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Air Quality Index for Ciudad Juárez based on a Community Collaboration Scheme

Índice de Calidad de Aire para Ciudad Juárez basado en un Esquema de Colaboración Comunitaria

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Abstract

There is a global concern for the increase in health costs in a poor air quality relationship especially in urban environments. In Ciudad Juárez, Chihuahua, although it has a discontinuous monitoring of air quality, there is no air quality program that includes thresholds and contingencies for poor quality. This article proposes an environmental quality index based on the algorithms of other entities and climatic variables typical of the characteristics of the city of Ciudad Juárez and El Paso. The system is in the way of integrating the measurements of gases such as Ozone, CO and PM2.5 as well as the meteorological variables of humidity, wind speed and temperature. To obtain the above, it is necessary to strategically install sensors in different areas of the city, extract their information, store them in databases, analyze the data and create a citizen warning mechanism when the value of the index can harm the health of people. Citizen participation is a fundamental element in the development of the project. This article shows the development of the environmental quality index for Ciudad Juárez and the results of the project.

Community-based monitoring, Air quality index, Climatology

Resumen

Existe una preocupación global por el incremento en los costos de salud en relación a una mala calidad del aire sobre todo en los entornos urbanos. En Ciudad Juárez, Chihuahua si bien se tiene un monitoreo discontinuo de la calidad del aire, no se cuenta con un programa de calidad de aire que contemple umbrales y contingencias por mala calidad. Este artículo propone un índice de calidad ambiental a partir de algoritmos desarrollados en otras entidades y variables climáticas propias de las características de la región de Ciudad Juárez y El Paso. El sistema atiende de manera integrada las mediciones de concentraciones de gases criterio como el Ozono, CO y $PM_{2.5}$ así como las variables meteorológicas de humedad, velocidad de viento y temperatura. Para lograr lo anterior es necesario instalar estratégicamente sensores en diferentes áreas de la Ciudad, extraer su información, almacenarlos en bases de datos, analizar los datos y crear un mecanismo de alerta ciudadana cuando el valor del índice puede perjudicar la salud de las personas. La participación ciudadana es un elemento primordial en el desarrollo del proyecto. Este artículo muestra el desarrollo del índice de calidad ambiental para Ciudad Juárez y los resultados obtenidos del proyecto.

Índice de calidad de aire, Climatología, Monitoreo comunitario

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Introduction

Advances in computing technologies have given rise to the development of general circulation climate models that allow studying the behavior of climatic variables in time horizons of more than 20 years, such as solar radiation, temperature, precipitation, among others. (Romero Placeres, Diego Olite, & Álvarez Toste, 2006). From these results, scenarios are created on the vulnerability of populations and environmental systems with a direct effect on economic activities like agriculture, ecosystems, energy, industry, consumption, production, tourism, disasters, fishing, human well-being, construction and livestock (Fuka et al., 2014). However, the results of these models are produced on scales of hundreds of kilometers, which makes them impractical for everyday and short-term products on a city scale.

To create products of a useful scale, it is necessary to integrate to satellite products and models of medium scale surface and height networks that allow it. Therefore, climate is a set of conditions, obtained by data, collected by weather stations. That is, the information we see allows us to establish climatic models with variations depending on where we are on the surface, in addition to studying the climatic changes that have occurred from the past and predicting the future (Guevara Sanginés, 2005). Environmental quality is understood as an arduous set of human and environmental factors that have a favorable or unfavorable impact on society's life (Nichol & Wong, 2005).

Within the public health area, the emission of greenhouse gases and radiactive forcing agents contribute to the increase of toxic aerosol loads in urban environments. While the former have a global effect, the latter affect the exposed people locally. Global climate change coupled with poor environmental conditions has a synergistic effect which keeps those responsible for public health programs on constant alert ("Climate Change and Health," 2017) (Querol, 2008).

This project addresses the need of having a practical and easy-to-interpret indicator that allows the community to be informed and alert. Most of the air quality indices are based on monitoring station readings with geospatial coverage of 5 km or more, so it does not necessarily reflect the environmental conditions that affect most people.

The idea is to "down-scaling" environmental conditions at geospatial scales of less than 1 km. In the case of Ciudad Juárez, there is no information system and, at the moment, there is only one reference station located north of the city. Therefore, there are areas of the city that may be exposed to dangerous concentrations and that are not registered by the reference stations. The next challenge is to disseminate information relevant to the community and decision makers, which includes not only weather information such as humidity, wind and temperature, but also relevant pollutants that, in the case of Ciudad Juárez, are ozone (in summer), suspended particles (all year) and carbon monoxide (especially in winter) (Correa García, 2011). Ideally, a practical indicator yields numerical values on a standardized scale for all gases and total suspended particles in a range between 1-100. The foregoing would serve as a basis for the identification and feasibility analysis applicable to the study and development of the environmental quality index.

This project presents a practical proposal of the index, which is associated with health hazard of the standardized levels from a palette of colors that distinguish the appropriate level. (MATUS C., PATRICIA, & LUCERO CH., 2002).

In the sections presented below, the elements that make up the environmental quality index are explained in detail, as well as the methodology used, and, finally, the results and conclusions obtained at the end of the project.

Air quality: elements and challenges

One of the challenges was to identify the elements that would comprise the air quality index and the methods for obtaining, storage, process and disseminate the information.

First, the variables used were: carbon monoxide (CO), ozone (O3) and fine particles with aerodynamic diameter less than 2.5 micrometers (PM2.5). The criteria used considered the toxicology of the pollutants and the damage they cause to health, as well as the diseases that result from exposure, the optimal frequency of measurement and average concentration values and their relevance in terms of presence in the atmosphere (Rosales-castillo et al., 2001) (Rojas Bracho & Garibay Bravo, 2003).

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To estimate the toxicology, the thresholds of protection and concentration criteria established in the Mexican Official Standards (Federation, 2012) were considered to evaluate air quality with respect to ozone (O3), sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), total suspended particles (TSP) and particles smaller than 10 micrometers (PM10).

Contaminante	Valores límite			Normas Oficiales Mexicanas
Ozono (O3)	Exposición aguda		Exposición crónica	
	Concentración y tiempo promedio	Frecuencia máxima aceptable	(Para protección de la salud de la población susceptible)	
	0.11 ppm (1 hora) (216 µg/m3)	Ninguna vez al año		Modificación a la NOM-020-SSA1-1993*
	0.08 ppm (8 horas)	Quinto máximo en un año		
Monóxido de carbono (CO)	11 ppm (8 horas) (12595 µg/m3)	1 vez al año		NOM-021-SSA1-1993**
Partículas con diámetro aerodinámico equivalente igual o menor a 10 micrómetros (PM10); Partículas menores a 2.5 micrómetros (PM2.5)	120 µg/m3 promedio de 24 horas. 65 µg/m3 promedio de 24 horas.	1 vez al año	50 µg/m3 (media aritmética anual) 15 µg/m3 (promedio aritmético anual)	Modificación a la NOM-025-SSA1-1993**
	* Diario Oficial de la Federación del 30 de octubre de 2002.			
	** Diario Oficial de la Federación del 26 de septiembre de 2005.			

Table 1 Official Mexican Standards
Source: SEMARNAT

An environmental indicator (Perevochtchikova, 2013) must therefore meet a series of fundamental requirements: (Quiroga, 2001) (Escobar, 2006)

- Be scientifically valid.
- Be representative.
- Be sensitive to changes that occur in the environment or in human activities related to it.
- Be based on reliable and good quality data.
- Offer relevant information to the user.

Methodology

One of the main foundations used for the development of this project was the IMECA, defined as a tool created to report pollution levels in an easy and timely manner, using the standard metric of the NADF-009-AIR-2006 standard which, through identifiers (1-100), informs the level of environmental quality every 1.8 or 24 hours depending on the values to be measured.

However, the method used in this project defines as a basis the equations and cut-off points established in the Official Mexican Standard for the variables used and adapts the readings with a minimum amount of time, making possible to monitor every 5 minutes or even reduce it up to half the time. The established variables are recorded, considering that their selection has been to satisfy the need to create devices for the Autonomous University of Ciudad Juárez.

Once available in the website, the processes of the collected data were established.

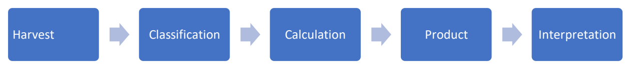

Figure 1 Processes for a quality index
Source: Own Elaboration

Collection

The collection, as the first process, is carried out through a web service, where it contains the readings with the actual values of the air quality station instrument and is updated every five minutes.

The values are stored in the SQL database, as well as MongoDB. However, only those that correspond to the variables mentioned above and which are used to define the environmental quality index are selected. Also, if necessary, the extraction of others such as: coarse suspended particles (PM10), sulfur dioxide (SO2) and nitrogen oxides (NOx) can be included.

Classification

The classification is established according to the collection, and is carried out individually in terms of the value of the data. Likewise, the range of Air Quality Index is determined based on a color palette used in Mexico City's air quality program, presented in Table 2, which is identified by means of a color assigned to the interval of the variable. The color ranges from green, which indicates good quality, to other colors, reaching a violet shade, which indicates that the quality is extremely bad. It is also necessary to detail that the air quality intervals have a difference of 50 points between each of them.

Assigned color	Quality Interval
(green)	0 – 50
(yellow)	51 – 100
(orange)	101 – 150
(red)	151 – 200
(purple)	Greater than 201

Table 2 Environmental indicator
Source: Own Elaboration.

The following table indicates, according to the color, the corresponding recommendations.

	The air quality is:
Good	Suitable for outdoor activities
Regular	You can carry out outdoor activities
Bad	Avoid outdoor activities, watch for air quality information
Very Bad	Avoid leaving home and keep windows closed, be aware of air quality information
Extremely Bad	Protect your health, do not use the car and avoid leaving home, be aware of air quality information

Table 3 Air quality indicator
Source: SEMARNAT

However, the cut-off points are different between each other. They were assigned a color where the reading value must have resided in one of them. Each interval depends on the concentration, defining different cut-off points, independent of each other. In addition, the intervals will not be unified, since they are in different units, that is, the CO interval in parts per million (PPM), the O3 interval in parts per billion (PPB) and the PM2.5 interval in micrograms/cubic meter (µg/m^3).

The concentration range (C) represents the value on the scale corresponding to each variable and will serve to perform the equation which will result in a number within the color range. The cut-off points for carbon dioxide (CO) in Table 4 are found in parts per million (PPM), but there is the possibility of converting to another unit if required.

Quality Interval	CO Interval
(green)	0.00 – 5.50
(yellow)	5.51 – 11.00
(orange)	11.01 – 16.50
(red)	16.51 – 22.00
(purple)	> 22.00

Table 4 Carbon monoxide intervals
Source: Prepared by the authors

The cut-off points for ozone (O3) in Table 5 are in parts per billion (PPB). This interval was modified to adapt from PPM to PPB, and it was verified that the same result was obtained without any variation due to the change of units.

Quality Interval	Interval O_3
(green)	0 – 55
(yellow)	56 – 110
(orange)	111 – 165
(red)	166 – 220
(purple)	> 220

Table 4 Ozone interval
Source: Own Elaboration

The cut-off points for suspended particles 2.5 in Table 6 are in microgram/cubic meter (µg/m^3). The interval between each one is different from the previous ones since it follows the United States quality index.

Quality Interval	Interval $PM_{2.5}$
(green)	0.00 – 15.40
(yellow)	15.50 – 40.40
(orange)	40.50 – 65.40
(red)	65.50 – 150.40
(purple)	> 150.40

Table 5 Interval of suspended particles *2.5*
Source: Own Elaboration

Calculation

The calculation of the environmental quality index is based on the process of air quality classification, since it depends on the interval that will correspond to the value recorded.

Air quality algorithms were used as the basis to determine a significant value of some color, in order to establish a correlation to a color. These equations are linked to the concentration range and air quality index. The above refers to the fact that the equation is equal to the concentration of the variable, where the intervals are involved, taking into account the cut-off points to replace the values depending on the case of each of them. More than 3 variables related to air quality can be considered or, if necessary, increase them.

The transformation equation varies according to the established cut-off points of the concentration ranges, but it can be generalized. The interval (I) is the result of the equation assigned according to the corresponding cut-off point.

CO intervals can be calculated with the general equation. They cover the average limit of eight hours:

I = C *100/11

The intervals of O3 can be calculated with the general equation and they cover the average permissible limit of one hour, taking into account that it was exclusively modified to be interpreted in PPB:

I = C *100/110

The transformation equation in Table 7 for CO is established according to the cut-off points, both of the quality range and the corresponding concentration range.

	C	I
CO	0.09	0.81
O3	32.36	29.41
PM2.5	19.45	58.77

Tabla 7 Carbon monoxide transformation equations
Source: Own Elaboration.

The transformation equation in Table 8 for O3 is established according to the cut-off points, both of the quality range and the corresponding concentration range.

Intervalo O_3	Equation O_3
0 – 55	I = C * 50/55
56 - 110	I = C * 50/55
111 - 165	I = C * 50/55
166 - 220	I = C * 50/55
> 220	I = C * 200/222

Tabla 8 Ozone transformation equations
Source: Own Elaboration

The transformation equation in Table 9 for PM2.5 is established according to the cut-off points, both of the quality range and the corresponding concentration range, which is part of the concentration range, considered necessary for the final result.

Interval PM2.5	Equation PM2.5
0 - 15.40	I = C * 50/15.4
15.50 – 40.40	I = 20.50+C * 49/24.9
40.50 – 65.40	I = 21.30+C * 49/24.9
65.50 - 150.40	I = 113.20+C * 49/84.9
> 150.40	I = C * 201/150.5

Table 9 Transformation equations of suspended particles 2.5
Source: Own Elaboration

Product

The product is the relation between the quality interval and the result of the transformation equation. First, the value obtained from the previous process must be assigned to a color that indicates the air quality.

For example, the collection process has a value of 0.09 PPM for carbon monoxide, a value of 32.36 PPB for ozone and a value of 19.45 $\mu g/m^3$ for suspended particles. Applying the cut-off intervals according to the previous concentrations in Table 9 and the quality range is obtained in Table 10.

	C	Intervalo	Ecuación
CO	0.09	0.00 - 5.50	I = C * 50/5.5
O3	32.36	0 – 55	I = C * 50/55
PM2.5	19.45	15.50– 40.40	I = 20.50+C * 49/24.9

Tabla 6 Calculation Example
Source: Own Elaboration

Interval CO	Equation CO
0.00 - 5.50	I = C * 50/5.5
5.51 - 11.00	I = C * 50/5.5
11.01 - 16.50	I = C * 50/5.5
16.52 - 22.00	I = C * 50/5.5
> 22.00	I = C * 200/22

Tabla 7 Example calculation result
Source: Own Elaboration.

The product that resulted from applying first the classification process and then the calculation process provides the interval individually, independent of one another.

Interpretation

The interpretation is the final phase of the process, which involves the previous steps, the product being related to the quality interval. It is also present when selecting which variable has the greatest importance in relation to the quality range. The foregoing was defined at the request of experts, since we did not consider with arithmetic any value obtained, as it would mean leaving the possibility prone to error. That is, not taking the average of the values resulting from the previous process, but selecting the one with a higher value.

For example, in Table 11 the color of the quality range in carbon monoxide and ozone is green, and in suspended particles 2.5 is yellow.

	I	Quality Interval
CO	0.81	
O3	29.41	
PM2.5	58.77	

Tabla 8 Interpretación de ejemplo
Source: Own Elaboration.

Using the average with the intervals in the previous table, it results in a value of 29.66 with a green color, indicating that it does not even approach the actual value of PM2.5.

Results

The results correspond to data generated by the IIT-01 reference station located on the campus of the Institute of Engineering and Technology of the Autonomous University of Ciudad Juárez (31 ° 44.28 'N, 106 ° 25.57' W).

This station samples every minute averages of the criteria gases (carbon monoxide, sulfur dioxide, tropospheric ozone, nitrogen oxides) and fine and coarse particles (PM2.5 and PM10). Four samples were taken on a random day within the first four months of 2019.

On February 6, maximum and minimum temperatures were reported respectively 18 °C/10 °C. 24 hours are shown in Graph 1 of the ozone air quality index.

It can be seen that during the day it was green, that is, the measured value did not exceed the range of 50. The above assures that the air quality was good for ozone.

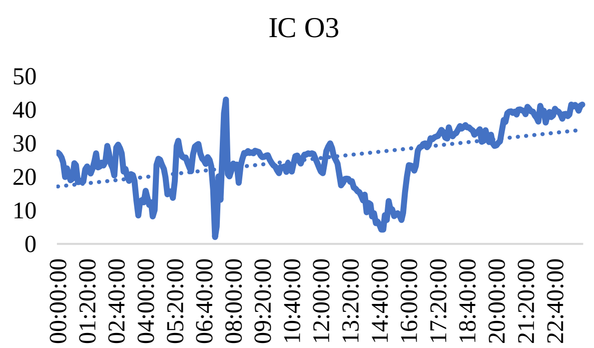

Gráfico 1 Índice de calidad para ozono 6 de febrero
Source: Own Elaboration.

Graph 2 shows 24 hours and, as with ozone, also resulted in green, so it could be said that there was good quality for carbon monoxide.

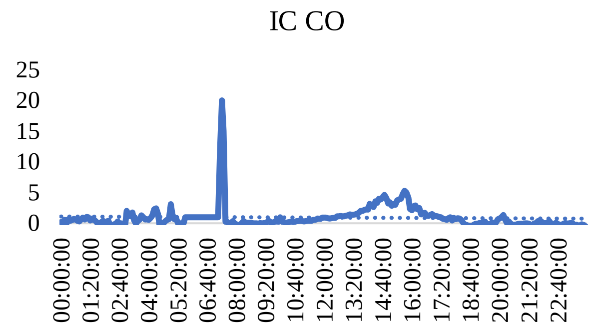

Gráfico 2 Quality index for carbon monoxide February 6
Source: Own Elaboration

In Graph 3, a noticeable change can be seen around 8:00 p.m. It should be noted that, according to the records of that day, the wind speed increased near the same time and particles began to increase, so that the air quality was regular.

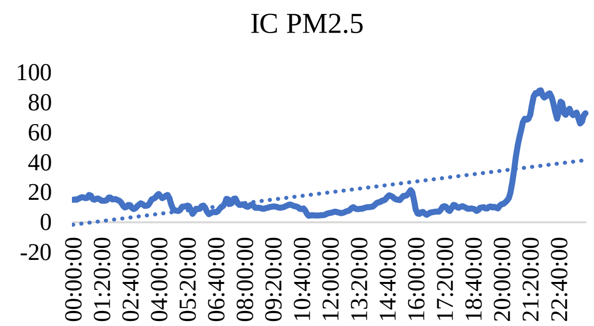

Gráfico 3 Índice de calidad para partículas suspendidas 2.5 6 de febrero
Source: Own Elaboration

In general, the air quality was good, except after 20:00 hours when it changed to moderate.

On March 7, maximum and minimum temperatures were reported as 27 °C/11 °C, respectively. In Graph 4 regarding ozone, it can be seen that the air quality in general was good, except for a few minutes, when it increased between two readings of 5 minutes each.

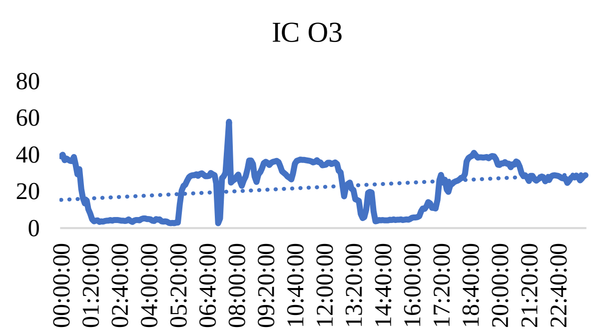

Gráfico 4 Índice de calidad para ozono 7 de marzo
Source: Own Elaboration.

In Graph 5 we can visualize that it is good, without having any drastic changes or any effect that could make it vary.

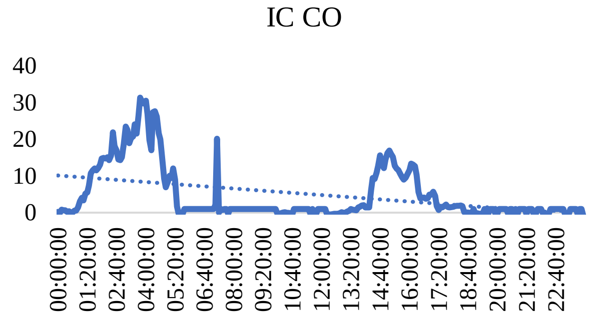

Gráfico 5 Quality index for carbon monoxide March 7
Source: Own Elaboration

In Graph 6, corresponding to suspended particles 2.5, the air quality was variable throughout the day, showing a considerable concentration in the time intervals. In general, the wind speed near 21:00 hours influenced the rise in air quality.

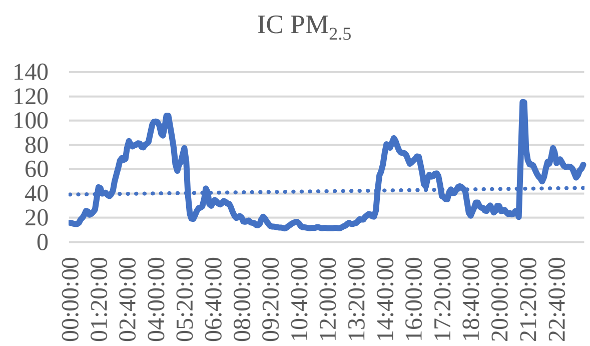

Gráfico 6 Quality index for suspended particles March 7
Source: Own Elaboration

On April 2, maximum and minimum temperatures were reported 26 °C/8 °C, respectively. Graph 7 shows the values of the air quality index for the assigned day. It can be seen that, at the beginning of the day, the quality was regular, as was the day before from 7:40 p.m.

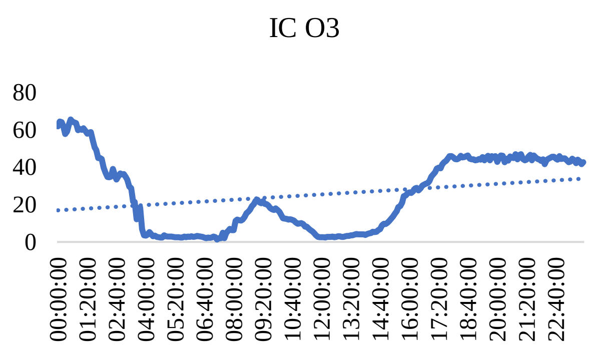

Gráfico 7 Ozone Quality Index April 2
Source: Own Elaboration

Graph 8 shows the results of the quality index for carbon monoxide, indicating that it was good during the entire day.

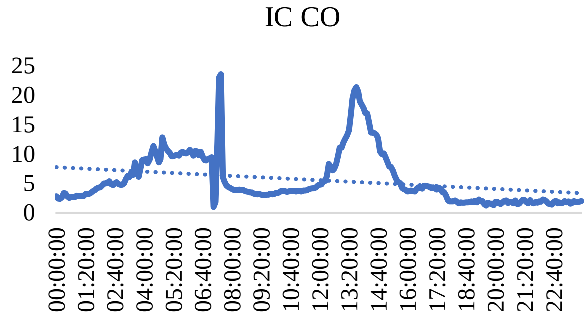

Gráfico 8 Quality index for carbon monoxide April 2
Source: Own Elaboration

The quality assigned to suspended particles 2.5 can be visualized in Graph 9, in which there are three different parameters: good, regular and bad. It is incorrect to answer why the levels were so high at a certain time, since the wind did not influence, for the established schedules do not match.

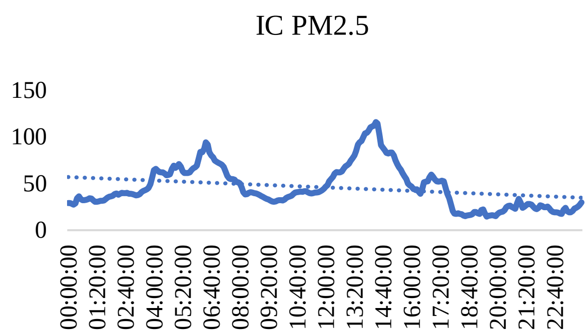

Gráfico 9 Quality index for suspended particles April 2
Source: Own Elaboration

On May 20, maximum and minimum temperatures were reported 27 °C/11 °C. In summary, Graph 10 shows that the level of air quality underwent variation.

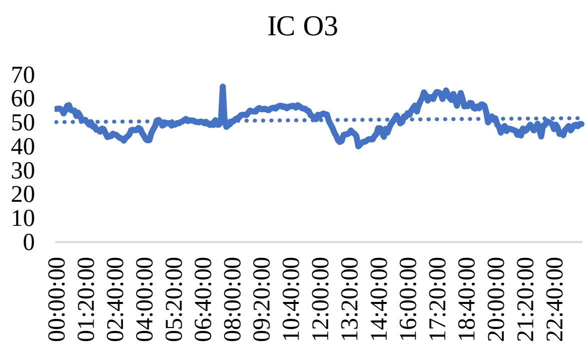

Gráfico 10 Ozone Quality Index May 20
Source: Own Elaboration

Graph 11 shows that the quality index for carbon monoxide was good, without high levels varying between hours.

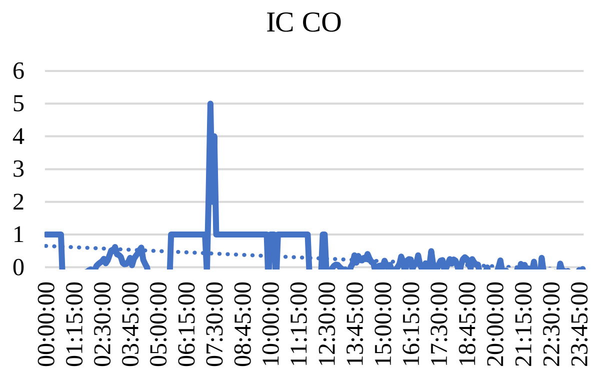

Gráfico 11 Quality index for carbon monoxide May 20
Source: Own Elaboration.

It is worth mentioning that the readings of the day described above recorded gusts of wind with high speed, which could indicate the reason for the increase in 2.5 particles, showed in Graph 12. The levels reached indicated that people should remain at home, since they were extremely bad.

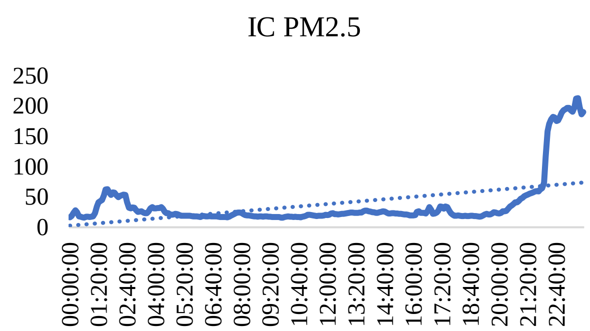

Gráfico 12 Quality index for suspended particles 2.5 May 20
Source: Own Elaboration

Additionally, it is intended to install air quality stations in strategic public places, so that the community of Ciudad Juárez can access the results of the index calculations through a mobile device and take their respective precautions. Each station will have its own QR on the deck and once a person reads it with their mobile device, the current weather conditions (last calculation of the air quality index) of the place where the station is located will be displayed. In this way, people will have the ability to make decisions related to their health.

The service offered at the reference station IIT-01 is shown in Figure 2. It has the option of adapting to both a web page and the screen of any device.

Figura 2 Servicio web disponible
Source: Own Elaboration.

It also has the reference to show the values of the variables used at the time of displaying the indicator, as can be seen below. Figure 3 shows the current conditions for ozone, carbon monoxide and 2.5 suspended particles, as well as the current temperature, time and day of consultation (necessary characteristics can be added).

Figura 3 Condiciones actuales 13/07/19
Source: Own Elaboration.

The values represent data not submitted by the processing.

Conclusions

An air quality index for Ciudad Juarez is necessary, since society is only used to be informed, for example, about temperature. However, by including various factors, some formulas and visualizing the results, information becomes even more extensive.

Each variable used for the air quality index is what our planet reflects. Being able to transform it into reality and, above all, unraveling its interior is, without a doubt, the expected result. Finally, the need to find novel solutions has been the great advantage of this project.

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