Analyzing Carbon Monoxide Emissions and Urban Mobility Patterns Using Google Earth Engine; Case Study: Casablanca

Habiba EL ALAMI EL KAMOURI[1], Rachid ESSAMOUD[1], Mustapha HAKDAOUI[2]

[1]*Laboratory of Geosciences, Geomatics and Environment, Faculty of Sciences Ben M'sick, Hassan II University of Casablanca, Morocco*
[2]*Applied Geology, Geomatics and Environment laboratory, The University Hassan II of Casablanca, Faculty of Sciences Ben M'sik, Casablanca, Morocco*
Email: habiba.elalami@gmail.com , habiba.elalami1-etu@etu.univh2c.ma

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Abstract

This study examines the relationship between carbon monoxide (CO) emissions and urban mobility patterns in Casablanca, largest city and economic hub, using Google Earth Engine's (GEE) cloud-based geospatial processing capabilities (Gorelick et al., 2017). Casablanca presents a compelling case study due to its rapid urbanization, increasing vehicle ownership rates, and challenges with traffic congestion that have intensified air quality concerns in recent years. By integrating satellite remote sensing TROPOMI (Veefkind et al., 2012) satellite sensor data and Google Earth Engine (GEE) techniques, we conducted a comprehensive spatio-temporal analysis of CO concentration patterns across Casablanca's diverse urban landscape. Our GEE-based methodology enabled efficient processing of large-scale datasets to identify critical mobility-pollution relationships across the city's major transportation corridors, industrial zones, and residential areas (Kumar et al., 2020; Amegah, 2018). We provide a comprehensive assessment of air quality in Casablanca and demonstrate the value of using geospatial approaches for informing policymakers and urban planners. The results highlight seasonal variations in CO levels, the identification of pollution hotspots, and the quantification of the influence of urban features and traffic on air quality.

1. Introduction

Carbon monoxide is a gas emitted due to incomplete combustion of fossil fuels and biofuels. Road transport was once a significant source of CO emissions, but the introduction of catalytic converters reduced these emissions significantly. CO concentrations tend to vary with traffic patterns during the day. The highest CO levels are found in urban areas, typically during rush hours at traffic locations. (Air quality in Europe – 2013 report).

Air pollutant emissions, namely CO, in Casablanca are due to rapid urbanization with an annual growth rate of 12.8% 1 (H. El Alami El Kamouri et al.) and an expanding vehicle fleet at a Compound annual growth rate of 4.5% from 2015 to 2024 (N.Samir et all. May 23, 2024). As Morocco's economic hub, the city faces serious air quality issues, with 33% of regional CO_2 emissions coming from transportation (N.Samir et all. May 23, 2024).

Casablanca Considering as economic capital, with his multiple typology of buildings. For exemple, residential buildings such as houses, commercial buildings and other types (E. Achbab et al., 2022). Due to its industrial and commercial development, Casablanca is the most polluted city in Morocco (Inchaouh and Tahiri, 2017), given the significant number of environmental problems it suffers from such as the problem of greenhouse gases caused mainly by the transport and industry sector.

This study advances prior NO_2 research in Casablanca (H. El Alami El Kamouri et al.) by analyzing CO dynamics through a cloud-based geospatial framework, with Using robust geospatial techniques and datasets such as Google Earth Engine (Gorelick et al., 2017), Sentinel-5P CO data, Sentinel-2 Land Use Data, ERA5, road network, and private car traffic data.

2. Materials and Methods

2.1 Study Area

Casablanca city (Figure 1) is the central part of the Wilaya of Casablanca-Settat Region, it is located on Morocco's Atlantic coast in the northwset of Morocco on north latitude of 33°35 and a west longitude of 7°25, bordered by the ocean to the west and Settat and Ben Slimane provinces to the north, east, and south. The city covers 1,140.54 km², with 18.8% (227.82 km²) being urbanized. Urban areas doubled since the 1980s, growing from 100 km².

Its position on the Atlantic Ocean plays a moderating role in all the climatic elements. The average temperatures are 12,4°C in winter and 22,9° in summer with a temperate and humid climate. The average annual rainfalls are between 300 and 500 mm (Ikram et al., 2014).

With a population of over 3.3 million in the metropolitan area, Casablanca has experienced rapid urbanization and motorization, leading to significant air quality challenges.

The landscape features plains, plateaus, scattered hills, and a 98 km coastline, extending 22 km at Mansouria. The soil varies, with Tirs in rural areas and sandy soil along the coast.

Rivers are minor, with Oued El Malleh, Oued N'fifikh, and Oued Hassar being the main ones. The city has 4000 ha of forests, mainly in Bouskoura.

The climate of Casablanca is a semi-arid one, with irregular rainfall, temperatures from 8˚C to 26˚C, and humidity levels always above 60%. Winds average 9 m/s from the northeast.

During the year, the city is lit 9 to 10 hours a day in summer and 5 to 6 hours a day in winter (E. Achbab et al., 2022.

Geologically, Casablanca sits on sandy tuff formations with a shallow layer of soil. Hydrogeologically, groundwater is sparse and not highly vulnerable.

Hydrology: Urban development dried up Oued Bouskoura's lower course, but flooding remains a risk during heavy rains.

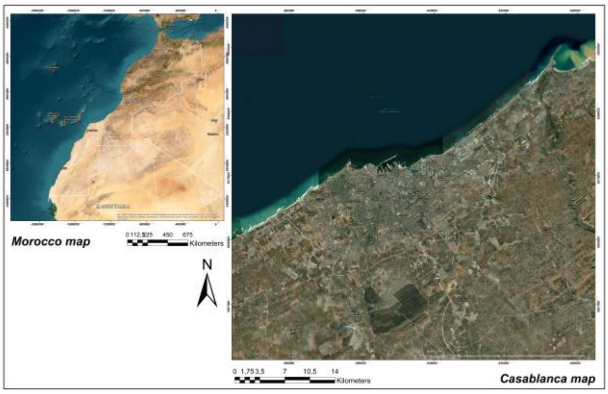

Figure 1. Location of the study area: (a) Morocco; (b) Casablanca city.

2.2 Data

This study utilized several satellite datasets accessed through Google Earth Engine (GEE): (1) Sentinel-5P CO data, (2) Sentinel-2 Land Use Data, (3) ERA5.

Other additional datasets were integrated into the analysis: (4) road network, and (5) private car traffic data.

2.3 Sentinel-5P CO data

The Sentinel-5 Precursor mission instrument acquires data pertinent to air quality assessment. The TROPOMI instrument, a multispectral sensor, records reflectance of wavelengths crucial for measuring atmospheric concentrations of ozone, methane, formaldehyde, aerosol, carbon monoxide, nitrogen oxide, and sulfur dioxide, as well as cloud characteristics at a spatial resolution of 0.01 arc degrees. (https://developers.google.com/earthengine/datasets/catalog/sentinel-5p).

TROPOMI on the Sentinel 5 Precursor (S5P) satellite observes the CO global abundance exploiting clear-sky and cloudy-sky Earth radiance measurements in the 2.3 µm spectral range of the shortwave infrared (SWIR) part of the solar spectrum.

TROPOMI clear sky observations provide CO total columns with sensitivity to the tropospheric boundary layer. (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_NRTI_L3_CO#bands).

Name	Units	Description
CO_column_number_density	mol/m^2	Vertically integrated CO column density.

a. https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_NRTI_L3_CO#bands.

Table 1. Key information about the Sentinel-5P

2.4 Sentinel-2 Land Use Data

For analysed the relationship between urban features and air quality, the Sentinel-2 satellite imagery was used to derive urban development indicators, such as the Normalized Difference Built-up Index (NDBI). (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_SR_HARMONIZED#description).

2.5 ERA5

ERA5-Land is a reanalysis dataset that provides a consistent view of the evolution of land variables over several decades at an enhanced resolution compared with ERA5.

Hourly wind speed and temperature data were obtained from ERA5-Land covering the study period (https://developers.google.com/earth-engine/datasets/catalog/ECMWF_ERA5_LAND_MONTHLY_BY_HOUR).

2.6 Road network and traffic data

Road network was collected from Organizing Authority for Urban Transport of Greatest Casablanca Region. A total of 587 vehicle traffic counts have been incorporated into the road network, covering the entire study area. Of these, 370 counts distinguish between different vehicle types.

Type of Data	Geographical Precision and Geolocation	Source
All-mode and mode-specific (PT, Bus, Tram, 2-wheelers, Private Car, Heavy Goods Vehicle) travel matrix during morning peak hour (2010), corresponding to households surveyed by ALG	OD by ZAT	ALG Household Survey 2011 (raw data with adjustment weights)

Table 2. Additional data of traffic road network

3. Methods

The methodology used in this study is: (1) Temporal Analysis. (2) Spatial Analysis. (3) Land Use Regression.

3.1 Temporal Analysis

For generate temporal aggregation monthly average CO, we used ee.Reducer.mean() function of GEE for study period between 2019 and 2024.

This proposed method, help to identify seasonal patterns and long-term trends in air pollution levels.

3.2 Spatial Analysis

For mapping the distribution of air pollutants and identify pollution hotspots across Casablanca, we applied spatial interpolation and hotspot detection methods.

ee.Reducer.mean() function of GEE was also used to generate the image series of the average of Carbon monoxide _monthly for the study period.

3.3 Land Use Regression

A regression modeling approach was used to quantify the influence of urban development indicators, traffic patterns, and meteorological factors like the impact of speed wind and temperature on CO concentrations (H. El Alami El Kamouri et al.).
However, the methodology of this approach (H. El Alami El Kamouri et al.), which is completely built on the GEE cloud computing platform, began firstly by selecting a collection of images of the S2 L2 sentinel, between 2019 and 2024, and calculate the Normalized Difference Built-up Index (NDBI) (Y. Zha, J. Gao & S. Ni (2003)).

$$NDBI = \frac{B11 - B8}{B11 + B8}$$

Secondly, use ERA5-Land on GEE to generate yearly charts of speed wind average and temperature average between 2019 and 2024, used ee.Reducer.mean() function of GEE, and use ee.Reducer.pearsonsCorrelation() function of GEE for correlation between CO concentration and various urban environmental factors, such as NDBI, speed wind and temperature, between 2019 and 2024.

4. Results

The methodology described above has led to four levels of results: (1) Temporal Patterns of CO; (2) Spatial Distribution of CO; (3) Relationship between CO, Urban Development, urban development indicators, traffic patterns, and meteorological factors.

4.1 Temporal Patterns of CO

The chart, levels from 2019 to 2024, of carbon monoxide (CO) monitoring in Casablanca city, shows several noteworthy trends and insights into the relationship between automobile traffic and air pollution.

Figure 1. Chart of carbon monoxide (CO) monitoring

The data indicates a general upward trend in CO levels, with annual fluctuations that can be attributed to a variety of factors.

In 2019, CO levels ranged between 0.0302 mol/m^2 and 0.0317 mol/m^2. This was followed by a slight increase in 2020, where levels ranged from 0.0306 mol/m^2 to 0.0326 mol/m^2, with notable peak 0.038 mol/m^2 was observed in spring months and minimum level 0.027 mol/m^2 in summer months. In 2021, several peaks were observed reaching 0.036 mol/m^2 in spring months, suggesting a significant rise in emissions, theoretically associated to increased traffic and industrial activities. However, 2022 distinguished a brief decrease in CO levels, with a maximum of 0.033 mol/m^2 in spring months and a minimum of 0.026 mol/m^2 in fall months, which could be due to specific regulatory interventions or changes in emission standards. The rising trend resumed in 2023 and 2024, with levels reaching a maximum of 0.035 mol/m^2 in fall months, accent the persistent challenge of managing air quality in urban environments.

4.2 Spatial Distribution of CO

The spatial analysis of CO average levels using GEE-based techniques identified various pollution hotspots in Casablanca. These hotspots were often located in areas with high traffic density, major transportation corridors, and industrial zones, highlighting the significant contribution of vehicular emissions and urban activities to air quality (Beirle et al., 2011).

The spatial analysis of CO average concentration levels (Figure 2) between 2019 and 2024 reveals that the highest concentrations, hotspots, were consistently verified along the coastal road in the city, an area characterized by the high traffic density of both private vehicles and heavy goods vehicles. This is principally driven by the significant freight transport activity concentrated in this zone.

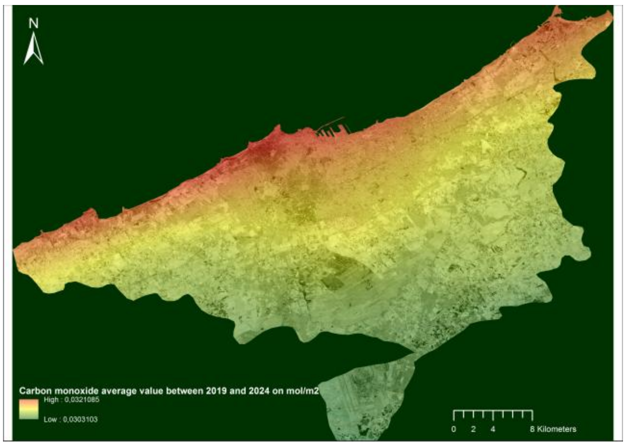

Figure 2. The spatial analysis of CO average concentration levels between 2019 and 2024.

4.3 Relationship between CO, Urban Development, urban development indicators, traffic patterns, and meteorological factors

Correlation analysis using ee.Reducer.pearsonsCorrelation() function of GEE reveals significant correlations between Carbon monoxide emissions average and urban development indicators, in Casablanca, from 2019 to 2024 (Table 3).

	Correlation Pearson's r	*P-value*
NDBI	-0.294	0
Temperature	0.689	0
U-Wind	0.393	0
V-Wind	-0.377	0
Private vehicles traffic	0.1975	0

Table 3. Correlation Pearson's r and P-value between CO concentration Average urban development indicators

The weak negative correlation is observed between CO levels and NDBI (r = -0.294), that reveals some explanations as the effect of urban form of Casablanca impacts significantly CO emissions suggesting that areas with higher building density often cover newer more energy-efficient structures, which may lead to reduced CO emissions per unit area (C. Huang et al. 2022).

The strong positive correlation between temperature and carbon monoxide (CO) levels (r = 0.689) signifies that CO concentrations increase considerably with rising temperatures. This can be explained by several factors: thermal inversions at higher temperatures reduce vertical mixing, leading to 15-30% higher CO concentrations (Shuoyan Hua. 2022).

Moreover, seasonal human activities reported to temperature changes, such as altered cooling/heating needs and mobility patterns, contribute up to 22% of CO variability (K. Alexandrino et al. 2020).

The moderate positive correlation between east-west winds (U-Wind) and CO levels (r = 0.393) proposes that these winds transport emissions from industrial areas or traffic corridors (S. Gheshlaghpoor et al. 2022). And the streets parallel to wind direction have up to 40% less pollutant dispersal (Li et al. (2019)). Additionally, noticed that these winds can bring pollution from neighboring regions (Y.Guo et al. 2020).

In contrast, the moderate negative correlation with north-south winds (V-Wind) (r = -0.377) indicates a reduction in CO levels. that's revealed that north-south corridors enhance pollutant dispersal, and found that these winds often bring cleaner air, reducing CO levels by 25-40%. (Y.Guo et al. 2020).

The weak correlation between traffic and CO levels (r = 1975) reflects changes in emission dynamics. Modern vehicles produce 70-85% less CO (Z.SUN et al. (2005)). Congestion increases CO emissions 2-3 times compared to free-flowing traffic (K. Zhang et al. (2011)).

Figure 3 clearly illustrate the impact of traffic in principal roads in air quality. They illustrate the elevated levels of concentration CO levels that were found along coastal road. Decrease gradually towards the center then the periphery. The decrease CO concentration in the center, despite the high traffic volume, supports the impact of newly manufactured vehicles.

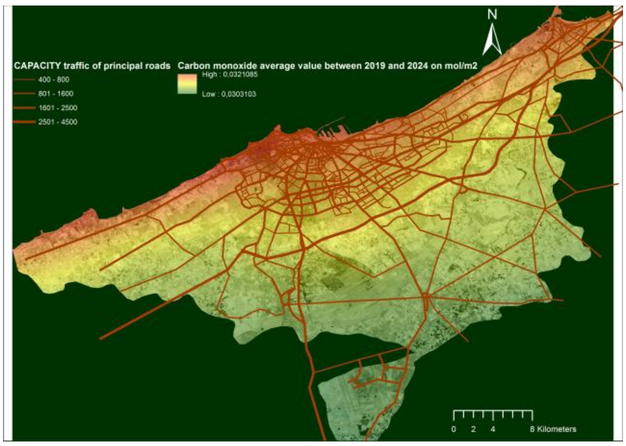

Figure 3. Superposition of principal roads with capacity traffic and value of carbon monoxid average concentration levels

5. Discussion

The negative correlation between the Normalized Difference Built-up Index (NDBI) and CO levels proposes that urban densification, when implemented with modern building standards and energy-efficient designs, might not worsen air quality as traditionally feared. Thoughtful urban design, in Casablanca, can help offset potential pollution increases associated with higher density.

The strong correlation between temperature and CO levels indicates that climate change and urban heat island effects could significantly intensify CO pollution. This highlights the importance of incorporating temperature considerations into air quality management strategies, especially during heat waves or summer periods, to effectively mitigate CO pollution risks.

Urban design that enhances air ventilation, particularly along north-south corridors, can considerably increase natural pollution dispersal. The urban planning responsive to wind patterns can reduce average pollution levels by 15-30%, making it a crucial component of effective air quality management.

The unexpectedly weak correlation between traffic and CO levels indicates that simple traffic reduction measures may not proportionally decrease CO pollution. Effective strategies should focus on addressing congestion patterns and combine traffic management with other approaches to achieve meaningful reductions in CO emissions.

6. Conclusion

This study presents the continuity of the previous study which concerned NOx research in Casablanca (H. El Alami El Kamouri et al.), by analyzing CO dynamics through a cloud-based geospatial framework. The first comprehensive analysis of the relationship between carbon monoxide pollution and urban mobility patterns in Casablanca using Google Earth Engine and satellite data. The research reveals bright spatial and temporal correlations between traffic activity and CO concentrations, with manifest hotspots in the downtown core, along major transportation corridors, and in industrial zones.
The GEE-based methodology demonstrated in this research suggestions a replicable approach for other rapidly developing urban areas fronting similar challenges of limited ground-based monitoring infrastructure. By leveraging cloud computing and promptly available satellite data, cities can develop more comprehensive understandings of their air quality challenges without requiring expensive expansions of monitoring networks.

Future research should focus on extending this methodology to include additional pollutants (PM2.5 and O3), developing predictive models to support air quality forecasting, and accompanying health impact assessments to measure the potential benefits of targeted interventions.

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