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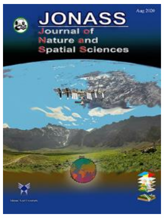

Case Study

Air quality and its impact on climate change in major urban areas across Cairo and Moscow cities

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ABSTRACT

Background and objective: Air pollution and its negative effects on human health have become a major issue around the world, especially in developing countries. Air pollutants such as nitrogen dioxide, sulfur dioxide, carbon monoxide, and aerosols, in addition, they have consequences on health, cause damage to vegetation and contribute to global climate change. Therefore, it is necessary to comprehensively monitor air pollutants and make appropriate management decisions to solve this issue. Remote sensing methods, especially Sentinel-5, the latest European Space Agency project (in cooperation with the Netherlands), which enables the recording of images in different spectral bands using the TROPOspheric Monitoring Instrument (TROPOMI) sensor, are recognized as a useful tool. A tool for monitoring all kinds of air pollutants

Materials and methods: In this study, the most significant air contaminants such as nitrogen dioxide, sulphur dioxide, carbon monoxide, and aerosol were monitored using Sentinel-5 satellite images for Cairo and Moscow cities in 2022. A large number of level 3 images, collected from Google Earth Engine, were used in this research.

Results and conclusion: The results show that due to urban development, an increase in vehicles, and increasing industrial growth, air quality in both cities is in poor condition. The decline in air quality has had a direct impact on climate change in these cities. The most important meteorological effect of climate change is on temperature. According to the results, although Moscow is located in a region with a favorable climate, high LST and rising ground temperatures in recent years can be associated with increased concentrations of air pollutants. In Cairo, the air pollution index was also at an inappropriate level, and the amount of particulate matter in this city is significantly higher than in Moscow, which can be due to the deserts around the city.

1. Introduction

Climate change, air pollution, and health risks are very important concerned areas of research worldwide. The emission of anthropogenic greenhouse gases causes a sharp rise in global temperatures

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and facilitates rising storms, droughts, floods, rising sea levels, and other adverse weather events (Watts et al., 2021). Climate change affects air quality by disturbing ventilation rates (wind speed, mixing depth, convection, front passages), dry precipitation, chemical production and loss rates, natural emissions, and background concentrations. The importance of this effect can be understood by analyzing the experienced annual fluctuations of air quality (Jacob & Winner, 2009; Vautard & Hauglustaine, 2007).

One of the main causes of air pollution is high greenhouse gases and unfavorable weather (Jacob & Winner, 2009). Also, human emissions of air pollutants, which are a direct concern for health, are associated with the simultaneous release of pollutants that have significant effects on the global climate (such as carbon dioxide, black carbon, sulfur dioxide, etc.) (Kinney, 2008). The most significant air pollutants include sulfur dioxide (SO2), carbon dioxide (CO2), carbon monoxide (CO), nitrogen dioxides (NO2), ozone (O3), methane (CH4), unstable organic carbon, chlorofluorocarbons, and suspended particles or aerosols, among which, SO2 is considered as one of the most toxic gases (Ghannadi et al., 2021).

Public health scientists have observed the impact of climate change on various health outcomes, including airborne, waterborne, and vector-borne diseases (Ravindra et al., 2019). It is predicted that the multifaceted health effects associated with climate change will increase the global mortality rate, curb economic development efforts, and lead to huge financial losses worldwide. In addition, pollutants behind the climate crisis have been shown to increase the incidence of chronic health diseases among those at risk and create populations that are even more vulnerable to the adverse health consequences of climate change (Michelson, 2022; Watts et al., 2021).

Air quality managers seek to protect public health by controlling emissions. Improvements in air quality may be offset by changes in climate statistics, for example, climate changes (Jacob & Winner, 2009). Policymakers in higher-income countries have shown increasing interest in air pollution levels and have subsequently implemented stricter air quality standards to improve ambient air quality (Ravindra et al., 2019). In response, air quality policies have been implemented around the world. The European Union has developed a broad set of rules that establishes health standards for several air pollutants (Fuentes et al., 2020).

Identifying climatic environmental issues and regional topography is often complicated by changing land development and human practices. Therefore, it is necessary to evaluate the relationship between land use patterns, topography, exposure to climate change, and human stimuli. The Google Earth Engine (GEE) is a multi-petabyte catalog of satellite imagery databases with planetary-scale analysis capable of studying climate, vegetation, soil, water, and many environmental factors, and mapping and quantifying changes trends, and trends differences (Jamali et al., 2022). The main objective of the S-5P mission is to make atmospheric measurements of air quality, atmospheric pressure, ozone, and UV radiation. S-5P bridges the gap in the continuity of observations between its ESA predecessors (GOME and SCIAMACHY) and the forthcoming Sentinel-5 and Sentinel-4 missions, planned to be launched in 2023(Tack et al., 2021).

According to the above-mentioned matters and the importance of the effects of air pollution on human health, damage to vegetation, and contributionto climate change, so a comprehensive integrated assessment of both air quality and climate change is critical to avoid potential trade-offs. This paper reports on consolidated ground-based validation results of the atmospheric NO2, SO2, and CO data produced operationally over the cities of Cairo and Moscow in April 2022 by the TROPOspheric Monitoring Instrument (TROPOMI) on board the ESA/EU Copernicus Sentinel-5 Precursor (S5P) satellite. Also, this study reported decadal trends and acceleration patterns of surface temperatures and vegetation conditions in Cairo and Moscow during April 2022.

2. Methodology

2.1. Study area

The study areas are Cairo the capital of Egypt and the largest city in the Arab world and Moscow, the capital and largest city of Russia. The Greater Cairo metropolitan area, with a population of 21.3 million, is the largest urban agglomeration in Africa, the largest in the Arab world and the Middle East, and the sixth-largest in the world by population Cairo is associated with ancient Egypt, as the pyramid complex of Giza and the ancient cities of Memphis and Heliopolis is located in its geographical area. It is located in the northeastern part of Egypt near the Nile Delta, the Nile River flows through it, and the Mediterranean Sea is 165 km north of it.

Moscow city is located on the Moskva River in central Russia and has a population of approximately 12.4 million within the city limits, over 17 million in the metropolitan area, and over 20 million in the metropolitan area. The area of the city is 2,511 square kilometers (970 sq mi), while the metropolitan area is 5,891 square kilometers (2,275 sq mi) and the metropolitan area is over 26,000 square kilometers (10,000 sq mi). Moscow is one of the largest cities in the world. It is the most populous city in Europe, the largest urban and metropolitan area in Europe, and the largest city in terms of land area in continental Europe. The location of Cairo and Moscow is shown in Fig. 1

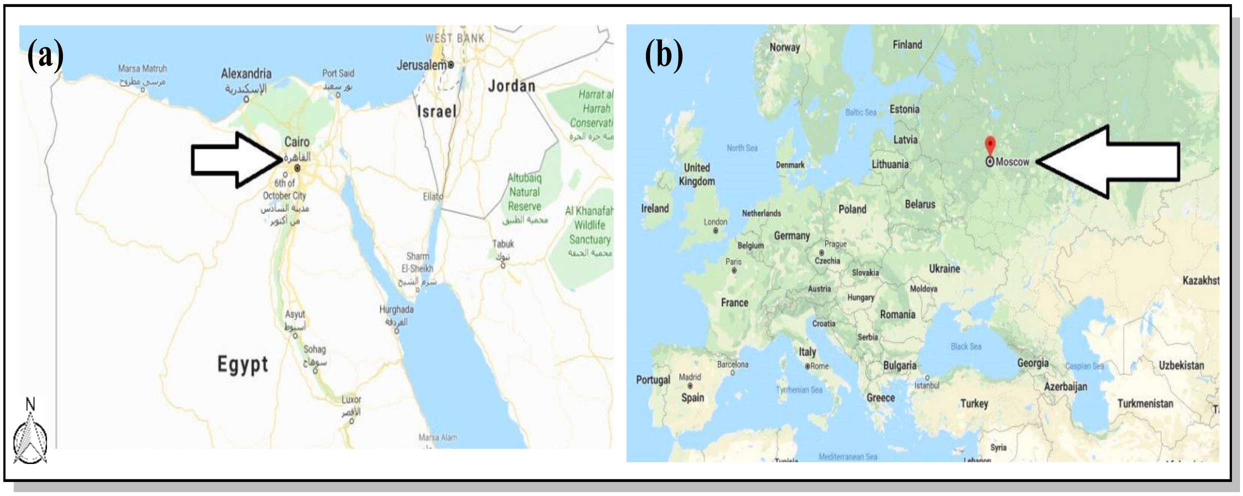


Fig. 1- Location of (a) Cairo, Egyptians and (b) Moscow, Russia

2.2. Data and methods

Data and methods used in this study, which includes data collection and tools used in the study (Fig. 2).

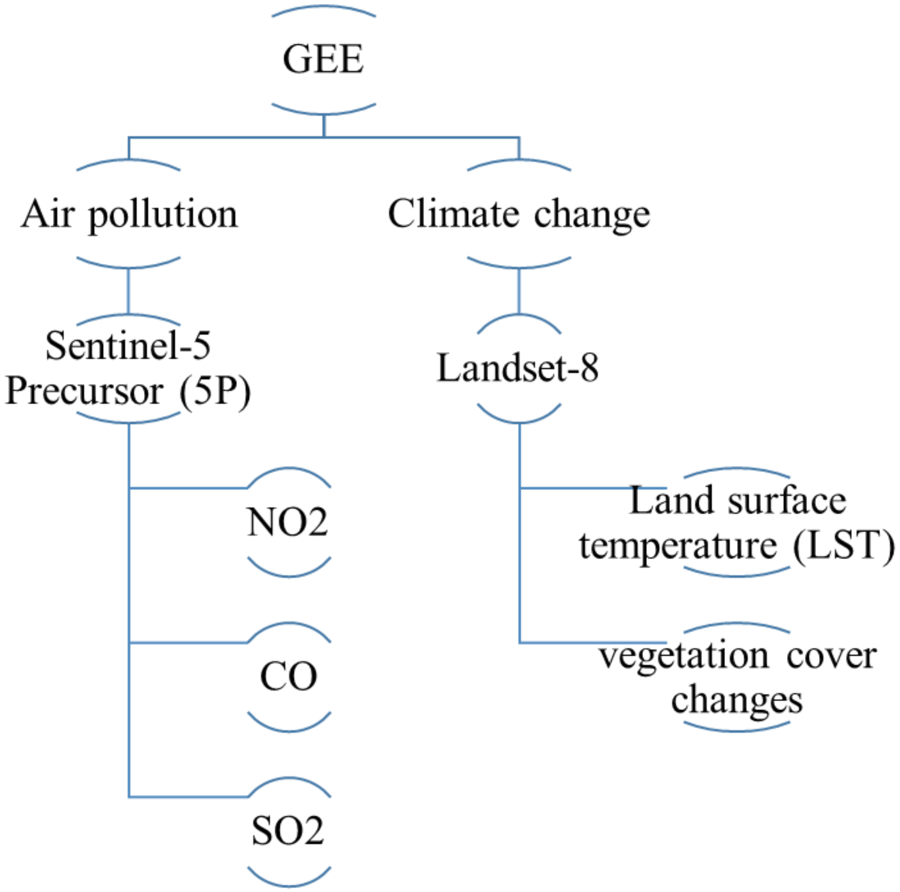


Fig. 2- Study plan flowchart

2.3. Remote sensing techniques

The study relied on Remote sensing techniques to monitor air pollutants concentrations in Cairo and Moscow cities during 2022-03-09 and 2022-04-20. The study used the products of Sentinel-5 Precursor (5P) which is a European Space Agency (ESA) satellite to monitor air pollutants with sensors referred to as TROPOMI (Tropospheric Monitoring Instrument) (ESA, 2019). The study depends on Sentinel-5P level 2 (L2) data for total vertical column and tropospheric column values for NO2 Nitrogen dioxide, SO2 sulfur dioxide, and CO carbon monoxide products. Satellite data were processed using the Google Earth Engine (GEE) cloud computing platform.

Time series data on Land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI) were obtained from the LANDSAT-8 in Cairo and Moscow cities in April 2022. The LST is commonly defined as the skin temperature of the earth’s surface, typically measured at 1.5 m above ground level with ventilated sensors sheltered from radiation. Also, LST can be measured through satellite-based sensors that use thermal infrared (TIR) spectral channels, earth-based methods, or aircraft equipped with sensors. This is achieved either with a single infrared band or through multi-bands after eliminating atmospheric weakening effects. These measurements are known to be strongly influenced by vegetation, soil moisture, elevation, and the interaction between satellite view, sun angle, earth gradient, and topographic effects, as well as atmospheric conditions (Jamali et al., 2022).

2.4. Results and discussion

Maps of the spatial distribution of tropospheric air quality index CO, SO2, NO2, and aerosol vertical column densities (VCDs) over Cairo and Moscow, during April 2022 are presented in Fig. 3 and 4. As can be found from the result, CO and SO2, NO2 density in Moscow city are higher than Cairo while aerosol concentration is upper in Cario than Moscow.

A physics-based retrieval approach was used to extract the observed atmospheric scattering properties and associated trace gases in the atmosphere. Carbon monoxide (CO) is an important gas to characterize the atmosphere for understanding tropospheric chemistry.CO has natural and anthropogenic sources and it is usually emitted from soils, plants, and the ocean, but the main sources of its emission are incomplete fossil fuel and biomass burning. It is also produced by the oxidation of CH4 and other hydrocarbons. The highest CO concentrations are found in the industrial regions of Moscow. The lifetime of CO is several weeks and can serve as a tracer for regional and inter-continental transport of polluted air. The main reduction process is the reaction with the .oH radical. The plume sensitivity varies with the light path for cloudy atmospheres and is therefore easy to estimate using the SP5 datasets. Here, Sentinel-5P is employed to estimate the vertically integrated CO column density at 0.01 arc degrees, which provides the CO concentrations ranging from a minimum of 0.031 to a maximum reported value of 0.037 mol/m2 in Cairo and 0.043 mol/m2 in Moscow.

SO2 also has natural and anthropogenic sources, which are emitted from volcanoes and produced through coal-fired power stations, industrial activities, or other fossil fuel-burning processes (e.g. cars or ships). The lifetime of SO2 in the troposphere is a few days, in the stratosphere, it can be several weeks. Volcanic eruptions that put ash and SO2 high into the atmosphere can be a major risk to aviation.

NO2 is another key atmospheric pollutant, which is produced by road traffic, power plants, and fossil fuel or biomass burning processes. Higher up in the troposphere, lightning, and aviation also produce NOx. The lifetime of NO2 is short, so that concentration is higher over land than in the cleaner air over the oceans. The maximum NO2 concentration in the study area was found to be 15 mol/m2 in Cairo and 0.34 mol/m2 in Moscow. The amount of NO2 in the atmosphere is linked to several emission sources, such as vehicular emissions and natural sources.

Aerosol, one of the most active and dynamic components of the atmosphere acts as an indicator of the state of the ecosystem and also shows possible sources of pollution. The main sources of natural aerosols in cities and industrial areas are the soil and, to a lesser extent, sources of bioaerosols.

Primary anthropogenic aerosols are caused by human activities and are released into the atmosphere by industrial companies, the thermal power industry, and transportation. Secondary aerosols, which are mostly the particles of a fine (submicron) fraction, are formed during microphysical and photochemical processes involving water vapor, organic compounds, and various precursor gases (Gubanova et al, 2022).

Gubanova et al. reported that the average daily values of PM2.5 aerosol concentration in near-surface air in Moscow during two years of 2020-2021 continuous monitoring were below the maximum permissible concentration (MPC) value (35 µg/m3, according to Russian standards; 25 µg/m3, according to World Health Organization (WHO) standards) all the time. For PM10 aerosol, this was almost always, except for a few episodes with average daily aerosol concentrations significantly above the MPC level (60 µg/m3, according to Russian standards; 50 µg/m3, according to WHO standards (Gubanova et al., 2022).

Dustiness of roads increases due to wind erosion of urban soils poorly protected by surface vegetation and sod layer. With an increase in transport speeds on large roads and greater wind-blowing intensity, small particles of road dust are suspended in the atmosphere, and the proportion of large particles gradually increases. Therefore, an increase in the size of the road and the intensity of the traffic flow from medium to large and major highways lead to a decrease in the toxicity equivalence factor (TEF) of the PM10 fraction (Vlasov et al., 2021).

Besides being the major Russian political, cultural, and educational center, Moscow remains an important industrial center with several hundred enterprises. In 2019, Moscow contributed about 20% to Russia's gross national product (Mazur et al., 2021). At the beginning of 2019, the car fleet of Moscow numbered about 4,380,000 vehicles (Vlasov et al., 2021). Motor vehicles contribute up to 98% of the total emissions, which amounted to 782,000 t in 2018 (Kul'bachevskii, 2019). Several decades have passed since Moscow was on the path of post-industrial development and passed the peak of production growth. Vast territories of factories and factories are scattered throughout Moscow. Overall, about 28,000 stationary emission sources concentrated in industrial zones of the city are registered in Moscow (Vlasov et al., 2021).

The air pollution sources in Cairo are different from Moscow and include the burning of rubbish, vehicle emissions (~4.5 million cars on the streets of Cairo), and urban industrial activities. In this city, air pollution produced many environmental problems related to aerosol particulate matter and high levels mostly of sulfur dioxide and lead. For this reason, it was listed as one of the most polluted cities in the world (Rovella et al., 2021). Additionally, Egypt's dry climate with its limited rainfall and prevalence of desert areas causes seasonal sand-laden weather. Additional air pollution has resulted in the chronic Black Cloud phenomenon since 1999. Efforts made by the EEAA to improve air quality concern mainly the cement industry which is an important economic sector of the Egyptian economy, but also agricultural waste management by controlling the bulk burning of rice straw. However, vehicle exhaust fumes are a major source of air pollution especially, in Cairo where traffic density is high (Abou-Ali & Thomas, 2012).

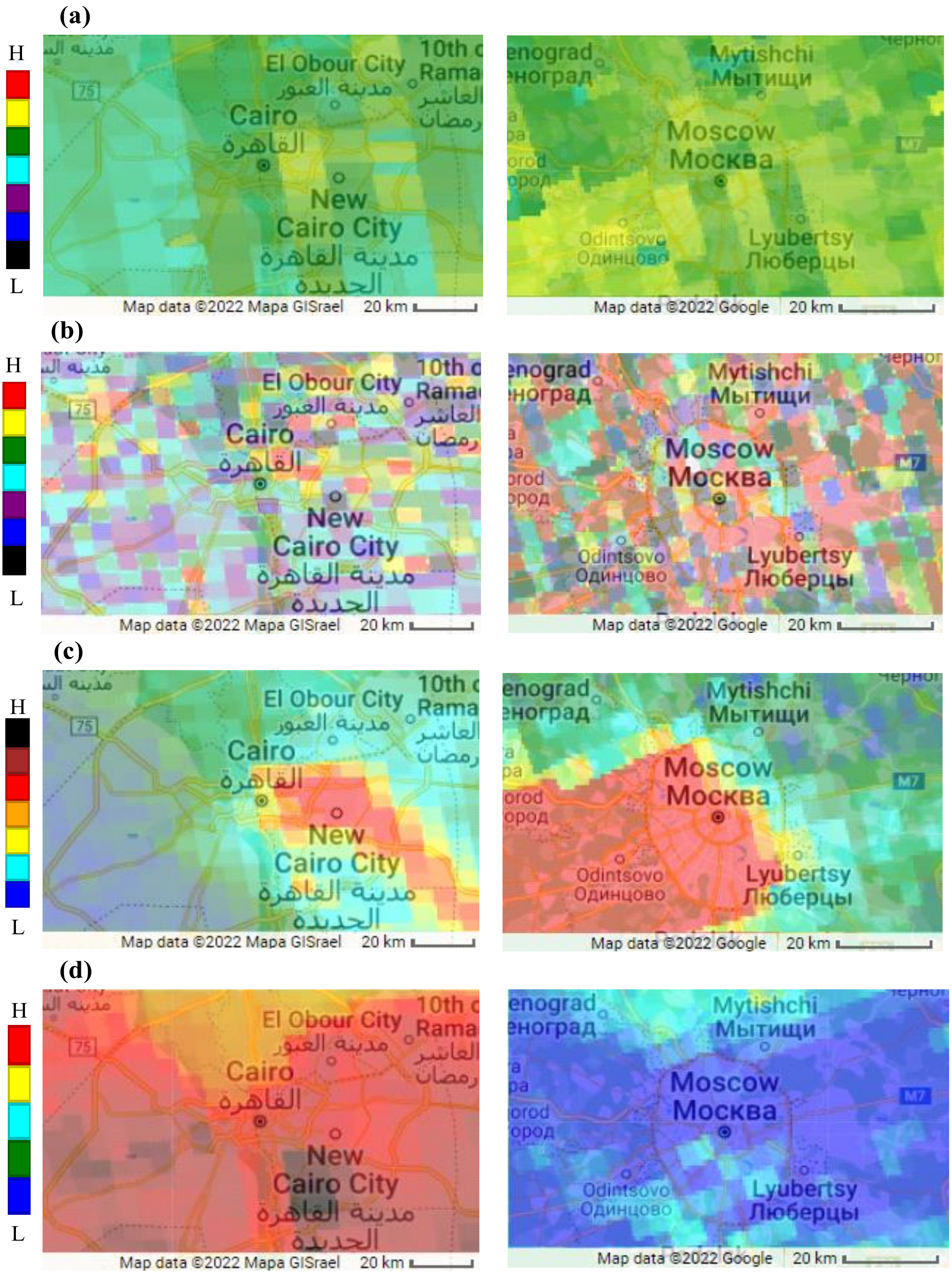


Fig. 3- TROPOMI tropospheric (a) CO, (b) SO2, (c) NO2 and (d) Aerosol concentration in Cairo and Moscow city

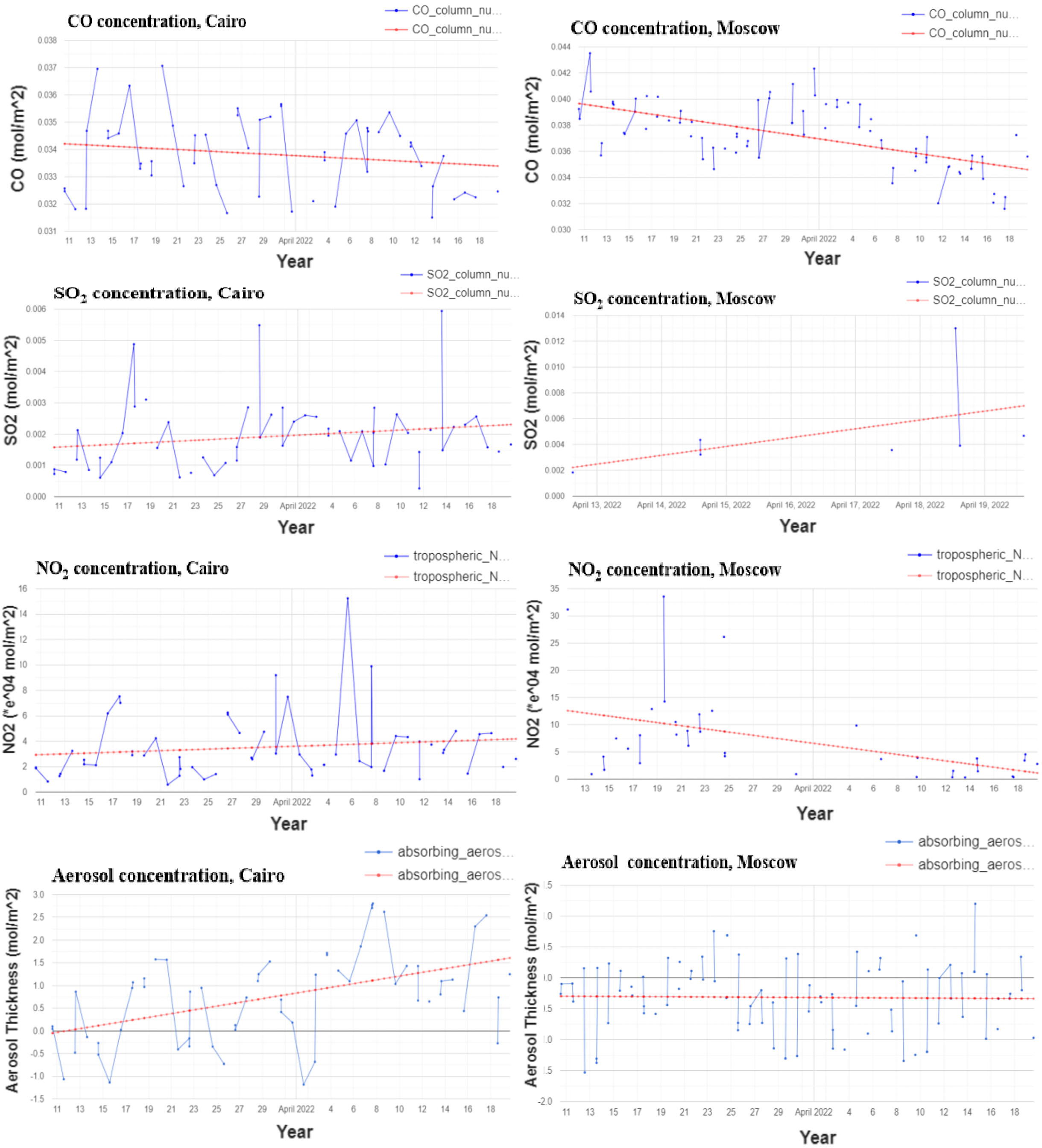


Fig. 4- The charts CO, SO2, NO2 and Aerosol column concentration obtained from TROPOMI tropospheric over Cairo and Moscow city

The wind direction plays an important role in terms of air pollution and air quality. The wind speed for both cities are presented in Fig.5. In Cairo, the wind blows from the north. In Moscow, most of the prevailing wind comes from the west and southwest. In summer, the future climate shows a decrease in the frequency of southwest winds and an increase in winds from the northwest, with a decrease in the frequency of stronger winds and an increase in the frequency of moderate winds (Athanassiadou et al., 2010). However, as noted by Hulme et al. Wind variations can vary significantly between different climate models and therefore cannot be considered as a reliable factor (Hulne et al., 2002). According to Fig. 5, it is clear that the wind speed in Moscow is higher than in Cairo, so given the industrial nature of the city and the wind in this city, it is natural that the spread of pollution in Moscow is higher.

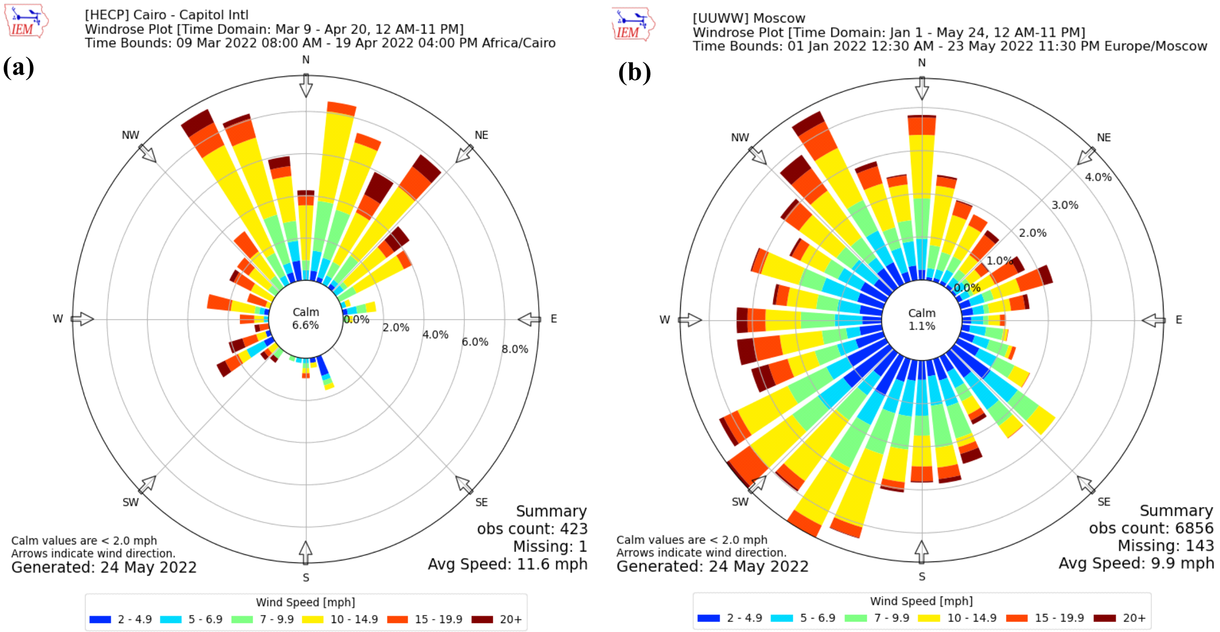


Fig.5- Wind Rose of (a) Cairo and (b) Moscow city

The LST and vegetation cover changes are two indicators of landscapes in a region. There was a strong correlation between LST anomalies, elevation, vegetation, and urban growth is significant to conservation (Jamali et al., 2022). Time series data on LST and Normalized Difference Vegetation Index (NDVI) were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor for Cairo and Moscow area. As result in fig.6, it was observed that LST rises in various elevations, and land uses.

This increase in temperature, warming, and increase in LST can dramatically increase vulnerability to drought, dust storms, floods, avalanches, and wildfires. There are ascending trends in temperature, especially in cities and residential areas, which reflect the changes that can be man-maid in the environment, These results are consistent with the research (Okeke et al., 2020). Also, McCarthy et al. (2010) showed that natural, mountain, forest, desert and non-urban areas are experiencing a warming process. A decrease in LST can be associated with a decrease in air pollutants, greenhouse gases, and water vapor content. The improvement in air quality with lower urban temperatures due to lockdown may be a temporary effect, but it provides an important link between human activities, air pollution, particulate matter, radiative flux, and temperature.

Lockdown for a shorter payback time shows significant improvement in environmental quality and provides a strong evidence base for policy implementation in this area on a larger scale to improve air quality (Parida et al., 2021). The NDVI map shows that the vegetation in Cairo is significantly lower than in Moscow, and given that Cairo is more desert, so the emission rate of a particle is quite evident. But in Moscow, vegetation prevents the transfer of particles to the surface, even though the wind frequency and stronger are high in this city. The results are in agreement with the results of the study of Hereher in 2017.

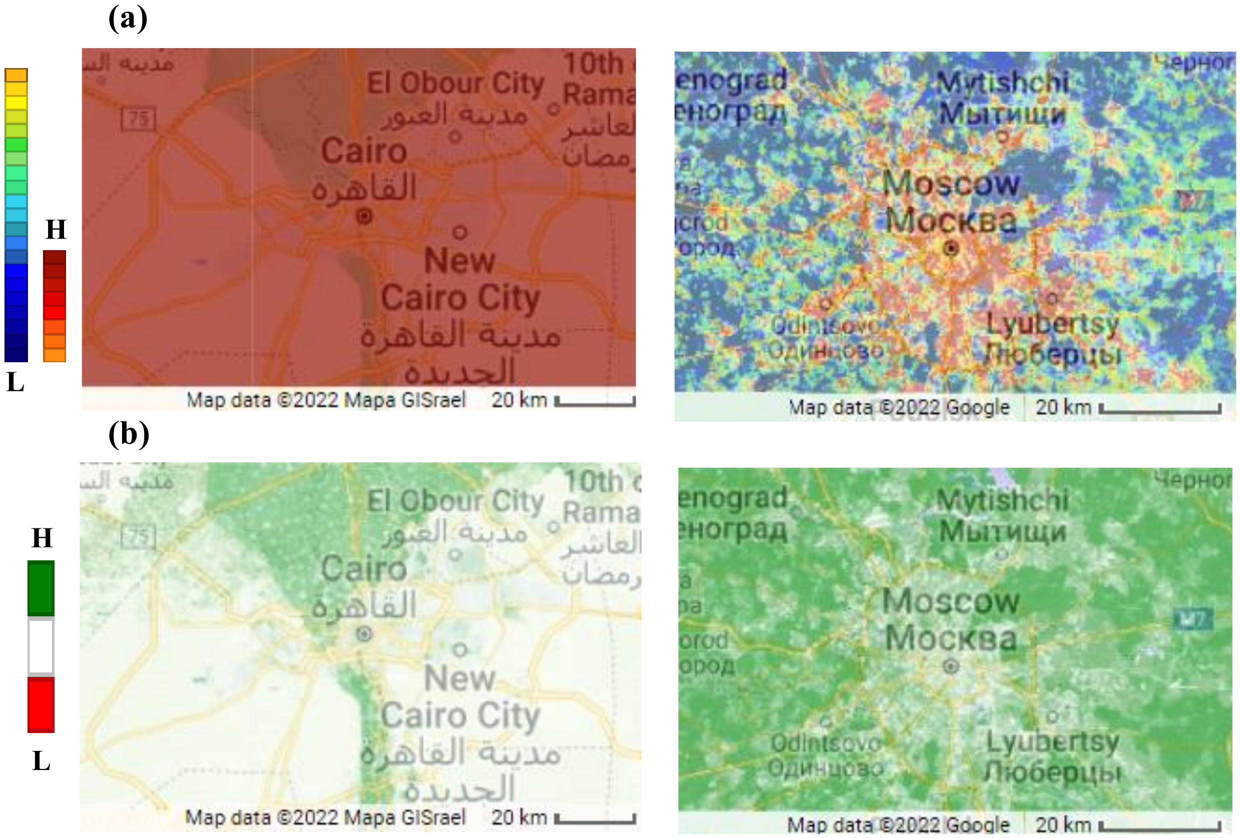


Fig. 6- Screenshot of the Landsat (a) LST and (b) NDVI map of Cairo and Moscow area

Time series of surface temperature anomalies of Cairo and Moscow cities was presented in Fig.7. It could be see that, global and hemispheric anomalies are with respect to the 20th century average. Coordinate anomalies are with respect to the 1991 to 2022 average. Fig. 7 shows significant changes between the past and current climates, and temperature increase substantially as expected. For around a decade, scholars have been discussing short-lived climate forcers and greenhouse gas mitigation in relation to combating climate change (Rogelj et al., 2014).

Smith et al. (2012) showed that future peak temperature is constrained by cumulative emissions of several long-lived gases (including CO2 and N2O) and emission rates of a separate basket of shorter-lived species (including CH4).Also, Najafi, Zwiers, and Gillett reported that although increased concentrations of greenhouse gases have caused warming over the past century, about 60% of the warming caused by greenhouse gases has been offset by the combined response to other anthropogenic factors, which is significantly more than the fraction of global warming caused by greenhouse gases caused by These compulsions have been neutralized (Najafi et al., 2015).

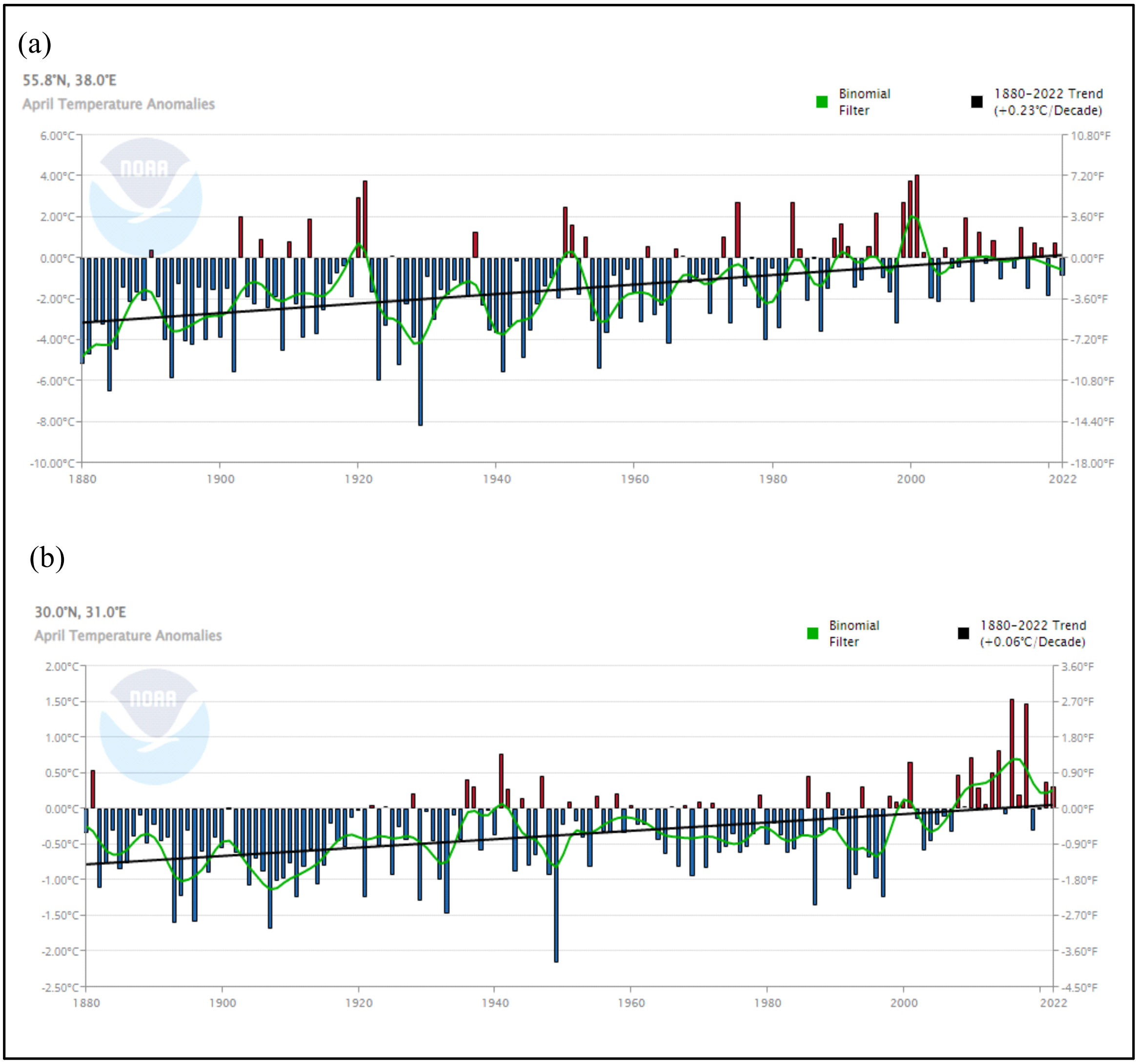
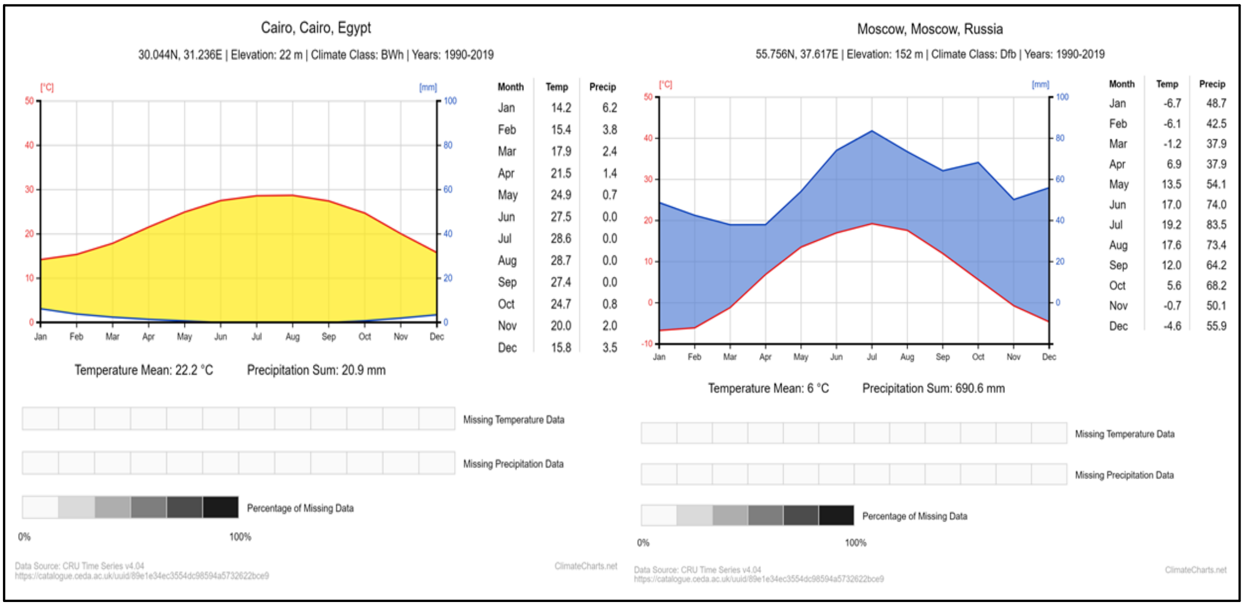


Fig. 7- Time series of surface temperature anomalies of (a) Cairo (b) Moscow

Also, temperature changes and precipitation during the years 1990 to 2019 in both cities are shown in Fig. 8. The average temperature in Cairo is 22.2 °C and the precipitation is 20.9 mm. In Moscow, the average temperature and precipitation during these years are between 6 °C and 690.6 mm. As can be seen from the results in Fig.8, the surface temperature in Cairo is much higher than the precipitation, while in Moscow precipitation is higher. The typical Mediterranean climate in Cairo is characterized by hot, dry summers and mild, rainy winters. Evaporation is especially high in the eastern half of its basin and is much higher than precipitation and river runoff in this area. This causes a decrease in sea level and an increase in salinity towards the east (Demirov & Pinardi, 2002).

As a result of its unique location and greenhouse gas emissions, the Mediterranean is a climatically sensitive region, often exposed to multiple stresses, such as a simultaneous water shortage and air pollution exposure that is favored by the Mediterranean climate and is likely to grow in the future due to the rapid urbanization(Kanakidou et al., 2011). Experiments with a climate model were performed to isolate the effects of greenhouse gases and aerosol particles on surface temperature and precipitation in simulations of future climate. The result demonstrated that the corresponding greenhouse gas effect following the representative concentration pathway 4.5 (RCP4.5) emission scenario leads to a global and Arctic warming. The model produces an annual mean northward shift in the intertropical convergence zone with reduced greenhouse gas emissions and subsequent warming of the Northern Hemisphere. (Acosta Navarro et al., 2017).



Cairo, Cairo, Egypt

30.044N, 31.236E | Elevation: 22 m | Climate Class: BWh | Years: 1990-2019

Month	Temp	Precip
Jan	14.2	6.2
Feb	15.4	3.8
Mar	17.9	2.4
Apr	21.5	1.4
May	24.9	0.7
Jun	27.5	0.0
Jul	28.6	0.0
Aug	28.7	0.0
Sep	27.4	0.0
Oct	24.7	0.8
Nov	20.0	2.0
Dec	15.8	3.5

Temperature Mean: 22.2 °C Precipitation Sum: 20.9 mm

Data Source: CRU Time Series v4.04
https://catalogue.ceda.ac.uk/uuid/89e1e34ec3554dc98594a5732622bce9

Moscow, Moscow, Russia

55.756N, 37.617E | Elevation: 152 m | Climate Class: Dfb | Years: 1990-2019

Month	Temp	Precip
Jan	-6.7	48.7
Feb	-6.1	42.5
Mar	-1.2	37.9
Apr	6.9	37.9
May	13.5	54.1
Jun	17.0	74.0
Jul	19.2	83.5
Aug	17.6	73.4
Sep	12.0	64.2
Oct	5.6	68.2
Nov	-0.7	50.1
Dec	-4.6	55.9

Temperature Mean: 6 °C Precipitation Sum: 690.6 mm

Data Source: CRU Time Series v4.04
https://catalogue.ceda.ac.uk/uuid/89e1e34ec3554dc98594a5732622bce9

Fig. 8- Climate Charts of (a) Cairo (b) Moscow area

3. Conclusion

In this study, some possible impacts of climate change on air quality are examined for Cairo and Moscow using meteorological data from simulations of the current climate and of a plausible future climate for April 2022. The results showed that the concentration of pollutants including CO, SO2, and NO2 in Moscow is much higher than in Cairo, which could be due to the industrial nature of this city. In Cairo, the high concentration of particles has a greater role in reducing the air quality of the city, which is mainly due to the existence of deserts around the city, as well as urban development and the increasing number of vehicles. Also, the prevailing wind and wind speeds in Moscow are significantly higher than in Cairo, which is expected as a result of the emission of more pollutants in this city. In addition, due to the dry climate of Cairo, the LST in this city is higher and of course, there is less vegetation cover. The most obvious meteorological impact of climate change is on temperature. Ground surface temperature series data also showed significant climate change in both cities, especially in Moscow.

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Consent to Publish (Authors consent to publishing)

Authors Contributions (All co-authors contributed to the manuscript)

Code availability (https://code.earthengine.google.com/2cd958bbef460c8cf95f83b2ddc3e36d
https://code.earthengine.google.com/2b08e44f3a54780b5913bc1afd20c2cf)

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