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Assessment of the Air Quality in Four Cities with Near Mining Activity in Mexico, using the Grey Clustering Method

Alexi Delgado, Emiliano Luna, Mónica Hernández, Karen Montero, Ch. Carbajal

Abstract: ***Air pollution is a problem in large cities, which increases with population growth and industrialization. This work assessed air quality in four Mexican cities related to mining activities near monitoring points. The method used for this study was the Grey Clustering method, which is based on the theory of grey systems. This method uses information with a high degree of uncertainty, air quality analysis being an issue that uses data with a high degree of uncertainty. The results revealed that all four cities have good air quality based on Metropolitan Air Quality Index (IMECA) standards, even when mining activities take place near these cities. The results of this work could help the relevant authorities to implement further studies on the impact of polluting emissions from mining activities on the environment.***

Keywords: Air pollution, Air quality assessment, Grey clustering method, Mining activity.

I. INTRODUCTION

The most vulnerable global challenges faced today are global warming and its effect on climate with deteriorating air quality [1] [2]. Exposure to air pollution is now well recognized by scientists, media and the population as a major public health issue [3] [4]. In this work, we apply the grey systems theory as a quantitative method, which was established by Julong Deng [5], this method based on center-point triangular whitenization weight functions (CTWF), is used to research problems with limited information and small samples [6];

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* Correspondence Author
Alexi Delgado*, Department of Engineering, Mining Engineering Section, Pontificia Universidad Católica del Perú – PUCP, Lima, Peru. Email: kdelgadov@pucp.edu.pe.
Emiliano Luna, Geological Engineering Program, Escuela Superior de Ingeniería y Arquitectura Ticomán, Instituto Politécnico Nacional, Mexico.
Mónica Hernández, Geological Engineering Program, Escuela Superior de Ingeniería y Arquitectura Ticomán, Instituto Politécnico Nacional, Mexico.
Karen Montero, Geological Engineering Program, Escuela Superior de Ingeniería y Arquitectura Ticomán, Instituto Politécnico Nacional, Mexico..
Ch. Carbajal, Administration Program, Universidad de Ciencias y Humanidades, Lima, Peru. Email: ccarbajal@uch.edu.pe.

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the last fact makes applicable the theory, in cases as social impact assessment [7], to assess water quality [8], to select the best air purifier system to urban, or to assess citizen criminality [9].

The air quality in Mexico is pronounced of acute way in the country, in a study published by WHO in 2014, of 1, 600 urban areas analyzed,

The Metropolitan Zone of the Valley of Mexico (ZMVM) is one of the most contaminated by PM10 (particles smaller than 10 micrometers or microns) [10] [11].

We conducted an air quality assessment during the week of April 8 to 14, 2019 in four cities of Mexico with mining activities and government air quality monitoring points that are up to date; in order to validate the CTWF method to air quality assessment problems with a high level of uncertainty.

The objective of this work is to evaluate the air quality of four cities and to verify if there is a direct relationship between the pollution of these cities and the mining activities present in the zones.

The present work is organized as follows: In Section 2, a description of CTWF method is detailed. Then, the case study on air quality assessment is developed in Section 3, followed by the results and discussion in Section 4. Finally, in Section 5, the conclusions are provided.

II. METHODOLOGY

The methodology used in this article to determine air quality in four cities in Mexico with nearby mining activities was the CTWF method [6]. The CTWF is described with the following definition: first, have a set of criteria (*C1*, *C2*, *C3* and *C4*), a set of grey classes (λ_1,λ_2,λ_3, λ_4 and λ_5) and finally, a set of objects (*G1*, *G2*, *G3* and *G4*). The method's steps are presented below [12]:

Step 1: Define the central points λ_1, λ_2, λ_3, λ_4 and λ_5 of the grey classes.

Step 2: By means of the arithmetic mean, the field data and the legislation are not dimensioned.

Step 3: Based on the number of grey classes, the triangular functions are established as shown in Fig. 1. Subsequently, with Equation 1, the correspondence rule of the triangular functions is defined. The field data is evaluated in the functions.

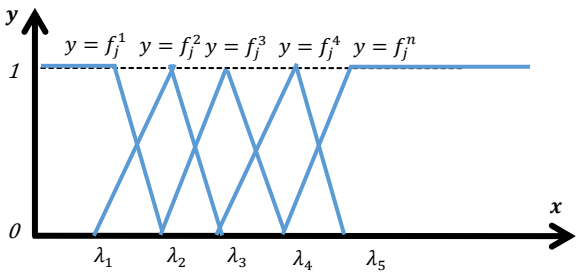

Fig. 1.Triangular function "CTWF" [6]

$$f_j^k(x_{ij}) = \begin{cases} \dfrac{x-\lambda_2}{\lambda_3-\lambda_2}, & x \notin [\lambda_2, \lambda_3] \\ \dfrac{\lambda_n - x}{\lambda_n - \lambda_3}, & x \in]\lambda_3, \lambda_n[\\ 0, & x \in [\lambda_2, \lambda_n] \end{cases} \quad (1)$$

Step 4: The clustering coefficient was applied to obtain the result (the weight was the same for each criterion), as shown in Equation 2.

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}).n_j \quad (2)$$

Where $f_j^k(x_{ij})$ is the CTWF, and n_j is the weight of criterion *j*.

Step 5: If$\max_{1\le k\le s}\{\sigma_i^k\} = \sigma_i^k$, it is decided that object *i* belongs to grey class *k**. If there are several objects in grey class *k**, these objects could be ordered according to the values of σ_i^k.

III. CASE STUDY

The analysis of air quality using the CTWF method was done in four cities of the Mexican Republic related to activities in the mining sector. These cities are shown in the Fig. 2.

Fig. 2.Cities of Mexico selected for the case study

A. Cities and monitoring points

In Mexico there are many cities where mining activity is developed, for this study four of those cities were selected based on the data availability from the Mexico government through the National Air Quality Information System (SINAICA) [13]. In the city of Monterrey the following companies are operating: Yesera Monterrey, S. A. de C. V., which exploits gypsum and the company Monterrey Lamosa Revestimientos, S. A. de C. V. of clay [14]; in Pachuca's city there is operating the mining company Real del Monte y Pachuca, S. A. de C. V. (Ag and Au) [15]; in the city of Saltillo is the limestone crushing company Concretos y triturados de Saltillo, S.A. de C.V., the clay calcination company; Ladrillera Saltillo Industrializada, S. A., the gypsum grinding and calcining company USG Mexico, S.A. de C.V and the thermal crushing and crushing plant of Cr and Mg oxides Refractory RHI, S.A. de C.V [16] and finally in the city of Zacatecas are 13 active plants of carved and laminated quarry [17].

The monitoring points of each city were chosen based on the availability of information required for each parameter. In Table I the description of each city and its corresponding monitoring point are shown.

TABLE I. Table of Monitoring Points

Code	City	Monitoring point	Description
G1	Monterrey	Santa Catarina	This point is located in the Colonia Centro in the Municipality of Santa Catarina, in Nuevo León's State.
G2	Pachuca	Jardín del Maestro	This monitoring point is located in the Colonia Centro in the Municipality of Pachuca de Soto, in the State of Hidalgo.
G3	Saltillo	Finanzas	This point is located in the Colonia Zona Centro in the Municipality of Saltillo, in the State of Coahuila de Zaragoza.
G4	Zacatecas	Explanada del congreso	This point is located in the Colonia Zacatecas Centro in the Municipality of Zacatecas, in Zacatecas State.

B. Evaluation of parameters

The parameters used for the study of air quality were chosen with respect to those established in the IMECA standards [18] [19]. The data of the parameters obtained in each monitoring point are an average of the week of April 8 to 14, 2019, these are shown in Table II.

TABLE II. Air Quality Parameters of Each Monitoring Point

Parameter	O3 [ppm]	NO2 [ppm]	SO2 [ppm]	CO [ppm]	PM10 [µg/m³]	PM2.5 [µg/m³]
Code	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*
G1	0.0023	0.0010	0.0088	0.8341	74.6828	18.0411
G2	0.5285	0.0110	0.0025	0.5933	61.946	21.4189
G3	0.0364	0.0151	0	0.4390	47.274	14.1131
G4	0.0517	0.0098	0.0001	0.7631	84.7262	15.4762

The air quality evaluation in the four cities is done in the IMECA scale, which divides the air quality into five levels and into five different colors for each function. The values established by the IMECA scale are shown in Table III.

TABLE III. IMECA Levels of Air Quality

Levels	Parameters					
	C1	*C2*	*C3*	*C4*	*C5*	*C6*
λ1 Good	0.000 - 0.055	0.000 – 0.105	0.000 - 0.065	0.00 – 5.50	0 – 60	0 – 15.4
λ2 Fair	0.055 - 0.110	0.105 – 0.210	0.065 - 0.130	5.51 - 11.00	61 – 120	15.5 – 40.4
λ3 Poor	0.110 - 0.165	0.210 - 0.315	0.130 - 0.195	11.01 - 16.50	121 – 220	40.5 – 65.4
λ4 Very Poor	0.165 - 0.220	0.315 - 0.420	0.195 - 0.260	16.51 – 22.00	221 – 320	65.5 – 150.4
λ5 Extremely Poor	>0.220	> 0.420	> 0.260	> 22.00	>320	> 150.4

C. Calculations

The calculations for this case study were based on the CTWF method, as it is shown below:

Step 1: The central points λ1, λ2, λ3, λ4 and λ5 of the five parameters of the grey classes present in the table were taken from Table III, the results are shown in Table IV.

TABLE IV. Center-Points of Grey Classes

Levels	Parameters					
	C1	*C2*	*C3*	*C4*	*C5*	*C6*
λ1	0.0275	0.0525	0.0325	2.75	30	7.7
λ2	0.0825	0.1575	0.0975	8.25	90	27.9
λ3	0.1375	0.2625	0.1625	13.75	170	52.9
λ4	0.1925	0.3675	0.2275	19.25	270	107.9
λ5	0.2475	0.4725	0.2925	24.75	370	162.9

Step 2: The data in Table II and IV were converted to non-dimensioned values, by dividing the values between the arithmetic means. The non-dimensioned data and the data of the IMECA scale are shown in Table V and Table VI.

TABLE V. Data Non-Dimensioned

IMECA DATA NON-DIMENSIONED						
Levels	*Parameters*					
	C1	*C2*	*C3*	*C4*	*C5*	*C6*
λ1	0.2	0.2	0.2	0.2	0.1613	0.1072
λ2	0.6	0.6	0.6	0.6	0.4839	0.3883
λ3	1	1	1	1	0.9140	0.7362
λ4	1.4	1.4	1.4	1.4	1.4516	1.5015
λ5	1.8	1.8	1.8	1.8	1.9892	2.2669

TABLE VI. Field Data Non-Dimensioned

FIELD DATA NON-DIMENSIONED

Code	*Parameters*					
	C1	*C2*	*C3*	*C4*	*C5*	*C6*
G1	0.0164	0.0038	0.0544	0.0607	0.4015	0.2510
G2	3.8438	0.0420	0.0152	0.0432	0.3330	0.2980
G3	0.26460	0.0576	0	0.0319	0.2542	0.1964
G4	0.3762	0.0375	0.0008	0.0555	0.4555	0.2154

Step 3: From the table V the triangular values were obtained. As an example, the functions of the first parameter are shown in Fig. 3.

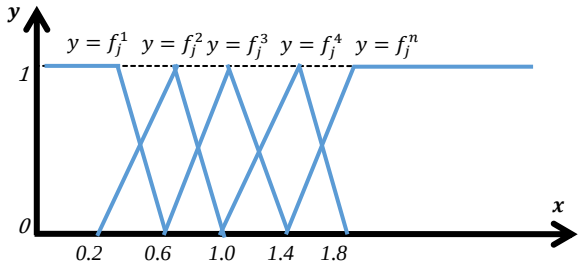

Fig. 3. CTWF for the case of study

Following the Fig. 3, the values of the functions were defined. In the Equations 3-7 the functions of the parameter C1 are shown as an example.

$$f_j^1 = \begin{cases} 1\ ;\ x\ \in\ [0;\ 0.2] \\ \dfrac{0.6 - x}{0.6 - 0.2}\ ;\ x\ \in\ \langle 0.2;\ 0.6\rangle \\ 0\ ; x \in [0.6; +\infty] \end{cases} \quad (3)$$

$$f_j^2 = \begin{cases} \dfrac{x - 0.2}{0.6 - 0.2} & ;\ x\ \in\ [0.2;\ 0.6] \\ \dfrac{0.6 - x}{0.6 - 0.2} & ;\ x\ \in\ \langle 0.6; 1\rangle \\ 0 \quad ;\ x \in [1; +\infty\ \acute{o}\ \ 0; 0.2] \end{cases} \quad (4)$$

$$f_j^3 = \begin{cases} \dfrac{x - 0.6}{1 - 0.6} & ;\ x\ \in\ [0.6; 1] \\ \dfrac{1.4 - x}{1.4 - 1} & ;\ x\ \in\ \langle 1; 1.4\rangle \\ 0 \quad ;\ x \in [1.4; +\infty\ \acute{o}\ \ 0; 0.6] \end{cases} \quad (5)$$

$$f_j^4 = \begin{cases} \dfrac{x - 1}{1.4 - 1} & ;\ x\ \in\ [1; 1.4] \\ \dfrac{1.8 - x}{1.8 - 1.4} & ;\ x\ \in\ \langle 1.4; 1.8\rangle \\ 0 \quad ;\ x \in [1.8; +\infty\ \acute{o}\ \ 0; 0.1] \end{cases} \quad (6)$$

$$f_j^4 = \begin{cases} \dfrac{x - 1.4}{1.8 - 1.4} & ;\ x\ \in\ [1; 1.4] \\ 1 \quad ;\ x\ \in\ \langle 1.8; +\infty\rangle \\ 0 \quad ;\ x \in [0; 1.4] \end{cases} \quad (7)$$

Then, the values from Table V, were replaced in the equations to calculate the CTWF values of each criteria. The results are shown in Table VII.

Table VII. The CTWF Values

G1	C1	C2	C3	C4	C5	C6
f_j^1	1	1	1	1	0.253	0.4873
f_j^2	0	0	0	0	0.7469	0.512
f_j^3	0	0	0	0	0	0
f_j^4	0	0	0	0	0	0
f_j^5	0	0	0	0	0	0
G2	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
f_j^1	0	1	1	1	0.4645	0.32
f_j^2	0	0	0	0	0.5354	0.6799
f_j^3	0	0	0	0	0	0
f_j^4	0	0	0	0	0	0
f_j^5	1	0	0	0	0	0
G3	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
f_j^1	0.8385	1	1	1	0.7106	0.6822
f_j^2	0.1615	0	0	0	0.2893	0.3177
f_j^3	0	0	0	0	0	0
f_j^4	0	0	0	0	0	0
f_j^5	0	0	0	0	0	0
G4	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
f_j^1	0.5595	1	1	1	0.0853	0.3589
f_j^2	0.4405	0	0	0	0.9145	0.2252
f_j^3	0	0	0	0	0	0
f_j^4	0	0	0	0	0	0
f_j^5	0	0	0	0	0	0

Step 4:

The clustering coefficient $\max_{1\le k\le s}\{\sigma^k{}_i\} = \sigma^k{}_i$ was obtained through Equation 2. For this work we decided that the six criteria have the same weight (nj = 0.1666), since they are parameters of high uncertainty. The clustering values obtained are shown in Table VIII.

TABLE VIII. Values of Clustering Coefficient

	G1	G2	G3	G4
$f_j^1(x)$	0.79005	0.6308	0.8719	0.6673
$f_j^2(x)$	0.2098	0.2026	0.1281	0.2634
$f_j^3(x)$	0	0	0	0
$f_j^4(x)$	0	0	0	0
$f_j^5(x)$	0	0.1666	0	0

Step 5: Maximum value

G1 where *k*=1. Therefore, G1 belongs to good grey class (λ1).

G2 where k=1. Therefore, G2 belongs to good grey class (λ1).

G3 where k=1. Therefore, G3 belongs to good grey class (λ1).

G4 where k=1. Therefore, G4 belongs to good grey class (λ1).

IV. RESULTS AND DISCUSSION

The results and the discussion are shown below:

A. The Case Study

The air quality in the 4 monitoring points of each city, correspond to a good class of greys, so that their air quality is good, this according to the IMECA standards [18] . The results are shown in the Fig 4.

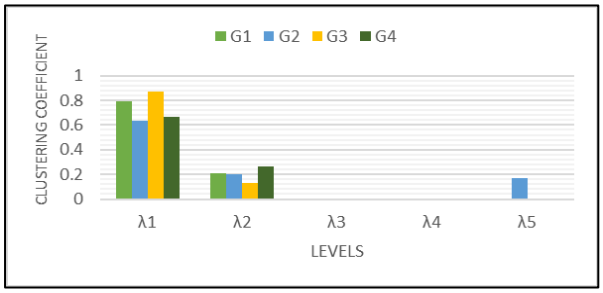

Fig. 4. Graphics of values of clustering coefficient s of each monitoring point. It is observed how all the monitoring points coincide in good level of the IMECA standards. G1=Monterrey, G2=Pachuca, G3=Saltillo, G4= Zacatecas.

With the results obtained, it is demonstrated that there would not be a direct relationship of the non-metallic and metallic mining activity with the air quality in said cities, so it is estimated that the air quality in these cities would be mainly due to other causes [20].

Although the 4 cities classify with good air quality, there are small differences between the good air qualities of these, so we can order them as follows. (The sequence tells us that G3 has a better air quality compared to other cities).

G3> G1> G4> G2

If we look at Fig 4 we can notice that G2 qualifies with good air quality (λ1), however, we see that it also has a minimum classification in λ5 (Extremely bad), we assume that this could be due to two main factors: 1) When reviewing the G2, we realize that it is the city of Pachuca, in which there is metallic mining activity (Ag, Au). 2) The city of Pachuca is 90.3 km from Mexico City, being the closest city to all those used in this work, so there could be a greater amount of industrial activity, as well as greater activity of polluting vehicles.

B. The CTWF method

The method used in the present work, has a good performance when applied in the environmental analysis on air quality. This work represents a level of uncertainty due to the simple fact that the variables that influence its study are very inconsistent, but when applying the CTWF method there is the advantage that it takes uncertainty into account since it is based on the theory of grey [6].

V. CONCLUSIONS

In this work we analyze air quality in four cities. The results give us an overview of how air is in these four cities which can be used by Mexican authorities as a source of information about the air quality of these areas.

With the results obtained we were able to conclude that our objective of evaluating the air quality in the four cities that were taken as an example was fulfilled since was found that there would not be a relationship between metallic and non-metallic mining in the four cities involved.

Although all the cities evaluated showed good air quality, more studies on the emission of pollutants near or directly from the areas where mining activities take place are needed in the future in order to know the amount of pollutants they imitate and their degree of influence on air quality. The CTWF method is very effective for air quality analysis, which is why its application is suggested in this type of work where the information has a high level of uncertainty.

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