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Atmospheric Co_2 Concentration Measured During Rush Hour In Bamako - Mali

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Abstract:
Air pollution has become a major concern in Bamako. Road traffic is considered the main cause of this pollution. The overall aim of this study is to assess atmospheric concentrations of carbon dioxide on major roads in Bamako during rush hour. In order to achieve the objectives of this study, the methodology was based on the use of the Testo 535 device to measure atmospheric CO_2 concentrations. Some physical parameters related to CO_2 concentrations were also measured. Data were recorded and processed using tools (Excel 2019, and the human exposure grid).
Research results show that average atmospheric CO_2 concentrations in the communes of the city of Bamako range from 347.20 (± 45.03) ppm to 420.80 (± 25.09) ppm, with an overall mean of 382.70 (± 20.27) ppm. The overall mean temperature in the city of Bamako is estimated at 28.97 (± 1.80) °C for a humidity of 65.23 (± 6.88) %. Taking as a reference the average concentration which is equal to 382.70 ppm, each liter of air contains approximately 0.00857 liters (8.57 milliliters) of CO .
However, variations in CO_2 concentrations are influenced by biological, physical and human environmental factors. Health risks of the utmost importance can arise from CO_2 air pollution. The results of this study show that Bamako's cars considerably degrade air quality. Mitigation measures must be taken to combat this air pollution.

Keywords: *Concentration, Atmospheric CO_2, Peak Hours, Bamako.*

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I. Introduction

The air we breathe is composed of: oxygen O_2 (20.95%), nitrogen N_2 (78.08%), argon Ar (0.93%), carbon dioxide CO_2 (0.038%) and noble gases (0.004%) [1].

Whatever the conditions or location, analyses show that it is never "pure" in the sense that it contains other, unmentioned components [2].

Certain gaseous substances can mix with the air, negatively modifying its composition and causing a situation prejudicial to the health, safety and well-being of man, fauna, flora or collective and individual property.

To prevent such harm in Mali, Article 38 of Law 2021 - 032 of May 24, 2021 on pollution and nuisances stipulates that, and I quote: "means of air, sea, river, road and rail transport, buildings, industrial, craft and agricultural establishments, mines and quarries, water treatment plants, generators, mills, or other immovable or movable objects must be built, operated or used in such a way as to avoid pollution of the atmosphere or odors that inconvenience populations and compromise public health or safety". CO_2 is a pollutant gas widely found in the air [3].

In 2015, worldwide CO_2 concentration reached the 400-ppm mark, rising to an unprecedented 420.99 ppm in May 2022. Higher (50% above) than during the pre-industrial era (278 ppm to 280 ppm), and not seen on earth for around 4 million years [4].

According to one study, the concentration of CO in the Bamako Road Park almost reaches the natural level of CO in the air, around 0.04% [5]. However, there is not enough information to substantiate this claim.

Carbon dioxide can come from a number of sources. On the one hand, the industrial revolution enables the massive production of polluting goods and services, during which polluting residues such as CO_2 escape. On the other hand, CO2 is naturally present in the atmosphere at a concentration of 0.038% [1].

Between 2015 and 2020, around 23 million used Light Commercial Vehicles (LCVs) were exported to 208 countries and other territories, and around 66% of used LCVs were exported to developing and transition countries. Despite the adoption of a vehicle directive for equivalent emission standards by 15 countries of the Economic Community of West African States (ECOWAS) [6].

In Bamako, transport vehicles are no strangers to the causes of various types of pollution. Indeed, CO_2 is a gas constantly emitted by transport vehicles in the Bamako conurbation [7]. The use of automobiles, especially used and depreciated ones, often banned from circulation in Western countries, as a means of personal or public transport, is the main source of air pollution [6].

Poor-quality fuels may also contribute to the chemical reactions that cause pollution. During the combustion of automotive hydrocarbons, carbon oxides are released into the atmosphere in significant quantities. However, in the presence of excess oxygen in the air, CO is automatically transformed into CO_2 [8].

Under normal conditions, CO_2 is not usually harmful, as it contributes to the thermal balance of the earth's surface and the respiration of living species. It is harmful to man and his environment [9]. However, a high concentration of this gas in the atmosphere could have harmful consequences for living beings. Numerous acute and chronic illnesses (pulmonary, cardiovascular, lung cancer, etc.) are perceived as a result of air pollution. In Mali, consultations due to air pollution-related illnesses are ranked second only to malaria [10].

Medical research is clarifying the harmful role of pollutants on health and their involvement in chronic respiratory and cardiovascular pathologies [11; 12].

The effects of air pollution on health are not limited to the respiratory system, but extend beyond it: pathologies of the cardiorespiratory system, diabetes, cancers, strokes, pathological outcomes for pregnancy and child development, as well as psychiatric and central nervous system effects [13; 14].

In addition to the direct risks to human health, CO_2 is the main greenhouse gas. Indeed, climate change is linked to an increase in atmospheric CO_2, with dramatic consequences for society and the economy, and an increase in extreme phenomena [15].

It has to be said, however, that the city's population and authorities are largely unaware of the potential risks associated with this type of air pollution, despite numerous awareness campaigns and the adoption of legal and regulatory texts. There is still a lack of rigorous monitoring of the relationship between pathologies and pollution levels in the city of Bamako [16].

In order to better assist decision-makers and inform national opinion of the level of air quality and the risks of increasing this gas in the city, we propose to evaluate the concentration of carbon dioxide (CO_2) at road junctions (traffic circles) in the city of Bamako, using the “Testo 535”. Specifically, the aim is to

- Measure atmospheric CO_2 at road junctions in the city of Bamako;
- Measure ambient air temperature and humidity on roads in the city of Bamako;
- Produce a spatial map of CO_2 emissions from road traffic in Bamako;
- Assess potential risks associated with CO_2 concentrations in the city (based on human exposure).

II. Material And Methods

Material

- Testo 535 and accessories ;
- ArcGis software
- Assessment grid from TESTUD François
- Note sheet (A4 sheet) ;
- Excel version 2019
- Pen ;
- Laptop HP ;
- Desktop Toshiba;
- Cell phone (OUKITEL).

Methods

In order to measure the concentration of atmospheric carbon dioxide in Bamako during peak hours, activities were carried out according to a well-structured procedure.

Sampling sites

Sampling took place in the city of Bamako (Mali), specifically in its six administrative communes, from August 22 to September 24, 2022.

In each commune, sites at crossroads (traffic circles) were targeted for measurements. These will enable fixed measurements to be taken of the CO_2 emitted by cars during road traffic. Temperature and humidity measurements were also taken.

The sites were selected on the basis of the amount of road traffic during peak hours in these areas.

Thirty-six (36) sampling points were selected in all six (6) communes of the Bamako district, and four (4) passes were made at each site.

Geographical coordinates (latitude (X) and longitude (Y)) were recorded.

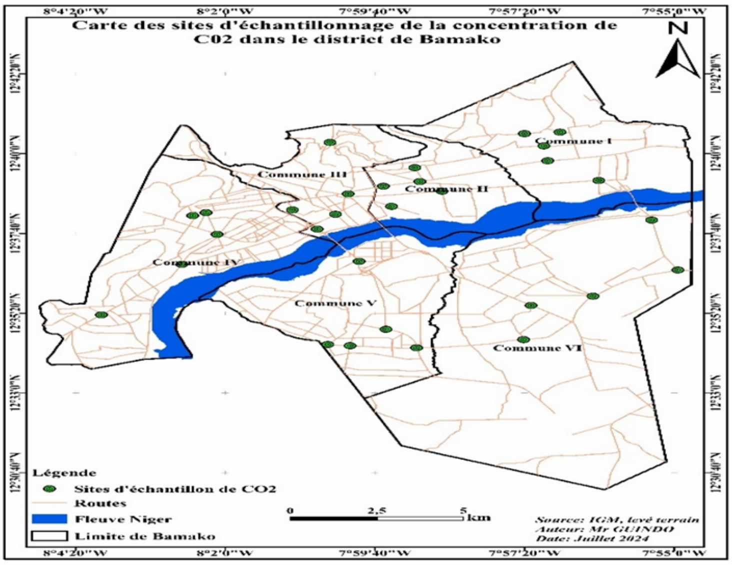

Figure 1: Map of CO_2 measurement sites in the city of Bamko

Measuring CO_2 content with Testo 535

CO_2 is measured using the Testo 535 (made in Germany). With its fixed probe, it is a precise indicator of the CO_2 content in the air.

In the field, the procedure is to start the device first. To do this, we press the device's on/off button ("l/0") and wait thirty seconds.

When the probe starts flashing, numerical values are displayed successively on the tester's LCD screen. After a few seconds, variations in site carbon dioxide concentrations flash.

We then wait two (2) minutes, until the variations are stable, before recording the data in the notebook. To record, click four (4) times on the
« », knowing that:

- ✓ *the first click corresponds to "HOLD", stopping the variation;*
- ✓ *the last three clicks communicate the maximum-minimum and average CO_2 values, represented by the "Max", "Min" and "Mean" designators respectively.*

Finally, once the data have been recorded, the unit is switched off by pressing the on/off button again.

In this way, each measurement point remains continuous until the end of collection.

NB: The Testo 535's measuring range is 0 to + 9999ppm, and contact with the probe is not recommended, due to exposure to UV rays.

Figure 2 : Testo 535 used during the campaign: Personal photograph, 2022

In addition to measuring CO_2 concentrations, we also took temperature and humidity measurements. These parameters can influence the atmospheric content of CO_2.

Measurement of important physical parameters (temperature and humidity)

Measurements were taken using the Humidity Temperature Meter android application. This application provides information on temperature and humidity variations over time and space.

To take measurements, we first need to activate the phone's location and have an internet connection (wifi, mobile data...).

We clicked on the respective radii of the parameters (temperature and humidity) to display the values. Data are expressed in degrees Celsius (°C) for temperature and percentage (%) for humidity.

Spatial mapping of CO_2 emissions from road traffic in Bamako.

The GIS software "ArcGis" was used for the mapping. It enabled the manipulation, management, analysis and editing of spatial data.

The use of its "arcMap, arcCatalog" and "Toolbox" applications facilitated the mapping of CO_2 emissions in the study area.

Assess the potential risks associated with CO_2 concentrations in the city (based on human exposure).

The assessment grid taken from TESTUD François (2022) was used for the evaluation. It assigns clinical signs to each atmospheric CO_2 concentration (Table 1). This made it possible to assess the severity of people's exposure to high levels of CO_2 in Bamako traffic.

Table 1: Assessment grid for human exposure

Concentrations	GOOD	AVERAGE	POOR
CO_2 Concentration (%)	< 3%	Entre 3% et 4%	> 4%
CO_2 Concentration (ppm)	< 300	] 300, 400 [	> 400

Source : Table from TESTUD. François, 2022

The human exposure assessment grid establishes that once the CO_2 concentration is below 3% (or <300ppm), the risk to human health is low; once this concentration is between 3% and 4% (or] 300 ppm, 400 ppm [), the health risk is medium; and once this same concentration is above > 4% (> 400 ppm), the risk to human health is high.

Measurement data processing

The data collected during atmospheric CO_2 measurements in the city of Bamako were subjected to various processing operations. The "Excel version 2019" software was used to perform calculations (averages, percentages, etc.) relating to the various CO_2 concentrations quickly and accurately. Graphical representations of the analyzed results were also produced.

III. Result

Measurements of atmospheric CO_2 from road traffic in the communes of Bamako

Table 2: Concentration of CO_2 and selected physical parameters

Communes	Average	Minimum	Maximum	Average T°	Average H%.
Commune I	377.60 ± 6.54	367.00 ± 16.17	403.80 ± 19.89	**29.4 ± 0.89**	**61.6 ± 4.51**
Commune II	420.80 ± 25.09	382.80 ± 23.55	434.80 ± 16.23	**28.2 ± 1.10**	**65.8 ± 1.79**
Commune III	389.80 ± 23.74	366.00 ± 20.91	431.80 ± 32.94	**31.2 ± 0.84**	**55.8 ± 2.17**
Commune IV	360.00 ± 17.26	302.40 ± 15.96	414.60 ± 10.45	**27 ± 1.73**	**72.8 ± 3.83**
Commune V	347.20 ± 45.03	339.20 ± 38.19	388.80 ± 27.80	**30.8 ± 0.45**	**62 ± 2.83**
Commune VI	400.80 ± 3.96	360.80 ± 18.25	435.40 ± 16.60	**27.2 ± 3.19**	**73.4 ± 9.79**
Bamako	**382.70 ± 20.27**	**353.03± 22.17**	**418.20 ± 20.65**	**28.97 ± 1.80**	**65.23 ± 6.88**

Analysis of CO2 measurement data and other physical parameters (temperature and humidity) collected at sampling points reveals that:

- average minimum atmospheric CO2 concentrations in the city's communes ranged from 302.40 (± 15.96) ppm to 382.80 (± 23.55) ppm, with an overall average minimum of 353.03 (± 22.17) ppm for the city of Bamako.
- average maximum atmospheric CO2 concentrations in the city's communes ranged from 388.80 (± 27.80) ppm to 435.40 (± 16.60) ppm, with an overall maximum average of 418.20 (± 20.65) ppm for the city of Bamako;
- average atmospheric CO2 concentrations in the city's communes ranged from 347.20 (± 45.03) ppm to 420.80 (± 25.09) ppm, with an overall mean of 382.70 (± 20.27) ppm for the city of Bamako.

The overall mean temperature in the city of Bamako is estimated at 28.97 (± 1.80) °C for a humidity of 65.23 (± 6.88) %.

Grouping information using Fisher's smallest significant difference (LSD) method and 95% confidence level.

Table 3: Concentration table with 95% confidence level

Communes	CO_2 Concentration	IC à 95 %
Commune II	**420.80 ± 25.09[a]**	(355.06; 400.14)
Commune VI	**400.80 ± 3.96[ab]**	(398.3; 443.3)
Commune III	**389.80 ± 23.74 [abc]**	(367.3; 412.3)
Commune I	377.60 ± 6.54[bcd]	(337.46; 382.54)
Commune IV	360.00 ± 17.26[cd]	(324.7; 369.7)
Commune V	347.20 ± 45.03[d]	(378.26; 423.34)
p-value	0.001 < 0.05	

**** Means not sharing a letter are significantly different.***

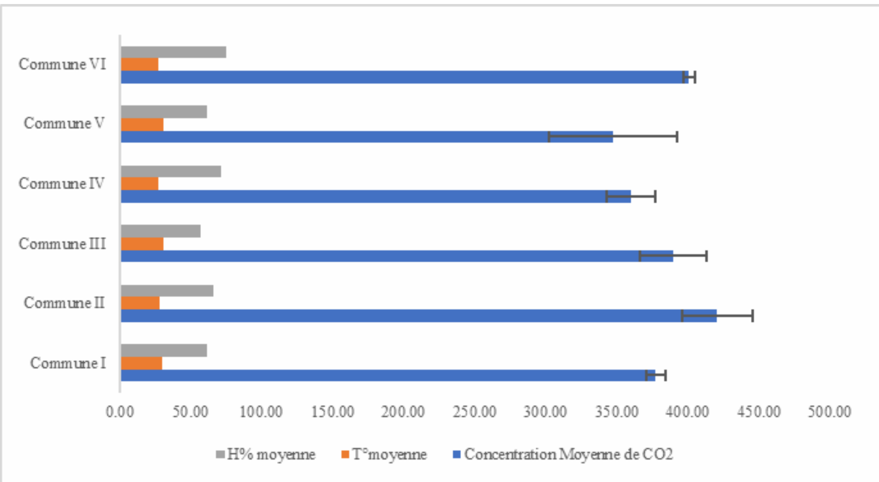

Figure 3 : Average CO_2 concentrations in communes as a function of average T° and average H%.

Measurement results show that communes II, III and VI have the highest average atmospheric CO_2 concentrations. Indeed, traffic is very heavy in these three (3) communes of the city. These communes are crisscrossed by busy roads, notably the RN 27, RN 5 and RN 6. During rush hour, traffic jams can be seen stretching for miles along these roads. These are communities with a high level of economic and industrial activity. Average temperatures in these communities at the time of measurement were 28.2 ± 1.10°C, 31.2 ± 0.84°C and 27.2 ± 3.19°C respectively, with average humidities between 66% and 75%.

Table 4: Assessment of atmospheric CO_2 concentration in Bamako's traffic zones

Communes	Average CO_2 concentration	Human exposure assessment
Commune I	377.60 ± 6.54	**Medium**
Commune II	**420.80 ± 25.09**	**Wrong**
Commune III	**389.80 ± 23.74**	**Wrong**
Commune IV	360.00 ± 17.26	**Medium**
Commune V	347.20 ± 45.03	**Medium**
Commune VI	**400.80 ± 3.96**	**Wrong**
Bamako	**382.70 ± 20.27**	**Wrong**

After a reading of the assessment results, the average CO_2 concentrations in communes II, III and VI are statically ≥ 4%, so they can generate major (high) health risks for the populations of these communes according to the matrix taken from the TESTUD article. François.

Thus, the average concentration of atmospheric CO_2 in Bamako's traffic zones, in the city, remains globally poor, generating risks Figure (4) is the result of a set of mathematical observations. Only two geographical data are represented: points and polygons. The points are graphic representations of the measurement sites, and the polygons are those of the various communes in the study area. The colored areas on the map represent zones with the above-mentioned concentration limits.

It can be deduced from this mapping that the atmospheric concentration of carbon dioxide from Bamako's road traffic is high in places, particularly in the northeastern part of the city.

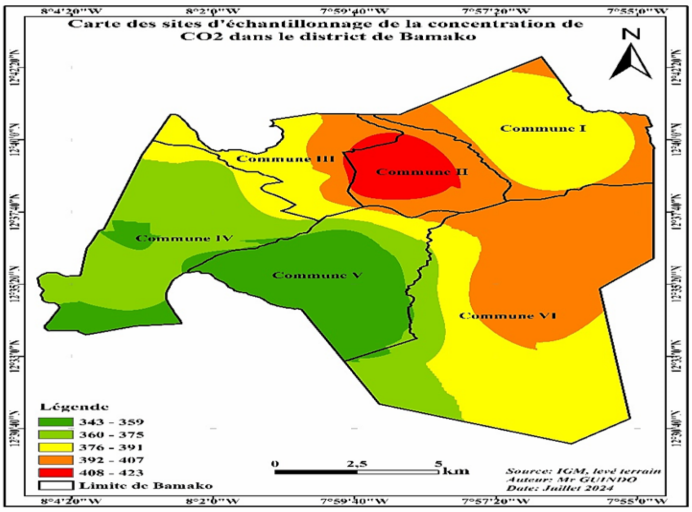

Figure 4: Mapping of spatial analysis of CO2 emissions from Bamako road traffic

IV. Discussion

The methodology adopted to assess atmospheric carbon dioxide emitted by automobile traffic in Bamako is based on the use of the “Testo 535” CO tester. The concentration of carbon dioxide generated by transport activities in the city is potentially influenced by various environmental aspects. These include related anthropogenic activities (industrial smoke, fossil fuel combustion, waste incineration), as well as temperature, humidity, and the presence of plants, animals and humans. Indeed, biophysical parameters, such as respiration and photosynthesis, can also modify CO concentrations [17].

However, sampling sites were carefully selected to minimize the influence of these aspects. Carbon dioxide sampling was carried out around traffic circles in Bamako, during August 2022.

The data obtained reveal high exposure of the Bamako population to carbon dioxide (CO) concentrations emitted by two- and four-wheel vehicles. The results show that CO levels in Bamako fluctuate between 347.20 ± 45.03 ppm and 420.80 ± 25.09 ppm, with an average of 382.70 ± 20.27 ppm. In practical terms, this means that on average, for one million molecules of air in Bamako, we find 382.70 (± 20.27) molecules of CO .

Taking as a reference the average concentration, which is equal to 382.70 ppm, each liter of air contains around 0.00857 liters (8.57 milliliters) of CO , corresponding to a mass of around 0.0168 grams. This concentration translates into a substantial total mass of CO , reaching around 47 tons for an air volume of 2,800,000 m³. This quantity is consistent with estimates expected for a large urban area or an extended measurement period.

These calculations are based on the following equations:

- Volume of CO in 1 liter of air = (382.70 × 22.4 L) / 1,000,000 = 0.00857 liter;
- Mass of CO in 1 liter of air = (0.00857 liter × 44 g) / 22.4 liters = 0.0168 gram;
- Total mass of CO for an air volume of 2,800,000 m³ = 0.0168g/liter × 2800000000 liters = 47040000 g = 47.04 tons.

This represents 0.855% of the normal concentration of carbon dioxide in atmospheric air, or 1.964g CO .

The high concentrations of CO_2 were recorded somewhat in the northern and central parts of the city. This area of heavy traffic is surrounded by hills. The low concentrations were recorded in the south-eastern part. This area is heavily forested, and the trees could act as a carbon sink.

CO_2 concentrations can be influenced by physical parameters such as temperature and humidity. However, during the course of this study, we did not record any significant levels of these parameters, which could strongly influence CO_2 levels in the city.

Nevertheless, the links between CO_2 and temperature lead to strong positive feedback, amplifying the initial disturbance [15]. The addition of carbon dioxide or water vapor causes the earth's surface to gain energy compared with the reference situation, so the city's temperature will rise [18].

According to [7], overall CO emissions in 2006 (9.6 tons) and 2013 (30.8 tons) are diluted in the atmosphere, resulting in much lower ppm concentrations than the 382.70 ppm measured locally during the study period. This points to a dramatic increase in the use of air-polluting machinery, with potentially significant health risks.

Indeed, high exposure to carbon dioxide (CO) leads to notable health repercussions, including hyperventilation, tachycardia, as well as respiratory and auditory disorders [19].

Furthermore, the World Bank study published in 2011 entitled "Environmental Analysis of the Urban Environment: Environmental Profile of the Cities of Bamako, Gao, Mopti and Sikasso" confirms this trend, reporting an increase in acute respiratory infections, corroborating the health effects observed in our analysis.

Research carried out at the Université des Sciences, des Techniques et des Technologies de Bamako (USTTB) between 2002 and 2013 indicates that the main source of air quality degradation is road traffic, with a predominance of two-wheelers over vehicles [12].

In addition, the CORUS/POLCA (Coopération pour la Recherche Universitaire Scientifique / Pollution des Capitales Africaines) project, implemented between 2007 and 2010, highlights the importance of anthropogenic sources, notably two-wheeled vehicles and residential combustion, in increasing fine particle mass concentrations in Bamako [20].

The growing vulnerability of Bamako's population to the potential risks of excessive CO_2 inhalation could be due to the socio-economic activities of unprotected roadside commuters, and others spending long hours in traffic jams on their way off duty, without any protection either. It's important to remember that poor indoor air quality remains a significant factor in this pollution.

To tackle these challenges, it is imperative to improve the monitoring of CO emissions in key sectors. The installation of air quality measurement stations would make it possible to track changes in CO levels, facilitating the implementation of appropriate mitigation and control measures.

V. Conclusion

At the end of this study, measurements of atmospheric CO_2 concentrations on the main roads in the city of Bamako were carried out, along with some of the physical parameters influencing these concentrations. Most of the data were mapped. As a result of the measurements, very high CO_2 concentrations were recorded at the sites during peak traffic hours. The level of exposure of the population to carbon dioxide (CO_2) was considerable, with significant potential risks according to the data collected. Human exposure to this pollution could lead to respiratory and heart disease. The health of the population would be threatened, especially that of the most vulnerable groups (children, the elderly, the poor, etc.).

However, with the strengthening of Mali's strategic air quality management plan and the use of environmentally-friendly technologies, it is possible to ensure efficient air quality management.

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