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Applying the Grey Systems Theory to Assess Air Quality in La Oroya - Peru

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***Abstract*– Air pollution is a problem in several mining and metallurgical operations, which can increase if the processing plants do not respect environmental standards. This work evaluates air quality with three monitoring stations in the years 1999, 2008 and 2014 in the city of La Oroya, near the Metallurgical Complex of the same name. The method used in this research was the grey clustering method, which is based on the grey systems theory. This technique allows working with data with a high degree of incertitude. An example would be the air quality analysis data. The results of this investigation reveal that in the year 1999 the air quality was extremely poor, while in 2008 it varied from poor to extremely poor; however, in 2014 the calculations show that the quality is good. These conclusions are obtained from the Ontario Ambient Quality Criteria (AAQC) and the Metropolitan Air Quality Index (IMECA). The results of this inquiry could motivate the competent authorities to carry out more studies to confirm that the air quality in La Oroya is good, since it was ranked as the fifth most polluted city.**

***Keywords*-- air quality assessment, grey clustering method, grey systems theory, metallurgical complex.**

I. Introduction

Nowadays, mankind is facing various problems caused by global warming and deteriorating air quality [1]. Many studies around the world have documented that air pollution is a problem that seriously affects all people [2]. In that sense, the mining industry is one of the activities that emits large amounts of dust, aerosols and potentially toxic elements when prevention measures are not taken [3].

In this work, the grey systems theory is applied as an evaluation method, which was developed by Julong Deng [4]. These concepts focus on studies involving limited data and small samples [5]; thus, this methodology is applicable to assess the quality of water, air or criminality [6].

In Peru, mining-metallurgical activities account for 20% of tax revenues and are mainly located in the highlands, where various activities such as agriculture, commerce, livestock, among others, are also developed [7]. The city of La Oroya is home to the Metallurgical Complex of the same name in which poly metallic minerals have been processed [8], which have generated emissions of heavy elements and sulfur dioxide in their purification process, so this metallurgical city presents a huge problem related to air pollution [9].

In this research study, an evaluation of air quality in La Oroya in the years 1999, 2008 and 2014 is carried out [10]. For this objective, air quality reports from the General Directorate of Environmental Health (DIGESA) have been used. Likewise, data has been collected from three stations (E-1,E-2,E-3) in each year, which are distributed in different areas of the city and have sampling equipment for suspended particles smaller than 10 microns, in order to apply the gray system method and evaluate air quality [11].

The purpose of this work is to develop the evaluation of La Oroya's air quality using the environmental standards of Ontario (Canada), and to verify the relationship of the different heavy metals with the activity of the metallurgical complex [12].

The organization of this work is as follows: In section 2, a description of the gray systems method and a detail of the theory is developed. Then, in Section 3, the air quality assessment case study is presented. In section 4, the results and discussion are shown, followed by the conclusions in Section 5.

II. Methodology

First of all, a scheme is made in order to give the steps of the methodology in a summarized way.

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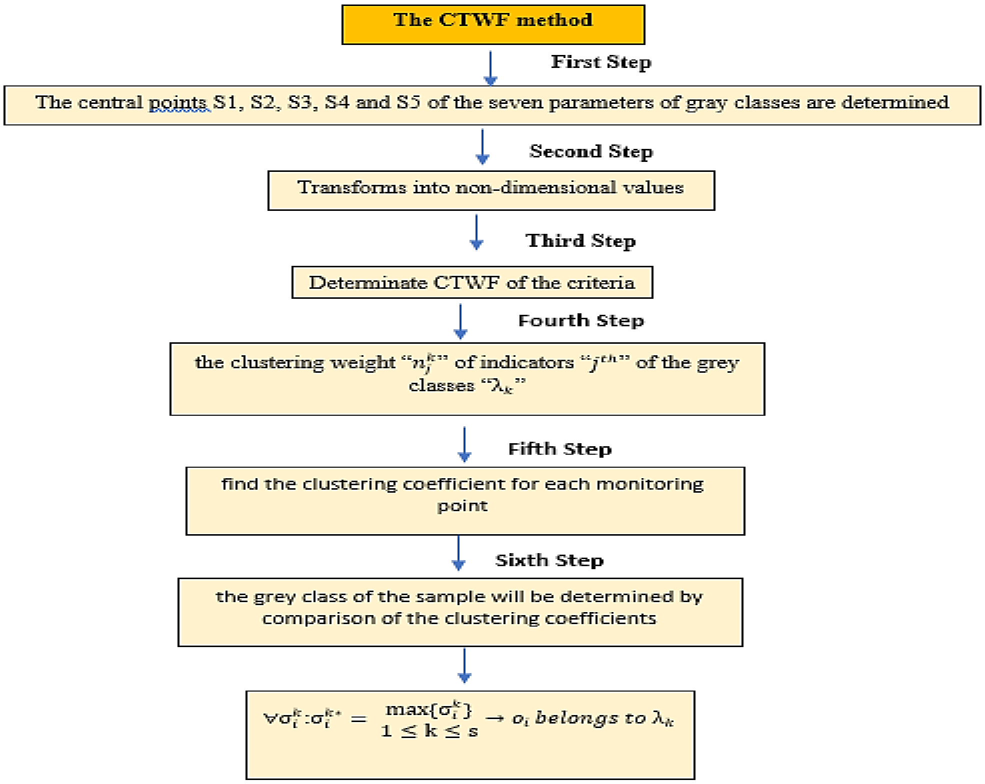

Grey clustering is a technique that is used in different assessments. In this paper, CTWF method will be applied for the evaluation of la Oroya's air quality.

A. First Step

The central points S1, S2, S3, S4 and S5 of the seven parameters of gray classes are determined.

B. Second Step

All knowledge used for the study are going to be reworked into non-dimensional values.

For this, the following equations are going to be used for a nondimensional transformation of the standard values:

$$\lambda_j^k = \frac{\lambda_i^k}{\frac{\sum_{j=1}^{n} \lambda_i^k}{s}} \tag{1}$$

Knowing that λ_i^k represents the values found on the air quality standard for each i parameter and k grey class; and λ_j^k describes the non-dimensional value of the parameters.

Subsequently, with the following equation it's obtained the non-dimensional values.

$$x_{ij} = \frac{x_{ii}}{\lambda_j^k} \tag{2}$$

C. Third Step

Calculate the CTWF of the criteria, using the three following equations:

$$f_j^1(x_{ij}) = \begin{cases} 1, x \in [0, \lambda_j^1] \\ \frac{\lambda_j^2 - x}{\lambda_j^2 - \lambda_j^1}, x \in (\lambda_j^1, \lambda_j^2) \\ 0, x \in [\lambda_j^2, \infty] \end{cases} \tag{3}$$

$$f_j^k(x_{ij}) = \begin{cases} \frac{x - \lambda_j^{k-1}}{\lambda_j^k - \lambda_j^{k-1}}, x \in [\lambda_j^{k-1}, \lambda_j^k] \\ \frac{\lambda_j^{k+1} - x}{\lambda_j^{k+1} - \lambda_j^k}, x \in (\lambda_j^k, \lambda_j^{k+1}) \\ 0, x \in [0, \lambda_j^{k-1}] \cup [\lambda_j^{k+1}, \infty) \\ k \neq \{1, s\} \end{cases} \tag{4}$$

$$f_j^s(x_{ij}) = \begin{cases} \frac{x - \lambda_j^{s-1}}{\lambda_j^s - \lambda_j^{s-1}}, x \in (\lambda_j^s, \lambda_j^{s-1}) \\ 1, x \in [\lambda_j^s, \infty) \\ 0, x \in [0, \lambda_j^{s-1}] \end{cases} \tag{5}$$

D. Fourth Step

Using the equation (6), calculate the clustering weight "n_j^k" of the parameters "j^{th}" of the grey classes "λ_k".

$$n_j^k = \frac{\frac{1}{\lambda_j^k}}{\sum_{j=1}^{n} \frac{1}{\lambda_j^k}} \tag{6}$$

E. *Fifth Step*

The clustering coefficient for each monitoring point is going to be calculated, having determined the clustering weight.

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k\left(x_{ij}\right).\eta_j \tag{7}$$

Where $f_j^k\left(x_{ij}\right)$ is the CTWF and η_j is the weight of criterion j.

F. *Sixth Step:*

Finally, the grey class of the sample will be calculated by comparison of the clustering coefficients. According to the equation (8), the chosen clustering coefficient should be the maximum value.

$$\forall \sigma_i^k : \sigma_i^{k*} = \underset{1 \leq k \leq s}{\max\{\sigma_i^k\}} \rightarrow o_i\ belongs\ to\ \lambda_k. \tag{8}$$

III. CASE STUDY

The evaluation of air quality in the years 1999, 2008 and 2014 using the CTWF method was carried out taking into account three monitoring stations within the city of La Oroya, where La Oroya Metallurgical Complex (LOMC) was developed. These monitoring points are shown in Figure 1.

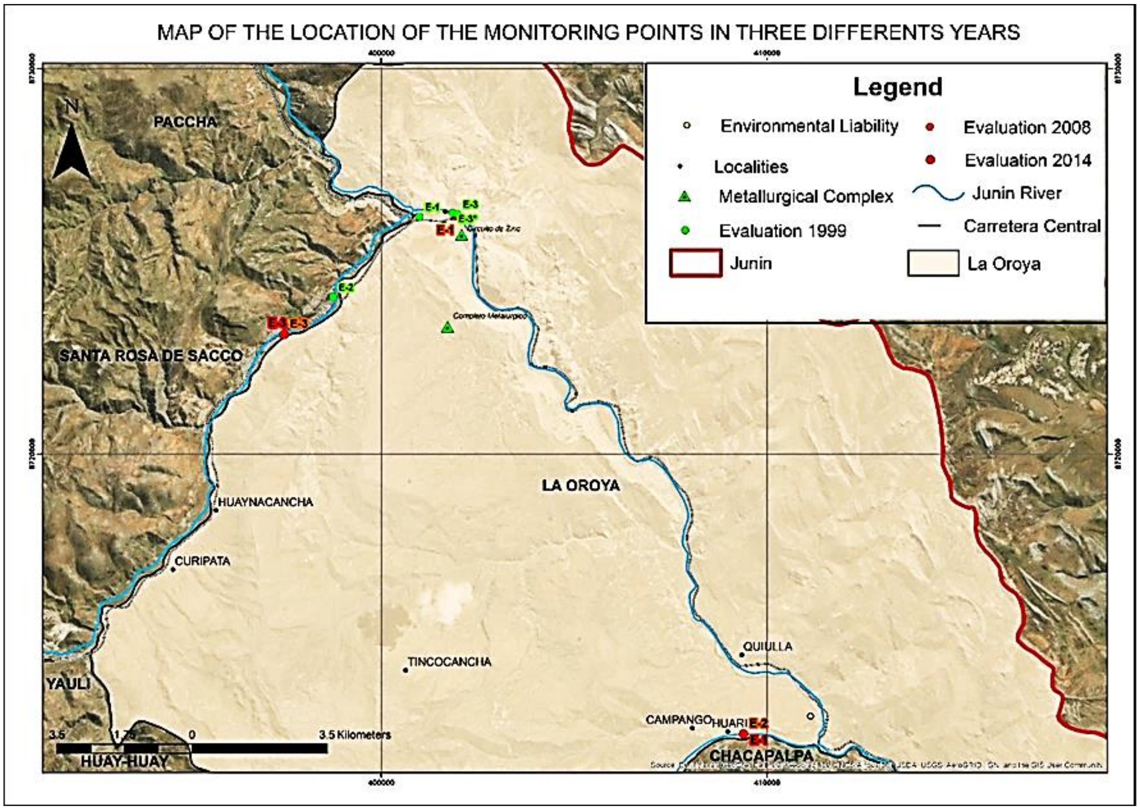

Fig. 1. Monitoring points selected for the case study

A. *Zones and monitoring points*

The city of La Oroya (Junín), located in the central Andean region of Peru, has been considered over the years one of the most polluted cities in the world according to studies carried out by the NGO Blacksmith Institute, due to toxic emissions of the polymetallic metallurgical complex that caused high levels of air contamination.

For the purpose of this study, the years 1999, 2008 and 2014 were analyzed, and three monitoring stations were analyzed by year. In 1999, the stations were located in Marcavalle and La Oroya Antigua; while, in the years 2008 and 2014, they were located in La Oroya Antigua, Huari and Santa Rosa de Sacco. Environmental monitoring was carried out by the General Directorate of Environmental Health (DIGESA) and 10-micron suspended particle sampling equipment was installed in each of the monitoring establishments.

The monitoring of air quality in the city of La Oroya in the years 1999 and 2008 was implemented while the La Oroya Metallurgical Complex was in operation, and although from 2009 Doe Run Perú S.RL [13], then owner of the smelter, stopped operations due to financial and environmental problems, the environmental liabilities still persist. On the other hand, DIGESA recorded the monitoring of air quality in its 2014 report. This document indicated the partial operation of the zinc circuit of the company Doe Run Perú S.R.L.

The monitoring points were chosen according to the availability of the required information for each parameter. On the other hand, it is necessary to mention that in 1999 a station (C.S. La Oroya) was removed from the original data due to its distance from the other stations.

The following tables show the monitoring points for each year.

TABLE I
Table of Monitoring Points (1999)

Code	Monitoring Station	Address	District
E-1	Central Peru Department of Occupational Health	Marcavalle H-201 Block	Marcavalle
E-2	Public School 31146 José Antonio Encinas	Tarma Street No. 530	Oroya Antigua
E-3	Cordova Commercial Store	Jr. Arequipa No. 216-218	Oroya Antigua

TABLE II
Table of Monitoring Points (2008 and 2014)

Code	Monitoring Station	Address	District
E-1	House	Pje. Galvez No. 122	Oroya Antigua
E-2	Public school No. 31149	Av. Brasil No. 222 Centro Poblado Menor de Huari	Huari
E-3	Santa Rosa de Sacco District Municipality	Mariano Melgar Street No. 208	Santa Rosa de Sacco

B. *Evaluation of parameters*

The parameters used for the study of air quality were chosen from the Environmental Quality Criteria (AAQC) of Ontario, Canada.

The data of the parameters gotten in each monitoring station is an average of the values collected during approximately a week. They are shown in Table III, IV and V. In 1999, monitoring was carried out from August 31 to September 6; while in 2008, it was held from March 26 to April 1. Finally, in 2014, the monitoring was implemented from September 22 to September 29.

TABLE III
Air Quality Parameters of Each Monitoring Station (1999)

Parameter	Cu	Pb	Mn	Fe	Zn	Cr	Cd
Code	***C1***	***C2***	***C3***	***C4***	***C5***	***C6***	***C7***
E-1	0,30	1,90	0,06	1,60	1,00	0,01	0,09
E-2	1,40	12,70	0,10	2,70	6,90	0,01	0,60
E-3	1,90	14,80	0,10	3,90	8,00	0,01	0,60

TABLE IV
Air Quality Parameters of Each Monitoring Station (2008)

Parameter	Cu	Pb	Mn	Fe	Zn	Cr	Cd
Code	***C1***	***C2***	***C3***	***C4***	***C5***	***C6***	***C7***
E-1	0,33	3,25	0,04	0,79	1,26	0,03	0,17
E-2	0,08	0,72	0,02	0,24	0,25	0,03	0,03
E-3	0,11	1,49	0,10	1,49	0,39	0,03	0,04

TABLE V
Air Quality Parameters of Each Monitoring Station (2014)

Parameter	Cu	Pb	Mn	Fe	Zn	Cr	Cd
Code	***C1***	***C2***	***C3***	***C4***	***C5***	***C6***	***C7***
E-1	0,153	0,148	0,018	0,294	0,217	0,001	0,006
E-2	0,214	0,028	0,038	0,964	0,106	0,001	0,004
E-3	0,021	0,028	0,013	0,233	0,106	0,001	0,004

The distribution of quality levels is based on the Metropolitan Air Quality Index (IMECA), which divides air quality into five levels, with their respective colors.

Taking into account the Environmental Quality Criteria (AAQC) of Ontario [14], Canada and the IMECA distribution, a range of values could be determined, categorizing the parameters in S1 when it is good, S2 when it is fair, S3 when it is poor, S4 when it is very poor and S5 when it is extremely poor [15].

The values of the air quality standard that will be taken as a reference are shown in Table VI.

TABLE VI
Levels of Air Quality

Levels	Parameter						
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
S1 Good	0 - 25	0 – 0,25	0 – 0,1	0 - 2	0 - 60	0 – 0,25	0 – 0,0125
S2 Fair	25 – 50	0,25 – 0,50	0,1 – 0,2	2 – 4	60 – 120	0,25 – 0,50	0,0125 – 0,025
S3 Poor	50 – 75	0,50 – 0,75	0,2 – 0,3	4 – 6	120 – 180	0,50 – 0,75	0,025 – 0,0375
S4 Very Poor	75 - 100	0,75 - 1	0,3 – 0,4	6 - 8	180 - 240	0,75 - 1	0,0375 – 0,050
S5 Extremely Poor	> 100	> 1	> 0,4	> 8	> 240	> 1	> 0,050

C. *Calculation*

For this case study, the calculations were based on the CTWF Method, as shown below:

Step 1: Having the previously established ranges in Table VI, the central points S1, S2, S3, S4 and S5 of the seven parameters of gray classes are determined. The results are shown in Table VII.

TABLE VII
Center-Points of Grey Classes

Levels	Parameter						
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
S1 Good	12,5	0,125	0,05	1	30	0,125	0,00625
S2 Fair	37,5	0,375	0,15	3	90	0,375	0,01875
S3 Poor	62,5	0,625	0,25	5	159	0,625	0,03125
S4 Very Poor	87,5	0,875	0,35	7	210	0,875	0,04375
S5 Extremely Poor	112,5	1,125	0,45	9	270	1,125	0,05625

Step 2: Both the standard data of Table VII and the field data of Tables III, IV and V, used in the study, are transformed into non-dimensioned values, dividing by the arithmetic mean of the values of Table VII. The non-dimensioned values are shown in Tables VIII and IX. In the case of the field data, only results of 1999 are shown, as an example.

TABLE VIII
Standard Data Non-Dimensioned

Levels	Parameter						
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
S1	0,20	0,20	0,20	0,20	0,20	0,20	0,20
S2	0,60	0,60	0,60	0,60	0,60	0,60	0,60
S3	1,00	1,00	1,00	1,00	1,00	1,00	1,00
S4	1,40	1,40	1,40	1,40	1,40	1,40	1,40
S5	1,80	1,80	1,80	1,80	1,80	1,80	1,80

TABLE IX
Field Data Non-Dimensioned (1999)

Code	Parameter						
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
E-1	0,00	3,04	0,24	0,32	0,01	0,02	2,88
E-2	0,02	20,32	0,40	0,54	0,05	0,02	19,20
E-3	0,03	23,68	0,40	0,78	0,05	0,02	19,20

Step 3: The 5 triangular functions are constructed for each parameter using the non-dimensioned values of Table VIII with reference to Figure 2.

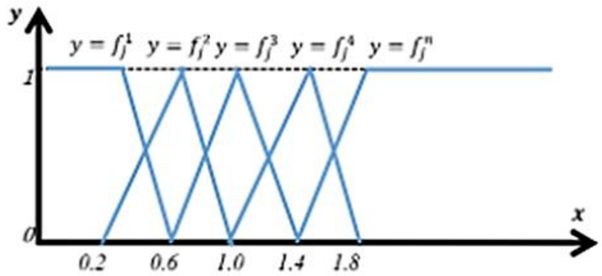

Fig. 2. CTWF for the case of study

Then, as an example, the functions for the first parameter (C1) are shown, applying equations (3), (4) and (5).

$$f_j^1 = \begin{cases} 0;\ x \notin [0,2\ ;\ 0,6] \\ 1;\ x \in [0,2\ ;\ 0,6] \\ \frac{0,6 - x}{0,6 - 0,2};\ x \in [0,2\ ;\ 0,6] \end{cases} \quad (9)$$

$$f_j^2 = \begin{cases} 0;\ x \notin [0,2\ ;\ 1] \\ \frac{x - 0,2}{0,6-0,2};\ x \in [0,2\ ;\ 0,6] \\ \frac{1 - x}{1 - 0,6};\ x \in [0,6\ ;\ 1] \end{cases} \quad (10)$$

$$f_j^3 = \begin{cases} 0;\ x \notin [0,6\ ;\ 1,4] \\ \frac{x - 0,6}{1 - 0,6};\ x \in [0,6\ ;\ 1] \\ \frac{1,4 - x}{1,4 - 1};\ x \in [1\ ;\ 1,4] \end{cases} \quad (11)$$

$$f_j^4 = \begin{cases} 0;\ x \notin [1\ ;\ 1,8] \\ \frac{x - 1}{1,4 - 1};\ x \in [1\ ;\ 1,4] \\ \frac{1,8 - x}{1,8 - 1,4};\ x \in [1,4\ ;\ 1,8] \end{cases} \quad (12)$$

$$f_j^5 = \begin{cases} 0;\ x \notin [0\ ;\ 1,4] \\ \frac{x - 1,4}{1,8 - 1,4};\ x \in [1,4\ ;\ 1,8] \\ 1;\ x \notin [0\ ;\ 1,8] \end{cases} \quad (13)$$

Subsequently, the data of Table IX, in other words, the non-dimensioned sample data obtained in the field, is replaced in the functions. The results of the station 1 in 1999 are shown in Table X, as an example.

TABLE X
The CTWF Values (1999)

Station 1							
E-1	***C1***	***C2***	***C3***	***C4***	***C5***	***C6***	***C7***
f1	1,00	0,00	0,90	0,70	1,00	1,00	0,00
f2	0,00	0,00	0,10	0,30	0,00	0,00	0,00
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,65	0,00	0,00	0,00
f5	0,00	1,00	0,00	0,00	0,00	0,00	1,00

Step 4: The target weight of the parameters was obtained using the harmonic mean method as shown in equation (6). The value of each target weight is shown in Table XI.

TABLE XI
Objective Weights of Each Parameter

Parameter	C1	C2	C3	C4	C5	C6	C7
S1	0,00	0,04	0,10	0,01	0,00	0,04	0,81
S2	0,00	0,04	0,10	0,01	0,00	0,04	0,81
S3	0,00	0,04	0,10	0,01	0,00	0,04	0,81
S4	0,00	0,04	0,10	0,01	0,00	0,04	0,81
S5	0,00	0,04	0,10	0,01	0,00	0,04	0,81

Step 5: After determining the clustering weight, the clustering coefficient of each monitoring station per year is determined using equation (7). Tables XII, XIII and XIV show the results for each year.

TABLE XII
Values of Clustering Coefficient (1999)

Station 1								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,00	0,90	0,70	1,00	1,00	0,00	0,14
f2	0,00	0,00	0,10	0,30	0,00	0,00	0,00	0,01
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,65	0,00	0,00	0,00	0,00
f5	0,00	1,00	0,00	0,00	0,00	0,00	1,00	**0,85**
Station 2								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,00	0,50	0,15	1,00	1,00	0,00	0,09
f2	0,00	0,00	0,50	0,85	0,00	0,00	0,00	0,06
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f5	0,00	1,00	0,00	0,00	0,00	0,00	1,00	**0,85**
Station 3								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,00	0,50	0,00	1,00	1,00	0,00	0,09
f2	0,00	0,00	0,50	0,55	0,00	0,00	0,00	0,05
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f5	0,00	1,00	0,00	0,00	0,00	0,00	1,00	**0,85**

TABLE XIII
Values of Clustering Coefficient (2008)

Station 1								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,00	1,00	1,00	1,00	1,00	0,00	0,15
f2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f5	0,00	1,00	0,00	0,00	0,00	0,00	1,00	**0,85**
Station 2								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,00	1,00	1,00	1,00	1,00	0,00	0,15
f2	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,08
f3	0,00	0,62	0,00	0,00	0,00	0,00	0,90	**0,76**
f4	0,00	0,38	0,00	0,00	0,00	0,00	0,00	0,02
f5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Station 3								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,00	0,50	0,76	1,00	1,00	0,00	0,10
f2	0,00	0,00	0,50	0,25	0,00	0,00	0,00	0,05
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,30	0,24
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,70	**0,57**
f5	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,04

TABLE XIV
Values of Clustering Coefficient (2014)

Station 1								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	0,90	1,00	1,00	1,00	1,00	1,00	**1,00**
f2	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Station 2								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	1,00	1,00	1,00	1,00	1,00	1,00	**1,00**
f2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Station 3								
Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**σ**
f1	1,00	1,00	1,00	1,00	1,00	1,00	1,00	**1,00**
f2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Step 6: Finally, the level of air quality in each station by year will be determined choosing the maximum value of the clustering, according to the equation 8. The maximum value for each criterion was highlighted in black in the previous step. The position of this value is compared with the distribution of quality levels based on the Metropolitan Air Quality Index (IMECA). The results are shown in Tables XV, XVI and XVII.

TABLE XV
Categories of Air Quality (1999)

Station	Result	Level
1	0,85	**S5 Extremely Poor**
2	0,85	**S5 Extremely Poor**
3	0,85	**S5 Extremely Poor**

TABLE XVI
Categories of Air Quality (2008)

Station	Result	Level
1	0,85	**S5 Extremely Poor**
2	0,76	**S3 Poor**
3	0,57	**S4 Very Poor**

TABLE XVII
Categories of Air Quality (2014)

Station	Result	Level
1	1,00	**S1 Good**
2	1,00	**S1 Good**
3	1,00	**S1 Good**

IV. RESULTS AND DISCUSSION

A. About the case study

The air quality in the years 1999, 2008 and 2014 has been changing. In principle, in the year 1999, the air quality, in the three monitoring stations, turned out to be an extremely poor grey class, according to IMECA standards.

On the other hand, in 2008, the air quality at the first station (E-1), located in the district of La Oroya Antigua, remained extremely poor; however, at stations E-2 and E-3 located in the district of Huari and Santa Rosa de Sacco, the air quality became poor and very poor, respectively.

Finally, in the year 2014, the air quality registers a significant improvement in the 3 monitoring stations compared to the years 1999 and 2008; since a good gray class was obtained.

The results obtained in each year are shown in Figure 3.

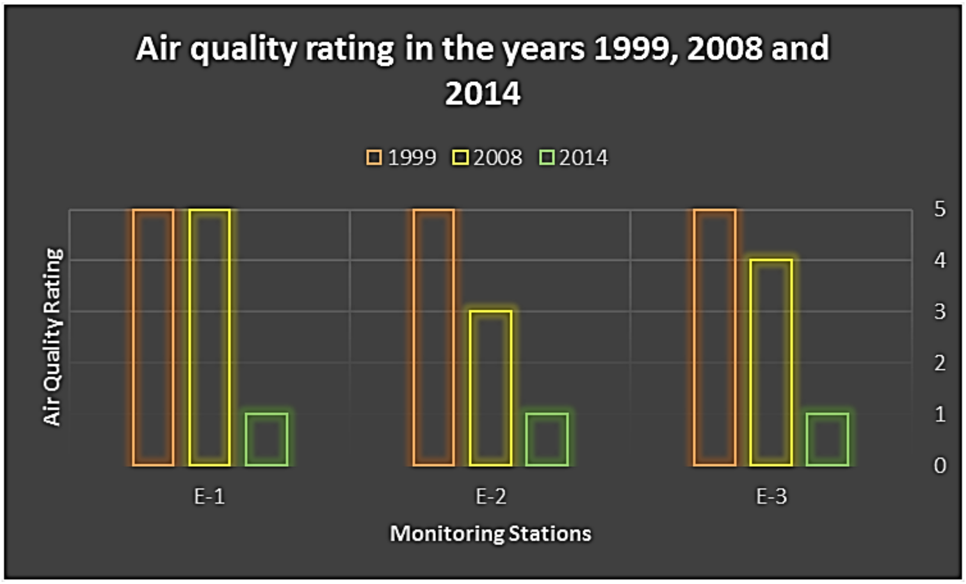

Fig. 3. Graph of values of grouping coefficients at each monitoring point of the years analyzed. It is observed how, throughout the years 1999, 2008 and 2014, the quality of the air improved, thus registering a better position in the levels of the IMECA standards.

With the results obtained, it is shown that there is a direct relationship between the quality of the air in the city of La Oroya and the mining activity carried out in that locality. In 1999, the air quality was extremely poor and we can assume that it was caused by the La Oroya Polymetallic Metallurgical Complex, given that since 1997, the year in which the property was transferred to Doe Run Peru, neither the State nor the company have been able to operate within standards compatible with health and the environment [16].

In 2008, the air quality in the city of La Oroya continued to be critical at station 1. On the other hand, at station 2, only poor quality was recorded. This may mean that there was progress in matters of improving the environmental impact; however, in 2011, according to the NGO Blacksmith Institute, the city of La Oroya was listed as the second city in the ranking of those with the most toxic air in the world. The authors of the report presented by the environmental NGO based their estimates on the presence of heavy metals, mercury and arsenic in the air [17].

At the end of 2014, according to the results obtained, they showed an improvement, thus obtaining an air quality categorized as good in all three stations, which would indicate that over time the situation in La Oroya improves. In contrast to these results, although between 2009 and 2012 the complex did not operate, the city of La Oroya was still among the 5 most polluted in the world [18]. However, this does not necessarily have to do with the emissions of gases and heavy metals into the air of this city. The refinery was in this situation, since the amount of environmental liabilities was and still is very high, the main reason why companies do not want to invest in it. Within the environmental liabilities, we have traces of heavy metals accumulated in the soil. An investigation by the UNMSM shows that the soils of the city of La Oroya Antigua are contaminated with lead, reaching extreme values that in some cases exceed 9000 mg/kg, clearly exceeding the Peruvian Soil Quality Standard for housing and for commercial, industrial and extractive soils that are 140 mg/Kg and 1200 mg/Kg, respectively [19]. On the other hand, it is likely that the number of parameters analyzed is insufficient, in other words, data is required for more parameters such as highly polluting heavy metals such as arsenic, mercury, particulate matter or toxic gases, that effectively demonstrate that the city of La Oroya is no longer contaminated. As an example, according to a report prepared by the Muqui Proposal and Action Network in 2012, a group of 24 children who underwent blood, hair and urine tests confirmed that they were affected with elevated levels of mercury, cadmium, lead and arsenic, much higher than allowed, despite the fact that the company stopped operating in 2009 [20].

B. About the methodology

The Grey Clustering method used as the basis for the development of this research, has a good performance in the environmental analysis of the years 1999, 2008 and 2014, in terms of air quality.

In the methodology applied, the harmonic mean was used as the weight of the objective criteria, however, with the aim of a more successful result in 2014 could be replaced by assigning equal weights by the method of the arithmetic mean; this because the air sampling data can present great variation and high uncertainty.

Other methods such as fuzzy logic can be used in the assessment of the emission of gases and heavy metals into the air, given that the interactions between pollutants and the physical and chemical variables that these imply, correspond to complex relationships that require diffuse inference techniques.

V. CONCLUSIONS

After analyzing the air quality in the years 1999, 2008 and 2014 using the CTWF method was carried out taking into account three monitoring stations within the city of La Oroya, it can be concluded that it has improved among the years studied, at a general level. The air quality analysis in 1999 shows that every monitoring points belong to category S5 according to the IMECA standards. On the other hand, the air quality analysis in 2008 reveals a remarkable improvement by validating that station 2 studied belong to category S3 and station 3 to category S4; however, the station 1 doesn't show changes. Finally, the air quality analysis in 2014 exposes a noticeable improvement by expressing that all of the monitoring points belong to category S1.

According to this study, it could be concluded that grey clustering is a method with a high efficiency for the air quality's evaluation compared with other methodologies. Some benefits of this system are the possibility of obtaining all the parameters at each monitoring point, as well as analyzing the differences between points of the same category. The use of this technique is recommended in works where the information has a high uncertainty.

Finally, it is important to notice that this study did not cover the quality of soil and water, which is where the suspended particles end up. A study will be important to determine the contamination of the soil and water of La Oroya and determine the impact of the mining industry.

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