Krotkov, N., Li, C., & Tamminen, J. (2018). Application of satellite-based sulfur dioxide observations to support the cleantech sector: Detecting emission reduction from copper smelters. Environmental Technology and Innovation, 12, 172–179. https://doi.org/10.1016/j.eti.2018.08.006

Kaloni, D., Lee, Y. H., & Dev, S. (2022). Air quality in the New Delhi metropolis under COVID-19 lockdown. Systems and Soft Computing, 4(February), 200035. https://doi.org/10.1016/j.sasc.2022.200035

Kumari, S., Yadav, A. C., Saharia, M., & Dev, S. (2022). Spatio-temporal analysis of air quality and its relationship with COVID-19 lockdown over Dublin. Remote Sensing Applications: Society and Environment, 28(July), 100835. https://doi.org/10.1016/j.rsase.2022.100835

Liu, W., Cai, M., Long, Z., Tong, X., Li, Y., Wang, L., Zhou, M., Wei, J., Lin, H., & Yin, P. (2023). Association between ambient sulfur dioxide pollution and asthma mortality: Evidence from a nationwide analysis in China. Ecotoxicology and Environmental Safety, 249(November 2022), 114442. https://doi.org/10.1016/j.ecoenv.2022.114442

Martín, C., Amigo, J. M., & Castro, K. (2023). Environmental science through orbiters. An example of Sentinel-5P on how the Covid-19 pandemic impacted the air quality. Chemometrics and Intelligent Laboratory Systems, 240(July), 0–7. https://doi.org/10.1016/j.chemolab.2023.104927

Matondang, M. A. (2022). Analysis of Spatial Management in Regional Development Planning (Case Study: Medan City). Jurnal Geografi, 14(2), 237. https://doi.org/10.24114/jg.v14i2.36643

Mejía C., D., Alvarez, H., Zalakeviciute, R., Macancela, D., Sanchez, C., & Bonilla, S. (2023). Sentinel satellite data monitoring of air pollutants with interpolation methods in Guayaquil, Ecuador. Remote Sensing Applications: Society and Environment, 31, 100990. https://doi.org/10.1016/j.rsase.2023.100990

Ridwana, R., Himayah, S., Fiqri, M., Rabbi, A., Maulana, I., Lugina, A., Al Kautsar, A., & Sakti, A. D. (2023). Monitoring Aerosol Optical Depth for Air Quality Through Himawari-8 in Urban Area West Java Province Indonesia. 15(2), 182–194. https://jurnal.unimed.ac.id/2012/index.php/geo/article/view/36866https://doi.org/10.24114/

Salgueiro, V., Guerrero-Rascado, J. L., Costa, M. J., Román, R., Cazorla, A., Serrano, A., Molero, F., Sicard, M., Córdoba-Jabonero, C., Bortoli, D., Comerón, A., Couto, F. T., López-Cayuela, M., Pérez-Ramírez, D., Potes, M., Muñiz-Rosado, J. A., Obregón, M. A., Barragán, R., Oliveira, D. C. F. S., … Alados-Arboledas, L. (2023). Characterization of Tajogaite volcanic plumes detected over the Iberian Peninsula from a set of satellite and ground-based remote sensing instrumentation. Remote Sensing of Environment, 295(June). https://doi.org/10.1016/j.rse.2023.113684

Schmidt, S., Kinne, J., Lautenbach, S., Blaschke, T., Lenz, D., & Resch, B. (2022). Greenwashing in the US metal industry? A novel approach combining SO2 concentrations from satellite data, a plant-level firm database and web text mining. Science of the Total Environment, 835(March), 155512. https://doi.org/10.1016/j.scitotenv.2022.155512

Shaygan, M., & Mokarram, M. (2023). Investigating patterns of air pollution in metropolises using remote sensing and neural networks during the COVID-19 pandemic. Advances in Space Research, 72(8), 3065–3081. https://doi.org/10.1016/j.asr.2023.06.027

Shikwambana, L., Mhangara, P., & Mbatha, N. (2020). Trend analysis and first time observations of sulphur dioxide and nitrogen dioxide in South Africa using TROPOMI/Sentinel-5 P data. International Journal of Applied Earth Observation and Geoinformation, 91(April), 102130. https://doi.org/10.1016/j.jag.2020.102130

Tampubolon, T., Yanti, J., & Tampubolon, F. R. (2023). Estimating Spatiotemporal Aerosol Index between MODIS and Sentinel 5 in Medan City. Journal of Physics: Conference Series, 2672(1). https://doi.org/10.1088/1742-

6596/2672/1/012007

Zhang, Z., Song, Y., Luo, P., Wu, P., Liu, X., & Wang, M. (2023). Elucidation of spatial disparities of factors that affect air pollutant concentrations in industrial regions at a continental level. International Journal of Applied Earth Observation and Geoinformation, 117(January), 103221. https://doi.org/10.1016/j.jag.2023.103221