Development of a low-cost outdoor carbon monoxide analyzer applied to the city of Oran, Algeria.

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Development of a low-cost outdoor carbon monoxide analyzer applied to the city of Oran, Algeria.

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Abstract

In Algeria, air pollution is classified as a major risk by the law. However, this risk is underestimated because there is no operational network for measuring air quality on a continuous basis.

Despite the heavy investments made to equip several cities with these measurement systems, they are out of order due to a lack of continuous financial support.

The alternative to the absence of these air pollution measurement networks can come from the recent development of electrochemical sensor technologies for air quality monitoring which arouses a certain interest because of their miniaturization, low energy consumption and low cost.

We developed a low-cost outdoor carbon monoxide analyzer called APOMOS (Air pollution Monitoring System) based on electrochemical sensor managed by microcontroller. An application developed with the Python language makes it possible to manage process and analyze the collected data.

In order to validate the APOMOS system, the recorded measurements are compared with measurements taken by a conventional analyzer.

Comparison of the measurements resulting from conventional analyzer and those resulting from the APOMOS system gives a coefficient of determination of 98.39 %. Two versions of this system have been designed. A fixed version and another embedded, equipped with a GPS sensor. These 2 variants were used in the city of Oran in Algeria to measure the concentration of carbon monoxide continuously. The targeted pollutant is carbon monoxide. However, the design of the APOMOS system allows its evolution in an easy way in order to integrate other sensors concerning the various atmospheric pollutants.

Keywords: Air quality, carbon monoxide, electrochemical sensor, microcontroller, APOMOS.

1. Introduction

Algeria has environmental problems, especially in highly industrialized and fast-growing urban areas such as Algiers, Oran and Annaba [1].

Indeed, the intense development of urbanization has largely contributed to the degradation of ambient air quality [2]. However, there is currently no network for the continuous measurement of air quality or data on levels of air pollution in large urban centers.

Oran, a dynamic Mediterranean city and the second largest Algerian agglomeration, located in the north-west of the country as shown by Figure 1, spread out according to a rapid pace of urban growth by artificialising an average of 110 ha per year [3]. It postponed its urbanization on neighboring agglomerations [4]. In recent years, these have become urban suburbs, encompassed by the dynamics of the agglomeration. This resulted in the creation of a metropolis of more than one million inhabitants since 2008, bringing together six chief towns of communes (Oran, Es Senia, Bir El Djir, Sidi Chami, El Kerma et Hassi Bounif) [5].

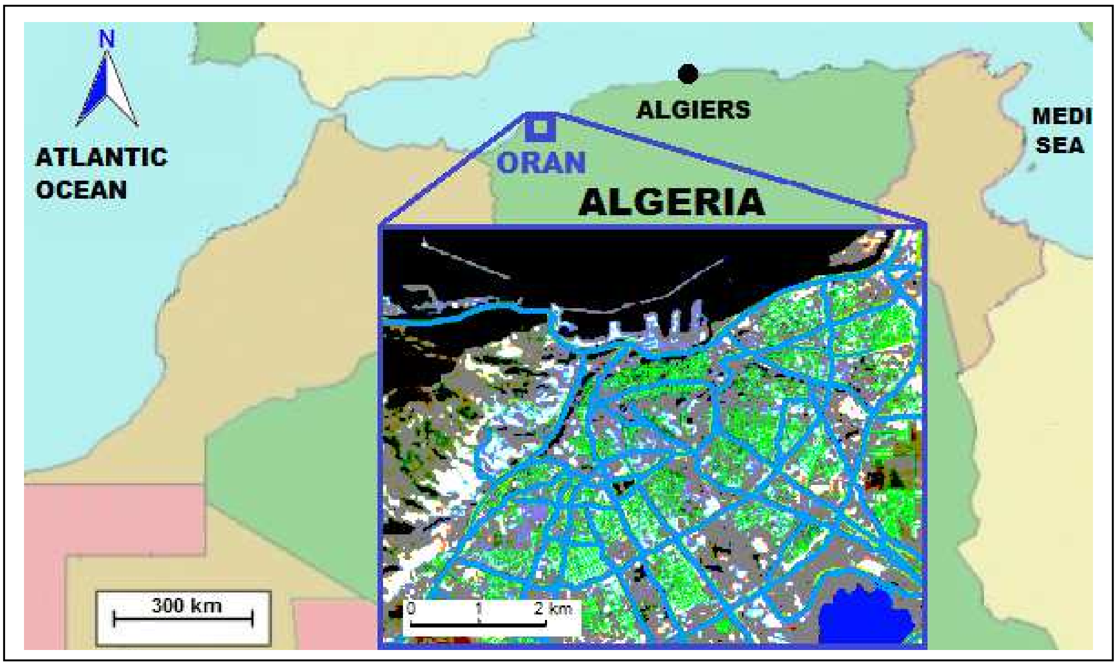

Fig.1 Geographic position of Oran city in Algeria.

Source : Authors.

The Oran region is experiencing a demographic decline in the municipality of Oran and a sharp increase in the population of the neighboring communes of Bir el Djir, Sidi Chahmi and Es Senia [6]. This phenomenon accentuates the need for mobility to the center of Oran because of its high attractiveness due to employment, shopping and leisure generating traffic overloads, thus contributing to the deterioration of air quality.

In order to assess the state of atmospheric pollution in the Oran region, it is necessary to measure it. The use of a system based on low-cost electrochemical sensors can be an interesting alternative in the absence of a network for the continuous measurement of air pollution.

In recent years, there has been a sharp rise in the use of low-cost sensor technologies for air pollution monitoring efforts [7,8].

These sensors are generally small, consume little energy, cost between 10 and 1,000 US Dollars, and measure concentrations of all major air pollutants. Compared to large, high-end solutions costing more than 100,000 US Dollars, low-cost sensors are particularly useful for large-scale static and mobile deployments [9,10,11].

Furthermore, low-cost air pollution sensors have been successfully integrated into various long-term deployments to provide detailed information on air pollution for quantitative studies and utilities [12].

The goal of this work is to design an integrated and scalable low-cost system to assess the continuous air quality in the Oran region. This system measures the concentrations of carbon monoxide in the first step. It may, thereafter, incorporate other electrochemical sensors for the main pollutants.

2. Materials and methods

Carbon monoxide, targeted in this study, is a major pollutant of air quality. It is an important compound for tropospheric chemistry. It is the dominant sink for hydroxyl radicals and is involved in ozone chemistry [13].

Carbon monoxide (CO) is a colorless and odorless gas that is very toxic. Liu et al. [14] have provided, through a national survey of 272 Chinese cities, evidence of a link between short-term exposure to carbon monoxide in ambient air and increased mortality from cardiovascular disease.

CO is not only a pollutant, but its presence is also evidence of incomplete combustion, resulting a loss of efficiency and therefore higher fuel consumption [15]. CO is formed during the combustion of biomass, fossil fuels and the oxidation of CH4 by OH radicals or other carbonaceous gases [16].

The high population density in the city of Oran causes heavy traffic [6]. The CO emitted by the large number of mobile vehicles over a long period is detrimental to human health [17].

In order to measure the concentrations of CO in outdoor ambient air in the Oran region, the solid-state, high sensitivity CO – TGS 2442 sensor was used.

This solid-state gas sensor is the heart of the designed monitoring system. The operating principle of the TGS2442 sensor is based on the sensitivity of certain metal oxides to different gases. For TGS2442, tin dioxide (SnO_2) reacts with CO molecules in the presence of oxygen (O_2) and releases free electrons. The electrons increase the conductivity and determine the decrease of the internal resistance. The sensor includes a heating element that accelerates the chemical reaction and maintains an adequate temperature inside the enclosure [15].

For each second, circuit voltage and heating voltage cycles are alternated as shown in Figure 2.

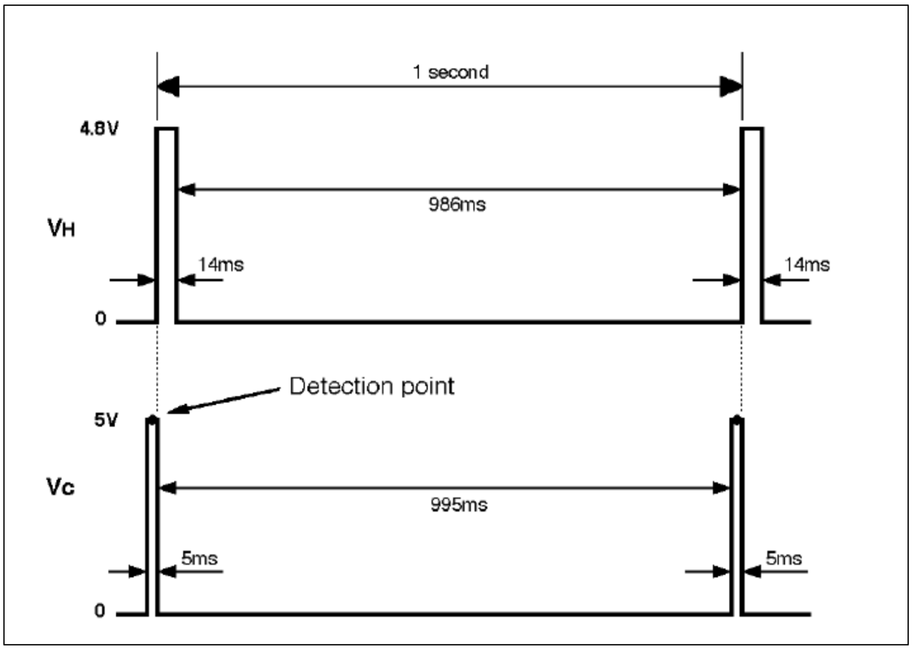

Fig.2 Circuit voltage and heating voltage cycles of TGS2442 Sensor.

Source : [18]

This operation is verified by measurements taken by an oscilloscope. Indeed, Figure 3 shows the same type of cycle cited by the manufacturer. We note that the 14 millisecond pulse starts immediately after the 5-millisecond pulse.

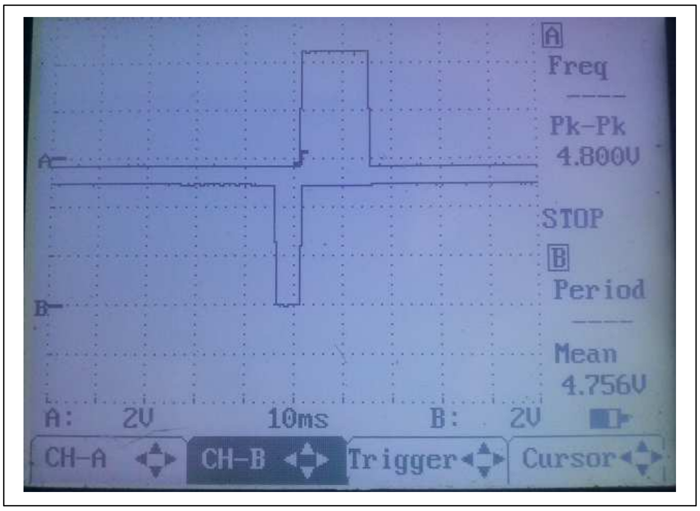

Fig.3 Double trace view of the outputs after 5 millisecond pulses followed by 14 millisecond pulses recorded by an oscilloscope.

Source : Authors

The sensor is integrated in an electronic assembly called APOMOS (Air pollution Monitoring System). It is equipped with a temperature sensor and a humidity sensor.

The heating resistor Rh of the sensor TGS2442 is controlled by a switching transistor type ZTX651, itself controlled by the RC5 output of the microcontroller.

The second resistor Rs integrated in the sensor is the element sensitive to carbon monoxide. Its value is high in a healthy environment, but drops sharply in the presence of the target gas, as shown in Figure 4.

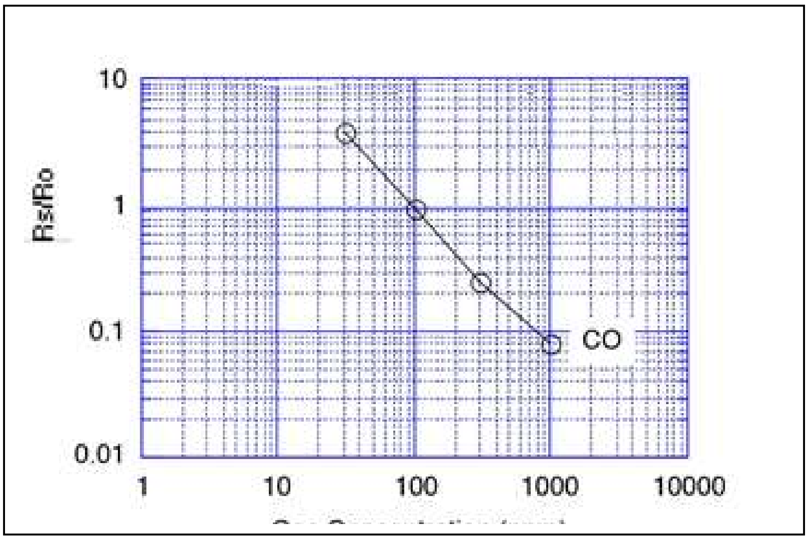

Fig.4 TGS2442 sensor response curves.

Source : [18]

According to the sensor manufacturer datasheet, the CO concentration is determined according to the following formula (Figaro, 2001).

$$C = 100 \times f\,(Rs)1/\alpha \qquad (1)$$

C : Concentration in ppm

f (Rs) : Function of the sensor resistance

α : Slope of the sensitivity curve

The slope of the sensitivity curve α is calculated using 2 sensor resistance function measurements for 50 ppm and 150 ppm.

$$\alpha = \frac{\log f\,(\mathrm{Rs})\,(150\ \mathrm{ppm}) - \log f\,(\mathrm{Rs})\,(50\ \mathrm{ppm})}{\log 150 - \log 50} \qquad (2)$$

The APOMOS prototype system is equipped with a temperature sensor type MCP9700A, sensitive from -40 ° C to + 125 ° C, with an accuracy of 0.5%, and a quiescent current of 6 µA; It is also equipped with a humidity sensor type HCZ-J3A.

The information collected by these 2 sensors is necessary to calculate the concentration of carbon monoxide because the measurements acquired on the TGS2442 are dependent on temperature and humidity as shown in Figure 5.

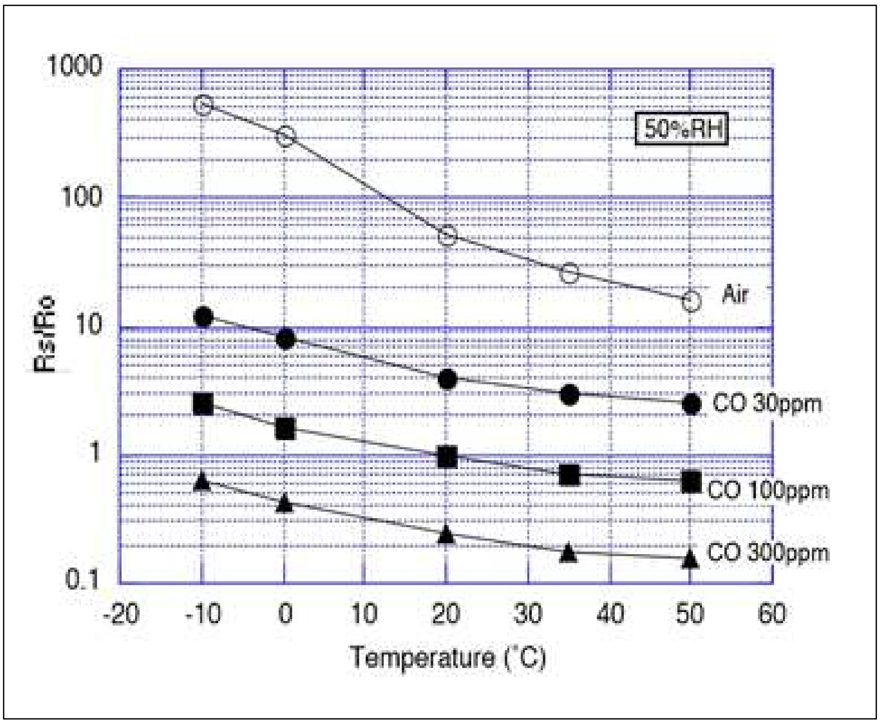

Fig.5 Influence of temperature and humidity on the TGS2442 sensor response curve.

Source : [18]

In order to validate the APOMOS system, a comparison is made with the GUNT IMR 1600 analyzer as shown in Figure 6.

a

Fig.6 (a) GUNT IMR 1600 analyzer - (b) APOMOS system with TGS2442 carbon monoxide sensor.

Source : Authors

The 2 measuring devices are placed in a containment chamber with a combustion source. The measurements collected and presented in Figure 7 show a relative agreement of the values expressed in ppm.

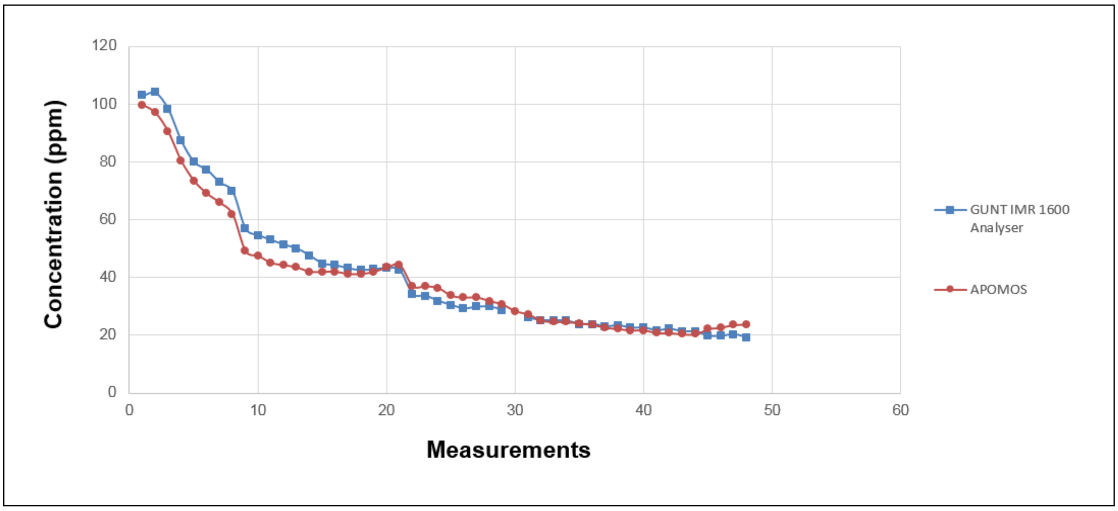

Fig.7 Comparison of the measurements expressed in ppm resulting from the GUNT IMR 1600 analyzer and those resulting from the APOMOS system.

Source : Authors

The point cloud comparison between the 2 measuring instruments indicates a coefficient of determination greater than 98% as shown in Figure 8.

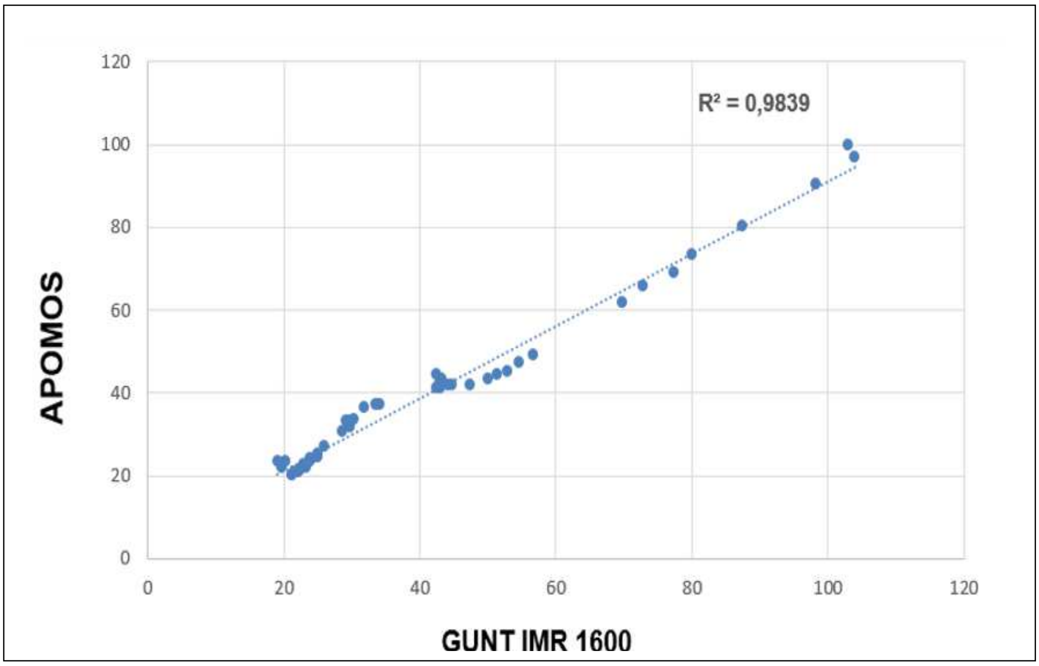

Fig.8 Comparison in point cloud of the measurements expressed in ppm resulting from the GUNT IMR 1600 analyzer and those resulting from the APOMOS system.

Source : Authors

The APOMOS system is connected to the computer with a USB Serial TTL converter allowing a USB connection to an RS232 link with a baud rate of 57600 bps.

The collected measurements are recorded in a database of SQLite type exploited by an application developed with the Python language which provides strong support for integration with other programming languages and other tools [19]. It allows us to configure the measurement system, save the data, process it, display it as a graph, and export the results in different formats. The interface, developed with PyQt and shown in Figure 9, facilitates access to the different functionalities of the APOMOS system.

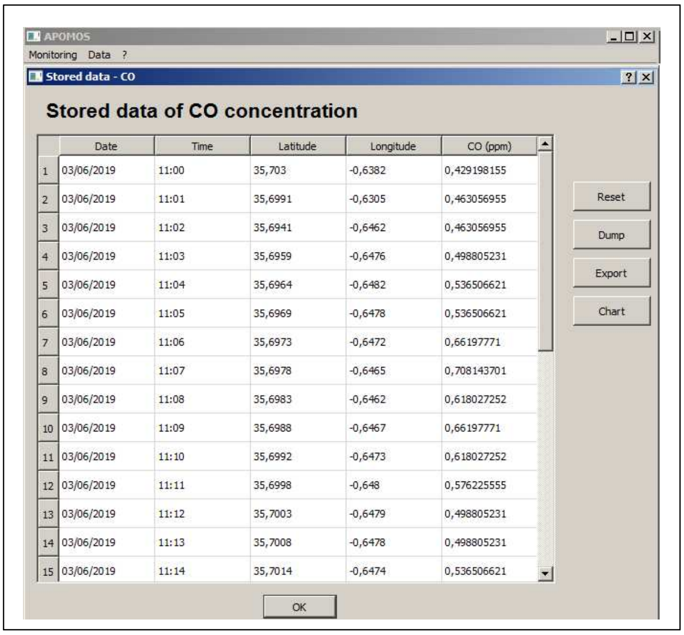

Fig.9 APOMOS system interface.

Source : Authors

A Global Positioning System (GPS) module, NEO-6M, is added to the APOMOS system to form a mobile version. Thus, measurements of CO concentration can be referenced in space and time during itinerant campaigns for the assessment of air quality in the city of Oran.

3. Results and discussion

The systems commonly used for monitoring air pollution consist of stations with large fixed sensors that continuously measure air pollutants. However, the establishment of these stations is limited by factors such as the prohibitive costs of control devices and sensors, the large size of the sensors used, the high power consumption and other technical complexities [20]

The public authorities have equipped the city of Oran with a network of 4 conventional air quality measurement stations. However, this measurement network is not operational until now.

Data on concentrations of air pollutants in Oran were collected during some academic research such as Zenata [21].

The APOMOS system with its 2 versions, one fixed and the other embedded, fills a considerable gap in air quality data in Oran.

The fixed version of the APOMOS system has been placed at the center of the city of Oran which has a dense urban traffic. The profile of carbon monoxide concentrations for a working day is shown in Figure 10. Concentration peaks correspond to the morning peak hour, which can reach 1717 vehicles / hour [22]. Another peak of lower intensity concentration is observed at evening peak hour.

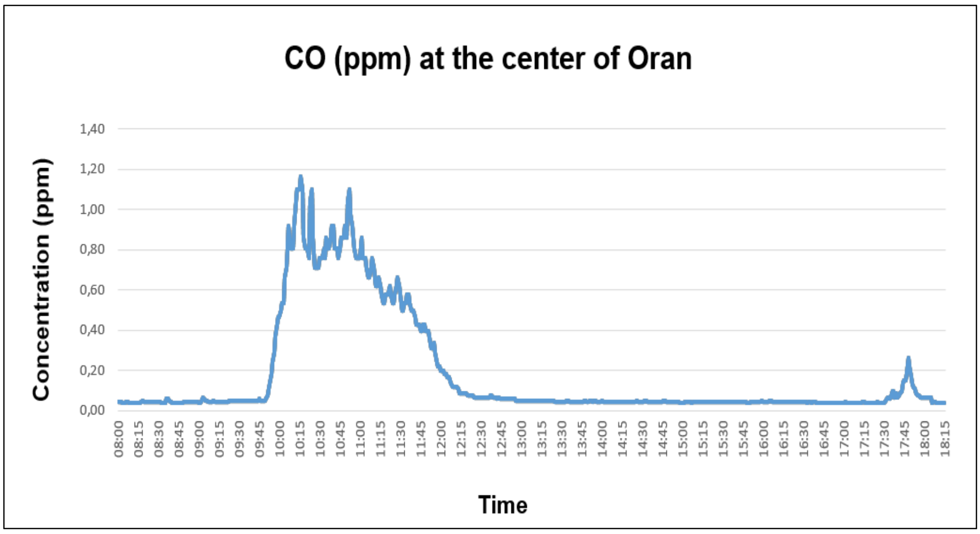

Fig.10 Profile of carbon monoxide concentrations in ppm for a working day collected in June 2019 by the fixed version of the APOMOS system in downtown Oran.

Source : Authors

The carbon monoxide concentrations recorded in Oran are of the same order of magnitude as the concentrations measured by the air quality monitoring station in the Bab-el-oued district in downtown Algiers as shown Figure 11.

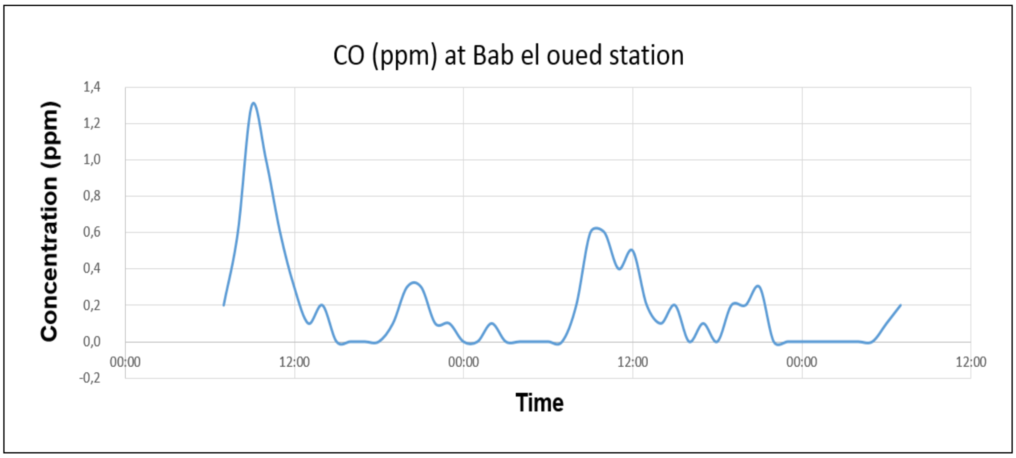

Fig.11 Concentrations of carbon monoxide recorded by the station of Bab-el-oued in Algiers in August 2006.

Source: The National Observatory for the Environment and Sustainable Development.

The concentrations recorded in Oran oscillate between 0.1 and 1.2 ppm. This is also the case with the Larbi Ben M'hidi street, which is considered to be the backbone of downtown Oran [23], of which Figure 12A shows the proportions of the maximum concentration recorded in downtown. Despite its congestion, this street is quite wide and airy by one of the prevailing winds in Oran west-southwest [24]. This explains relatively low carbon monoxide concentrations.

As shown in Fig.12B, these concentrations are stronger at the Independence Boulevard which includes an emblematic place in Oran commonly known as Tahtaha. It is a Boulevard with intense commercial activity. In addition, the measurements with the mobile version of the APOMOS system coincided with the eve of the Muslim festival of Aid El Fitr which knows a large influx of citizens for purchases related to this celebration.

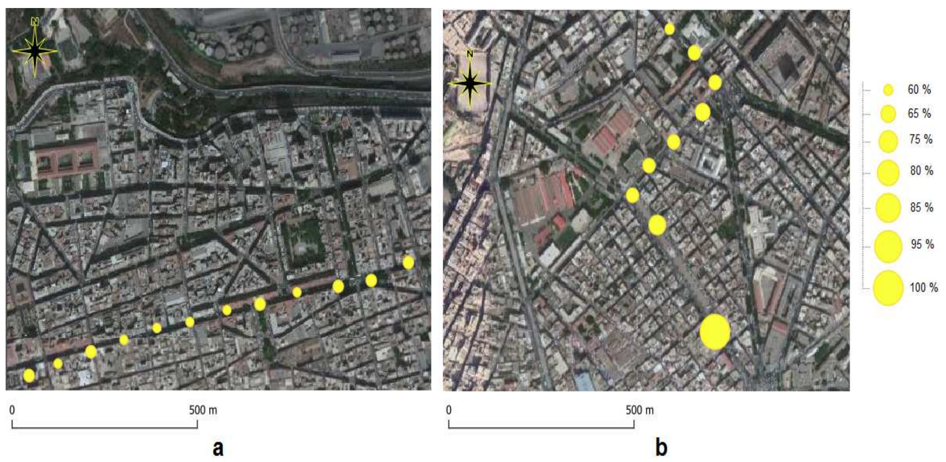

Fig.12 **(a)** Percentages of maximum concentration acquired on June 03rd, 2019 by the mobile version of the APOMOS system for measurement points on Rue Larbi Ben H'hidi in downtown Oran.

(b) Percentages of maximum concentration acquired on June 03rd, 2019 by the mobile version of the APOMOS system for the measurement points of the Independence Boulevard called Tahtaha in downtown Oran.

Source : Authors

Admittedly, the concentrations recorded are far from the level set by the World Health Organization [25] guidelines as the main streets of the city are large and subject to prevailing winds. However, these concentrations could increase significantly during special weather events that prevent winds from circulating. This situation will be even more problematic in the narrow downtown streets, which are lined with tall buildings forming canyon streets. Hence the interest of constant and widely distributed surveillance in space.

3. Conclusions

The monitoring of air quality in developing countries is in a deplorable state [26] because the monitoring of air pollution is a costly policy, which requires sufficient and sustainable financial means. In Algeria, despite the investments made to acquire these surveillance networks, they are no longer operational.

The purpose of this work is the development of an affordable air quality measurement system in several aspects: the cost, the realization and the exploitation.

The relatively old TGS2442 sensor has already proven its robustness and reliability.

It was purchased less than 7 dollars, its cost and that of the other components, enables the realization of several replicas of APOMOS system. In addition, the use of open source and free programming tools helps to control development costs. The small dimensions of the designed system make it portable and easy to operate.

Thus, the availability of portable personal analyzers for monitoring the air quality at low cost and low consumption can help significantly denser monitoring networks in urban pollution [27]. These new technologies with production at the lowest cost allow global and fast distribution [28].

The APOMOS system has been validated and tested in the city of Oran for carbon monoxide only but its scalability is ensured by the design of the electronic assembly. The APOMOS system can then easily accommodate other sensors to measure the concentrations of other air pollutants.

The replication of APOMOS system will make it possible to carry out continuous measurements of air pollution spread over large geographic areas, especially in urban areas, thus helping to protect people from exposure to poor air quality.

Declarations

Availability of data and materials

All data generated or analyzed during this study can be obtained from the corresponding author.

Competing interests

The authors declare they have no competing interests.

Funding

The authors confirm that no funding was received to carry out this study.

Authors' contributions

All the authors have contributed to the structure, content, and writing of the paper. All authors read and approved the final manuscript.

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Figures

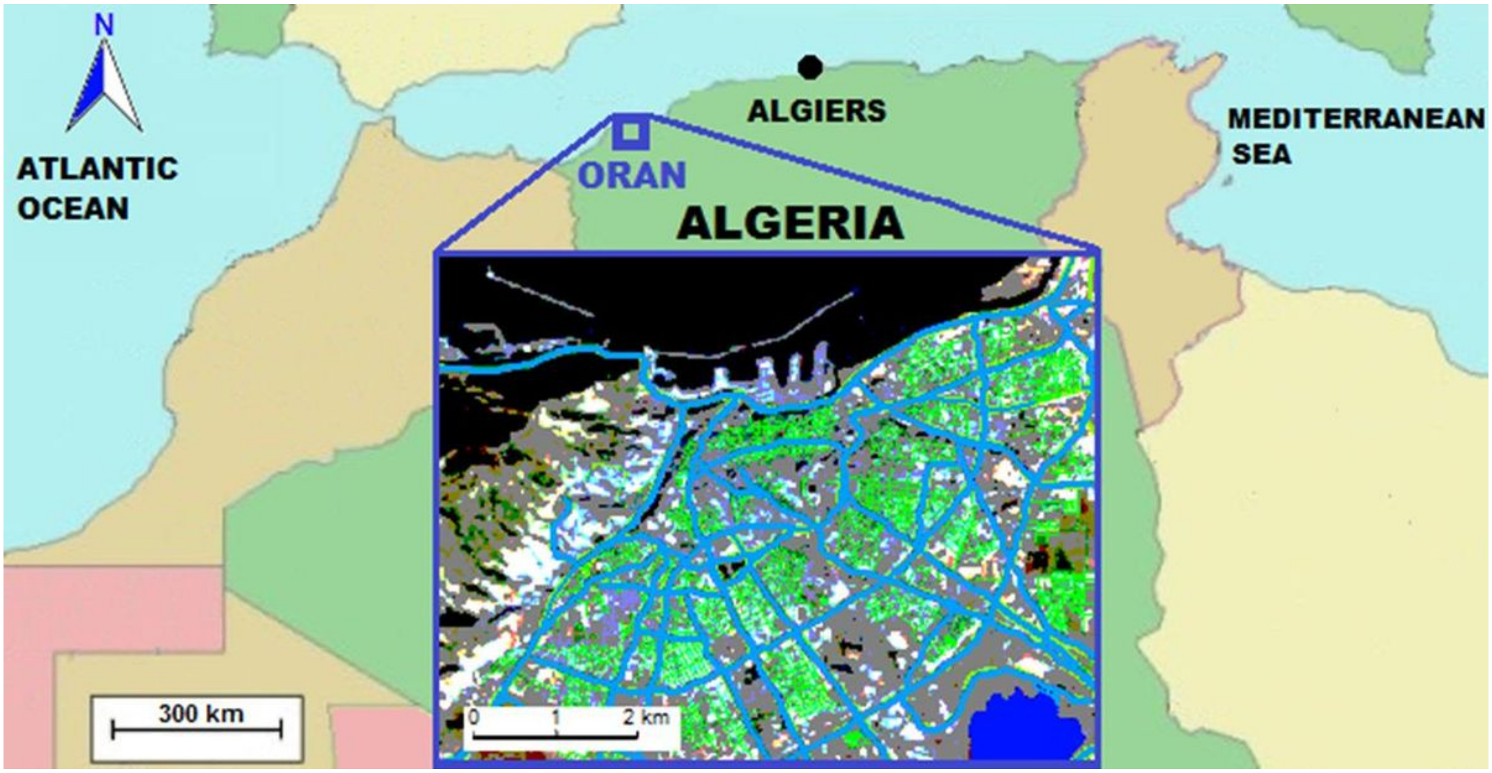


Figure 1

Geographic position of Oran city in Algeria.

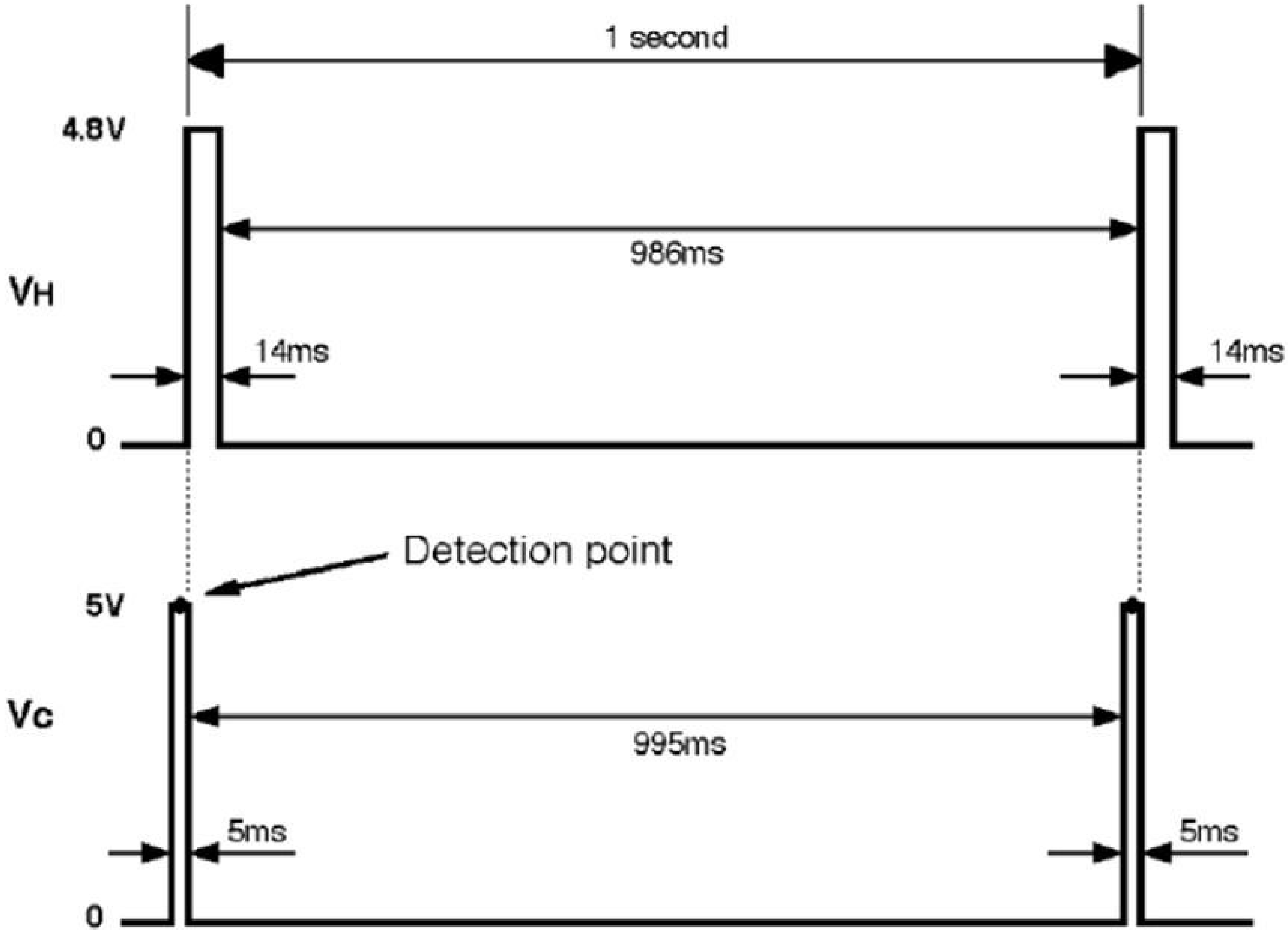


Figure 2

Circuit voltage and heating voltage cycles of TGS2442 Sensor.

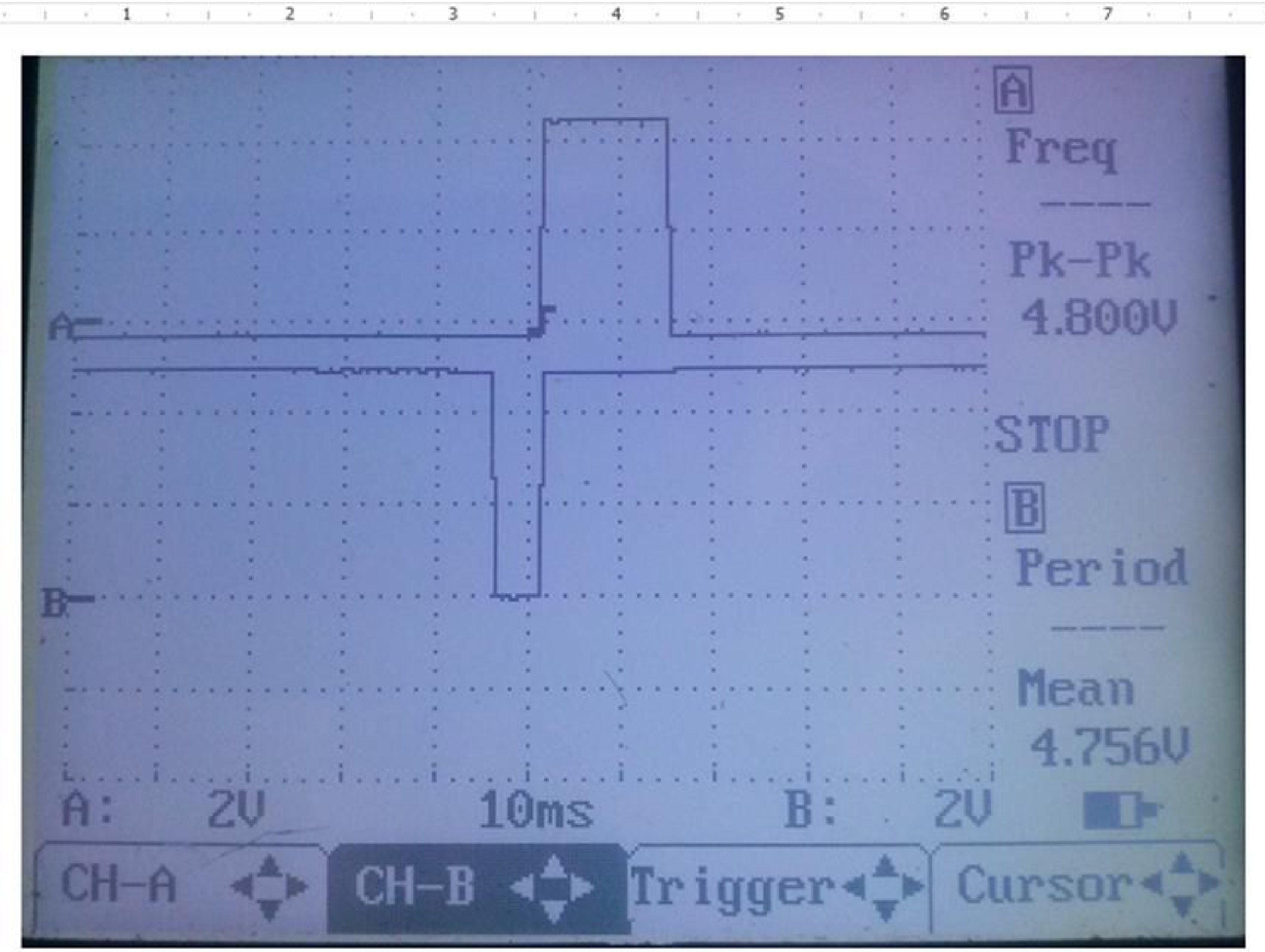


Figure 3

Double trace view of the outputs after 5 millisecond pulses followed by 14 millisecond pulses recorded by an oscilloscope.

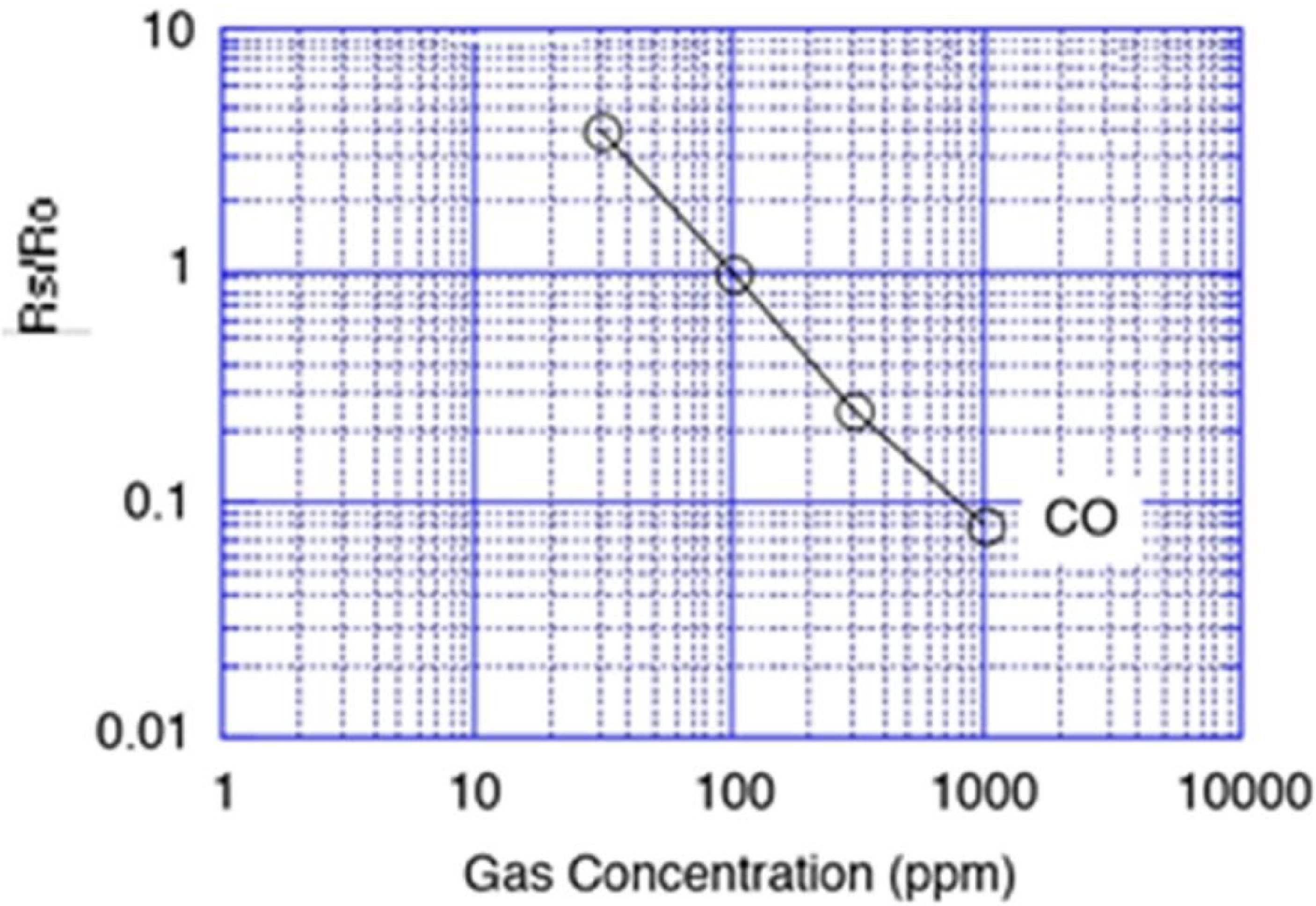


Figure 4

TGS2442 sensor response curves.

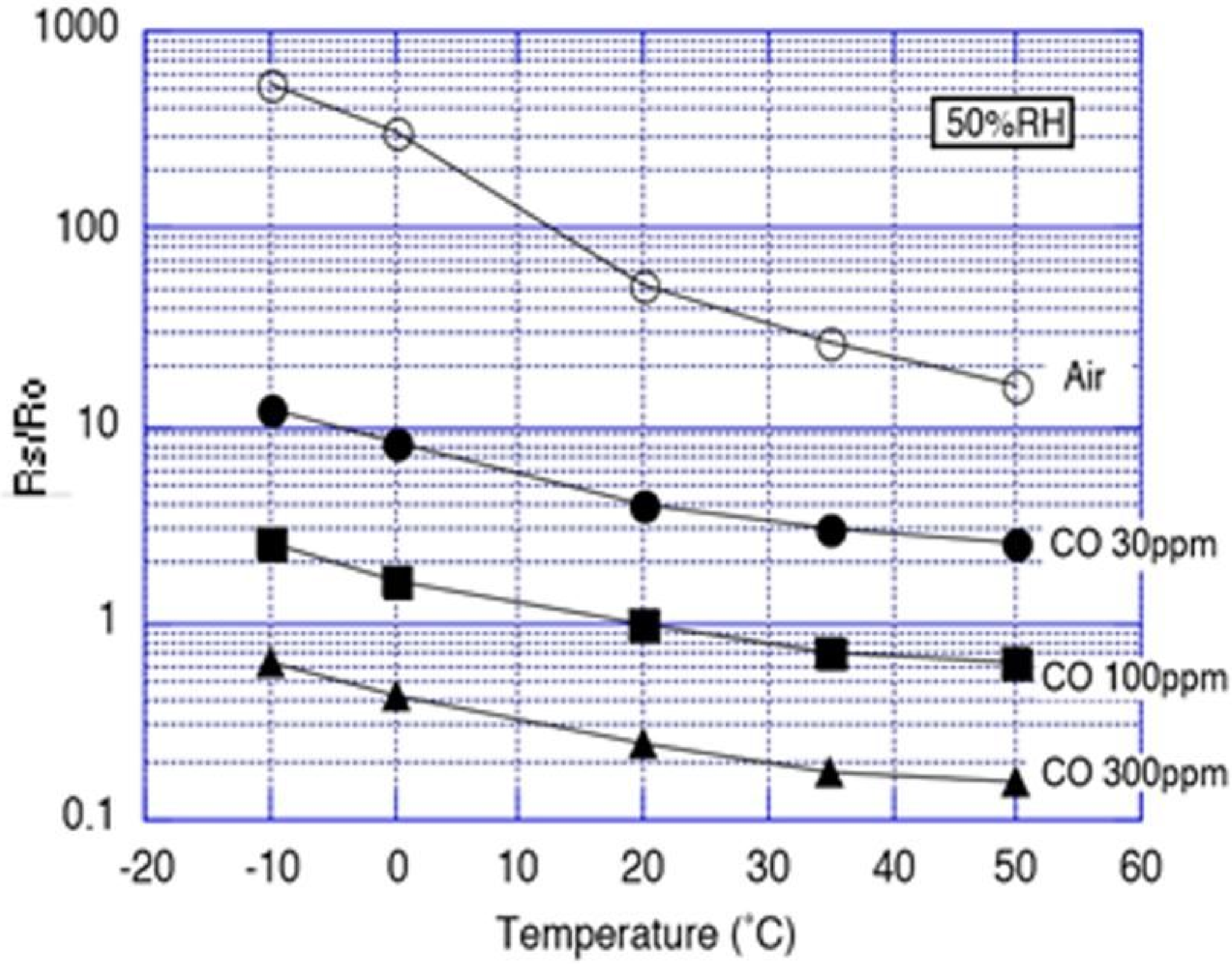


Figure 5

Influence of temperature and humidity on the TGS2442 sensor response curve.

Figure 6

(a) GUNT IMR 1600 analyzer - (b) APOMOS system with TGS2442 carbon monoxide sensor.

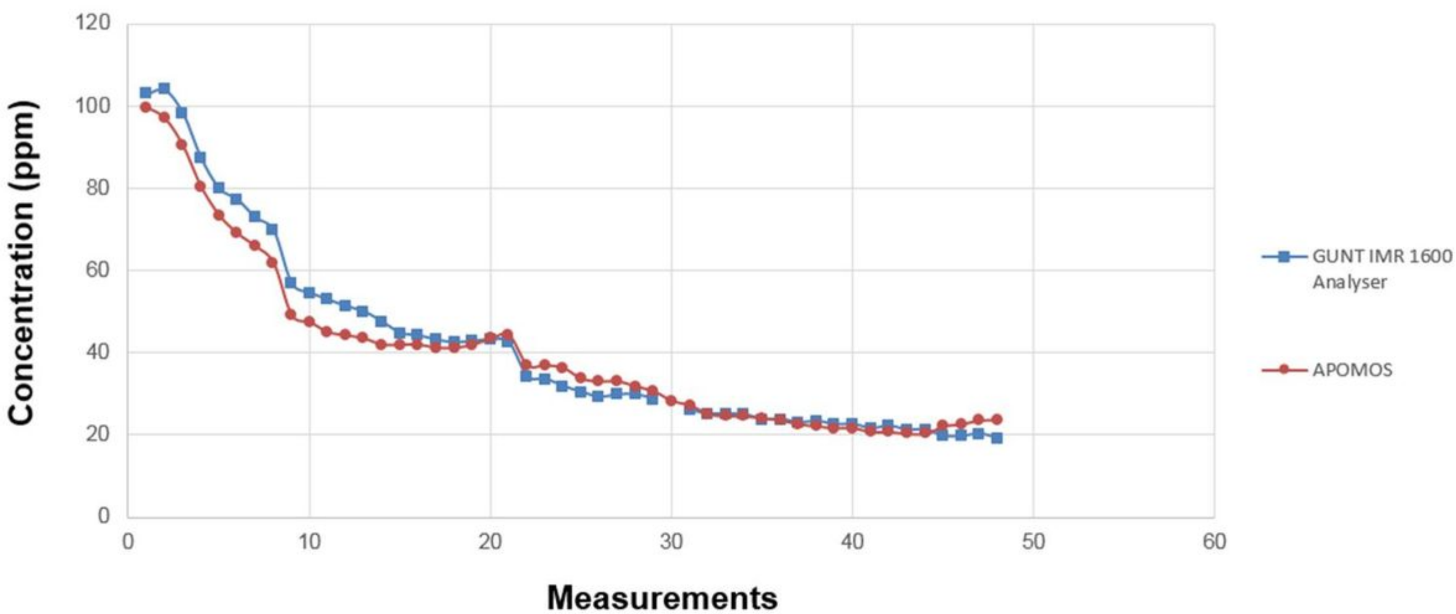


Figure 7

Comparison of the measurements expressed in ppm resulting from the GUNT229 IMR 1600 analyzer and those resulting from the APOMOS system.

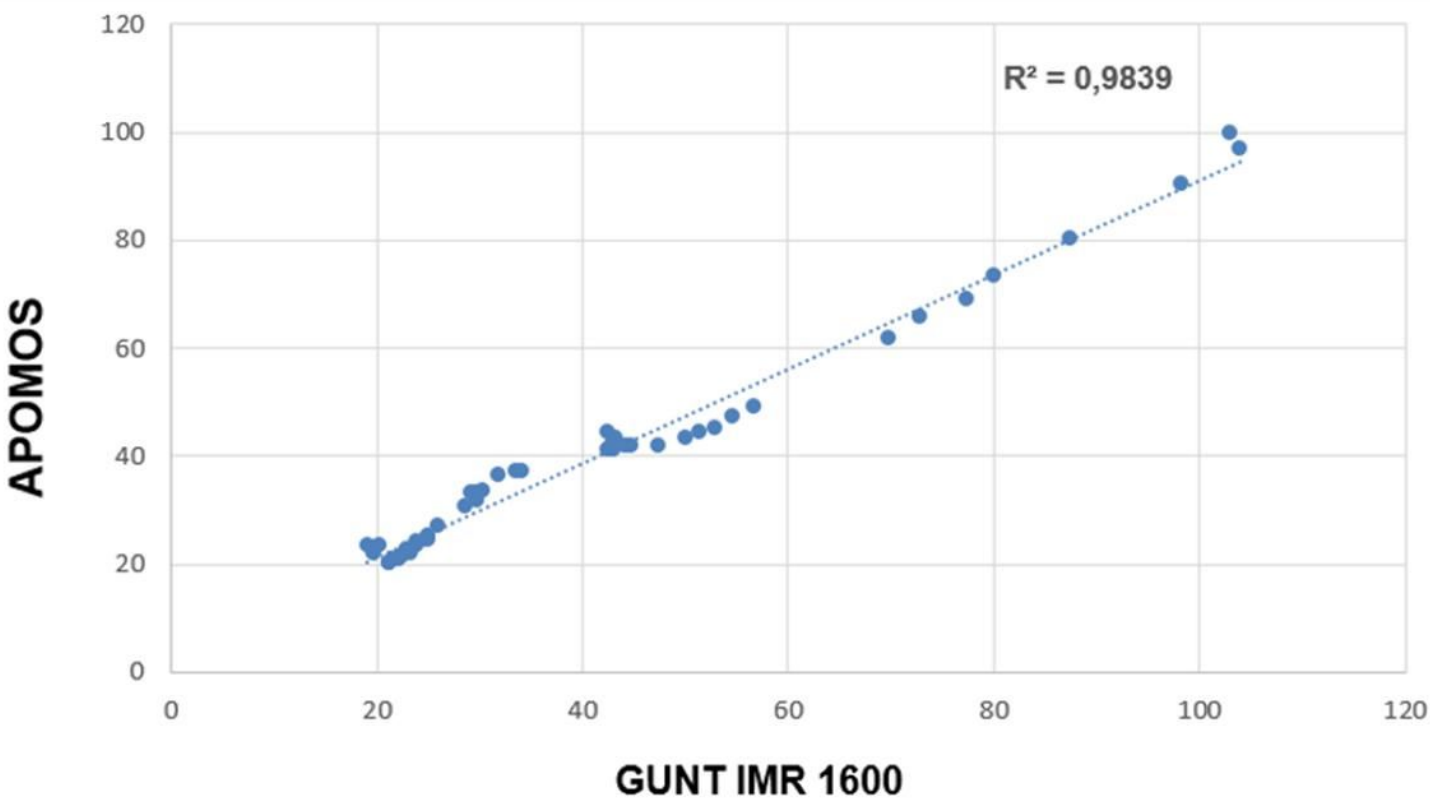
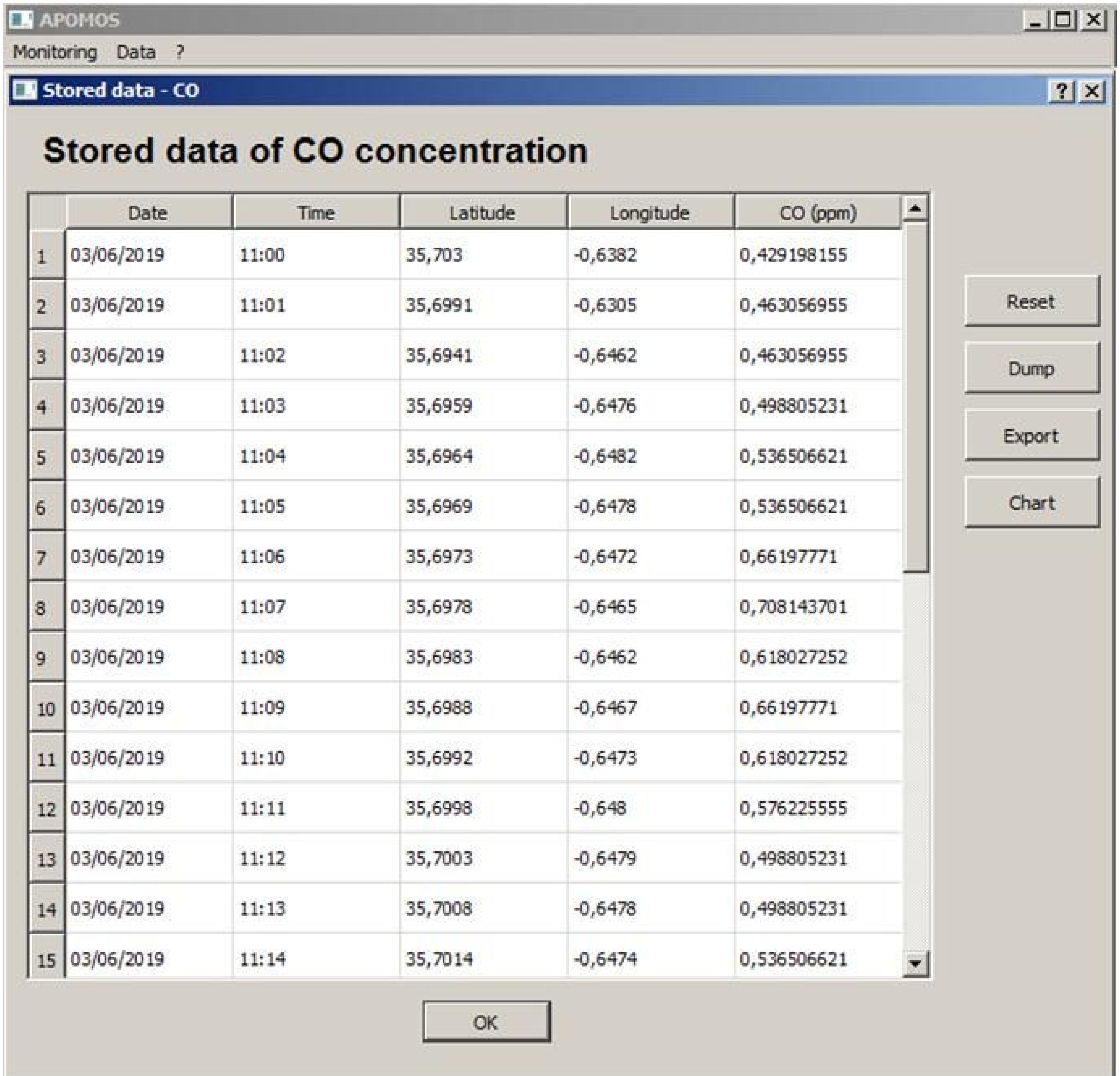


Figure 8

Comparison in point cloud of the measurements expressed in ppm resulting from the GUNT IMR 1600 analyzer and those resulting from the APOMOS system.



	Date	Time	Latitude	Longitude	CO (ppm)
1	03/06/2019	11:00	35,703	-0,6382	0,429198155
2	03/06/2019	11:01	35,6991	-0,6305	0,463056955
3	03/06/2019	11:02	35,6941	-0,6462	0,463056955
4	03/06/2019	11:03	35,6959	-0,6476	0,498805231
5	03/06/2019	11:04	35,6964	-0,6482	0,536506621
6	03/06/2019	11:05	35,6969	-0,6478	0,536506621
7	03/06/2019	11:06	35,6973	-0,6472	0,66197771
8	03/06/2019	11:07	35,6978	-0,6465	0,708143701
9	03/06/2019	11:08	35,6983	-0,6462	0,618027252
10	03/06/2019	11:09	35,6988	-0,6467	0,66197771
11	03/06/2019	11:10	35,6992	-0,6473	0,618027252
12	03/06/2019	11:11	35,6998	-0,648	0,576225555
13	03/06/2019	11:12	35,7003	-0,6479	0,498805231
14	03/06/2019	11:13	35,7008	-0,6478	0,498805231
15	03/06/2019	11:14	35,7014	-0,6474	0,536506621

Figure 9

APOMOS system interface.

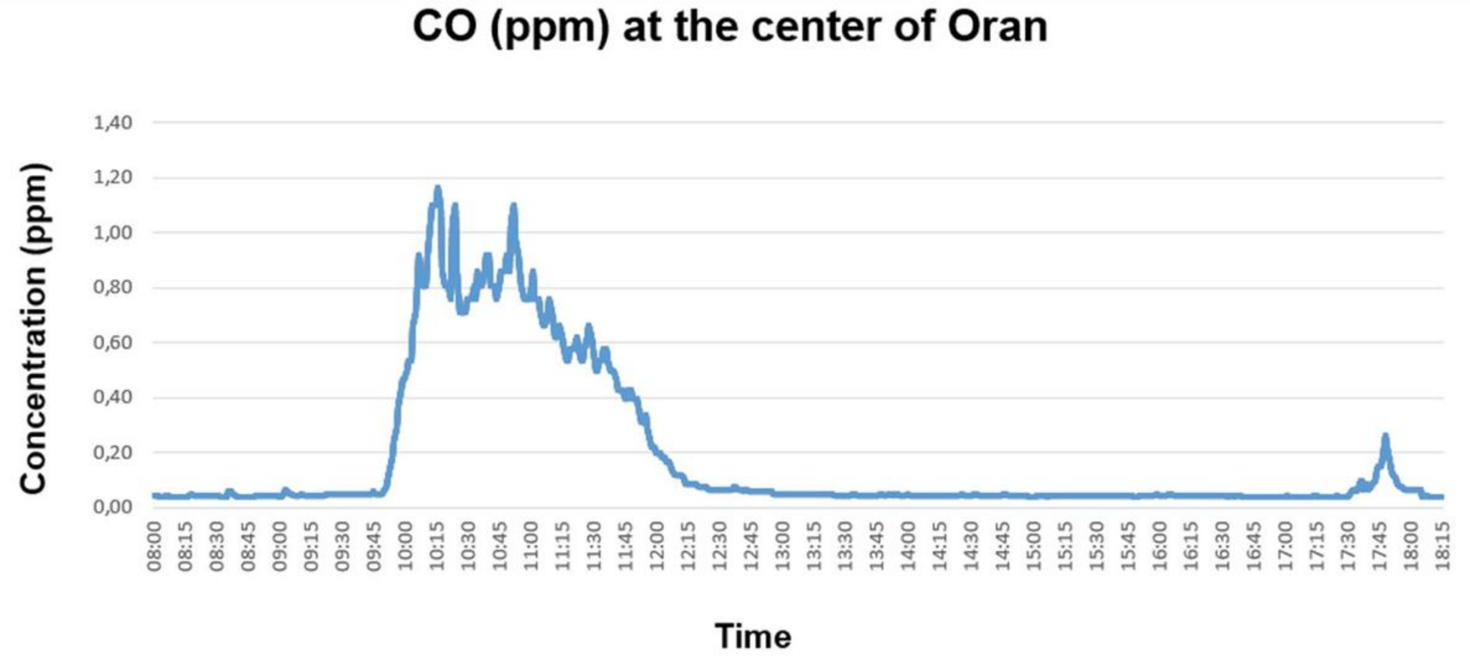


Figure 10

Profile of carbon monoxide concentrations in ppm for a working day collected in June 2019 by the fixed version of the APOMOS system in downtown Oran.

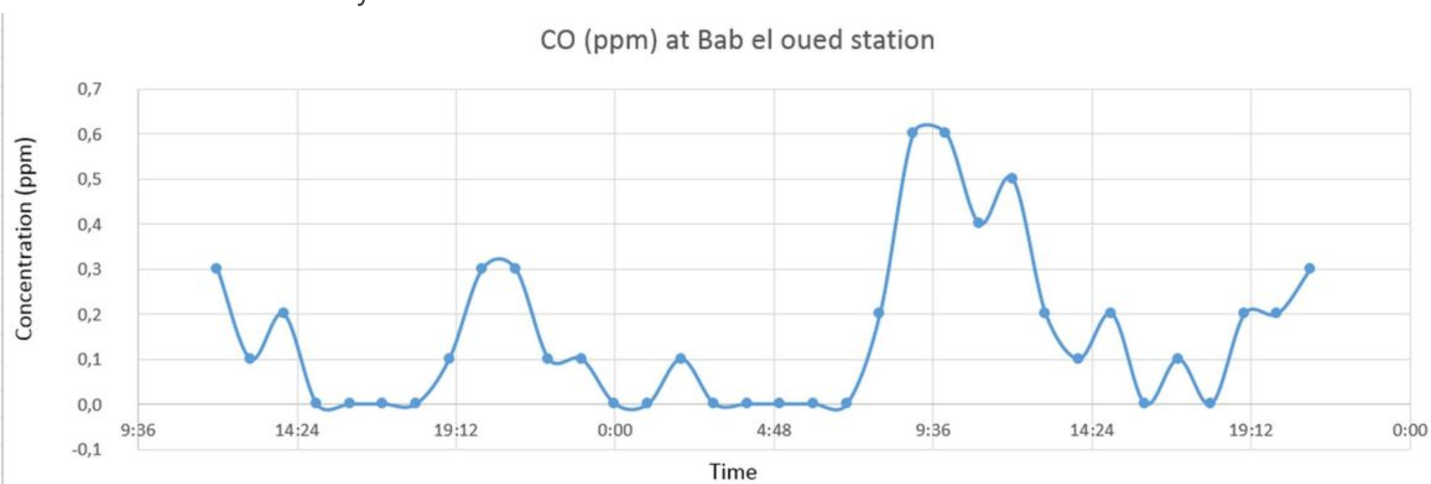


Figure 11

Concentrations of carbon monoxide recorded by the station of Bab-el-oued in Algiers in August 2006.

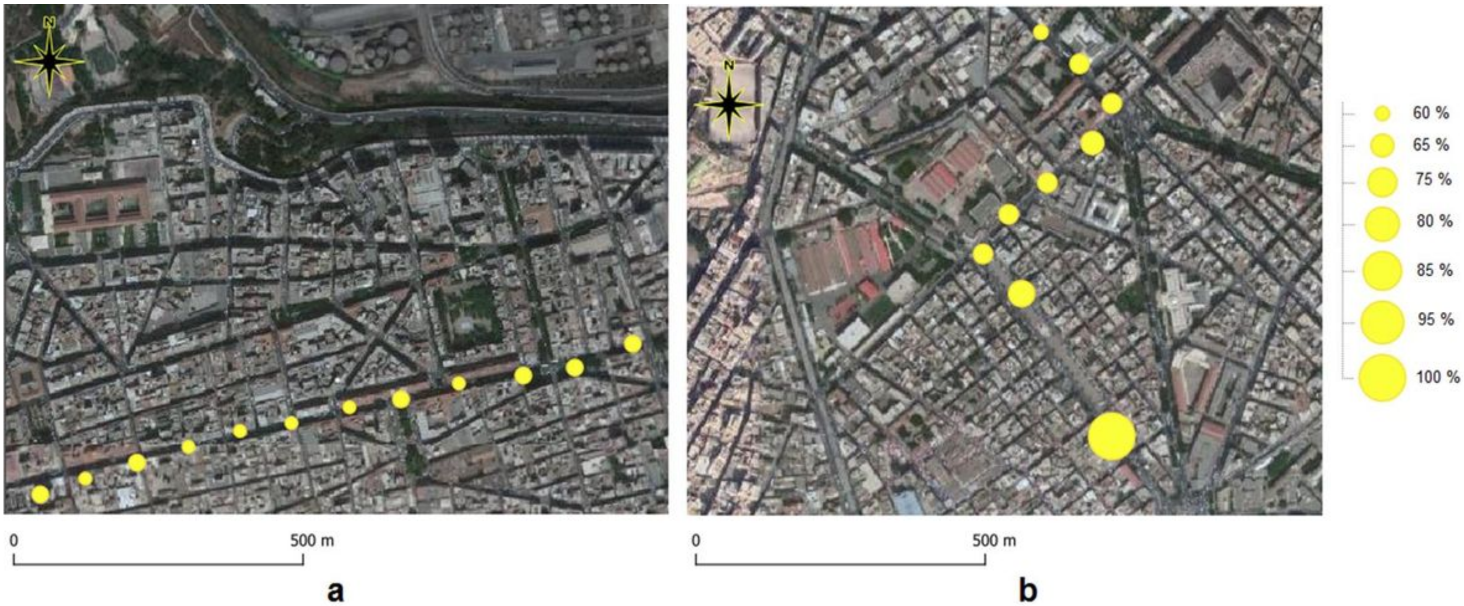


Figure 12

(a) Percentages of maximum concentration acquired on June 03rd, 2019 by the mobile version of the APOMOS system for measurement points on Rue Larbi Ben H'hidi in downtown Oran.