International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 09, September 2022)
Manuscript Received: 10 July 2022, Received in Revised form: 22 August 2022, Accepted:01 September 2022 DOI: 10.46338/ijetae0922_01

Assessment and Analysis of Soil Quality in an Industrial Zone from Lima, Peru Using the Grey Clustering Method

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***Abstract*—Within the district of Ventanilla there are many lead smelting companies, which emit gases containing heavy metals that, when transported to human settlements, could be causing damage to the health of the population, mostly harming young children. At present, the evaluation of soil quality involves the monitoring of various indicators that are analysed independently, leaving aside the systemic approach in which the elements interact and often restrict each other, making the analysis very complex. In this sense, a superior analysis system is proposed based on the Grey Clustering method, which is based on the theory of grey systems, an artificial intelligence approach that allows for an integral evaluation and takes into account the high degree of uncertainty present in the environment. The proposed methodology was used for the study of soil quality in the industrial park of the district of Ventanilla - Mi Perú, specifically in 3 Areas of Potential Interest (API): "Mercado Virgen de Guadalupe", "Patio de La I.E.P. Arturo Padilla Espinoza" and "AA.HH. Las Casuarinas". The results of the evaluation of soil quality using the Grey Clustering method showed that 40% of the total number of monitoring points have very poor soil quality, with the Virgen de Guadalupe Market area having 75% of the monitoring points with very poor soil quality. Finally, the present study can be of great use to the competent authorities related to the surveillance and monitoring of soil quality, as well as the health of the nearby population in order to make decisions on the control of nearby industrial activities.**

***Keywords*—Soil quality, Integral assessment, Grey clustering, Heavy metals**

I. INTRODUCTION

The Constitutional Province of Callao is located on the central coast of Peru, with 28.31% of its territory under mining concession[1]; one of its districts is Ventanilla. In Pérez's research [2] he points out that the companies located in Ventanilla emit gases containing heavy metals such as lead which, when transported to human settlements, cause damage to the health of the population, mostly affecting children between the ages of 3 and 5 years old.

In the industrial zone of Ventanilla - Mi Perú, the Environmental Assessment reports by the Environmental Assessment Directorate (DEAM) of the Environmental Assessment and Enforcement Agency (OEFA) indicate that some areas of potential interest (API) have soils contaminated by lead, arsenic and cadmium, as several sampling points have been identified that exceed the ECAs for soils, as well as background levels[3].

Currently, for the analysis of soil quality, several factors are monitored, which are evaluated independently, leaving aside the systemic approach where the various elements interact and mutually restrict each other [4],for this reason, a superior evaluation system is proposed based on the Grey Clustering method which is based on the theory of grey systems which is an approach of artificial intelligence, initially developed by Deng in 1985, this method takes into account the high degree of uncertainty present in the environment [5] and has been used for the evaluation of the quality of other environmental components (air or water), however, for the soil component it has not yet been widely studied [6]. The Grey Clustering Method can be applied by grey incidence of grey whitening matrices or weighting functions. In this work, the "Central Point Triangulation based on Whitenisation Functions - CTWF" was applied, as the CTWF is mainly applied to test whether the observation objects belong to predetermined classes, known as grey classes [7] as evidenced by the studies of innovative strategy selection [8], water quality assessment of the Huallaga River [9] and air quality assessment [10].

The case study of the research is developed in the industrial park of Ventanilla - Mi Perú, which is related to the development of industrial activities in the place, therefore, the population adjacent to the industrial park has expressed its discomfort against the development of lead smelting companies that, according to its appreciations, would be polluting the environment and, therefore, generating affectations to the health of the people of the place.

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Furthermore, according to a report by the Regional Technical Group and air and soil quality monitoring carried out by public institutions in the area, some activities carried out in the Ventanilla industrial park generate emissions of particulate matter containing heavy metals (lead and cadmium), which are favoured by wind speed and direction and are transported towards the population area, in addition to degrading the quality of the air and soil in the study zone[3].

Therefore, the specific objective of the research is to determine the soil quality classification of the industrial zone of Ventanilla - Mi Perú, based on the Grey Clustering methodology, with the elements to be analysed being metals such as cadmium, lead and mercury, where we will focus on three areas of potential interest, which are: Mercado Virgen de Guadalupe (CS-MVG), AAHH Las Casuarinas (CS-LC) and I.E.P. Arturo Padilla Espinoza (CS-APE).

This research is organised as follows: Section I presents the Introduction; Section II, the literature review; Section III, the methodology; Section IV, the case study; Section V, the dimensioned standards; Section VI, the results and discussion; and finally, Section VII, the conclusion.

II. Literature Review

Liangqian Fan, Fenghui Chen y Yuliang Fan, en 2012, se utilizó el método de Grey Clustering mejorado para Liangqian Fan, Fenghui Chen and Yuliang Fan, in 2012, used the improved Grey Clustering method to demonstrate its effectiveness with data obtained from other research showing the concentrations of Cd, Hg, Pb, Cr, Cu and Zn with eight monitoring points, and the evaluation criteria were determined by the background values and critical contents of heavy metals in soils. After the weights and clustering coefficients were obtained, it was possible to compare the normal Grey Clustering method with the improved one. It was identified that out of the eight sampling points, only three points show inconsistencies, and this is due to the fact that the two methods use different whitenisation functions. Therefore, the evaluation of these methods was carried out and it was concluded that the improved method presents a higher accuracy with the results obtained when observing the closeness of the results to the monitoring data on which it was based[6].

Wang Liping, Lai Kunrong and Zhou Weibo, in 2011, used the Grey Clustering method in assessing water quality in the Fenchuan River (China), where according to the Clustering coefficient, the water quality of Jinjiabian and Madongxiang mainstream was relatively good, which was found to be slightly polluted, therefore, corrective measures could be taken to ensure its early rehabilitation, while the water quality of the downstream mainstream Linzhengzheng River and the Guanzhuang Bypass was seriously polluted, where urgent measures for its rehabilitation were needed[11].

Jia Wang, Xu Wang, Xinhua Zhang, Haichen Li, Xiaohui Lei, Hao Wang and Lixin Wang, in 2018, the analysis of the differences of water quality impacts of different indicators on water samples was conducted and the Grey Clustering method based on an improved analysis of the hierarchy process was used to evaluate surface water quality. For the different water quality indicators, the importance they have is assigned and the weights are calculated by the analytical processes of the hierarchy, hence a variant in the latter was the weight to be assigned calculated by the Clustering coefficient and the assessed water quality considers the differences of the contribution ratio with the different pollution indicators. After carrying out the respective analyses and comparisons, it was concluded that the Grey Clustering method is a much more scientific and reasonable method that can provide the basis for the assessment of water quality, as well as provide guidelines for the proper management of water resources[12].

Joseph Rosas and Jose Iannacone, in 2020, carried out an assessment of the bioaccumulation of potentially toxic elements using the species Sarcocornia neei from the regional conservation area humedales de ventanilla, callao region, in Peru. Samples were taken from three geographical areas of the wetland and fifteen potentially toxic elements were analysed in plant and soil samples using a plasma coupled mass spectrometer. As a result, the concentrations of lead, arsenic and cadmium exceed the values of the environmental quality standard and, therefore, generate contamination to the surrounding ecosystems and impact on the quality of the people living in the vicinity [13].

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DESA & DIGESA, in 2018, carried out a sanitary and environmental assessment of soils covering population areas as well as industrial areas in the district of Ventanilla in Peru, where sampling and laboratory analysis identified the existence of high levels of lead, cadmium and arsenic in human and industrial settlements, exceeding the standards for soil in their residential and industrial uses [14].

Hence, the purpose of the paper is to present this new problem present in the industrial zone of the district of ventanilla, district of lima, department of Peru, where it is evident that the monitored values of the soil samples exceed their environmental quality standards and also the grey clustering method will be used, which has not been developed much in demonstrating the environmental quality present in certain components providing information of great value for future decision making.

III. Methodology

The CTWF method, which was developed to perform soil quality assessment, is described assuming that there are m study objects, parameters and k grey classifications and a set of monitoring values Xij= (i=1, 2 ..., m; j=1, 2..., n). Then, to perform the CTWF method, the following steps are followed[8][15].

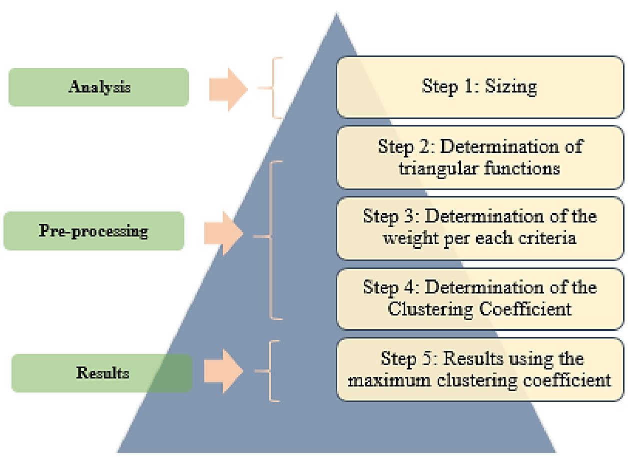

Fig. 1. Diagram of the CTWF method

Step 1: The dimensioning is carried out for each soil quality parameter (j), according to the standard used by Liangqian[6]. The dimensioned monitoring data for each soil quality parameter is also obtained for each study area to be evaluated (i).

Step 2: Grey classes are established based on the standard used by Liangqian[6].

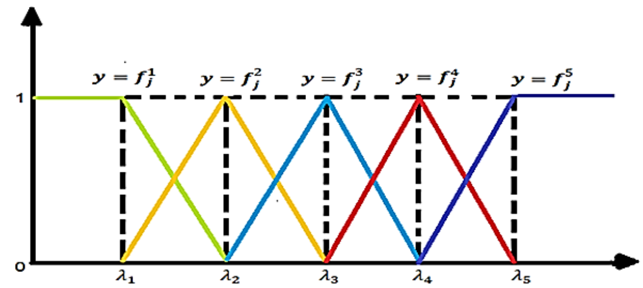

Fig. 2. CTWF According to the standard used by Liangqian[6]

Where:

Now, for the k-th grey class, k=1,2,3,4,5,6, of the j-th parameter, j=1, 2...n for a monitoring value Xij, the CTWFs are calculated by Equations 1-3

$$f_j^1(x_{ij}) = \begin{cases} 1 & x \in \left[0, \lambda_j^1\right] \\ \frac{\lambda_j^2 - x}{\lambda_j^2 - \lambda_j^1} & x \in \langle \lambda_j^1, \lambda_j^2 \rangle \\ 0 & x \in \left[\lambda_j^2, +\infty\right\rangle \end{cases} \qquad (1)$$

$$\boldsymbol{f_j^k(x_{ij})} = \begin{cases} \frac{x - \lambda_j^{k-1}}{\lambda_j^k - \lambda_j^{k-1}} & x \in \left\langle \boldsymbol{\lambda_j^{k-1}}, \boldsymbol{\lambda_j^k} \right] \\ \frac{\lambda_j^{k+1} - x}{\lambda_j^{k+1} - \lambda_j^k} & x \in \langle \boldsymbol{\lambda_j^k}, \boldsymbol{\lambda_j^{k+1}} \rangle \\ 0 & x \in \left[0, \boldsymbol{\lambda_j^{k-1}}\right] U \left[\boldsymbol{\lambda_j^{k+1}}, +\infty\right\rangle \end{cases} \qquad (2)$$

$$f_j^6(x_{ij}) = \begin{cases} \frac{x - \lambda_j^5}{\lambda_j^6 - \lambda_j^5} & x \in \langle \lambda_j^5, \lambda_j^6 \rangle \\ 1 & x \in \langle \lambda_j^6, +\infty \rangle \\ 0 & x \in \left[0, \lambda_j^5\right] \end{cases} \qquad (3)$$

Step 3: Calculate the clustering weight (nij) of each parameter, according to the standard used by Liangqian[6], in an objective manner by the Equation.

$$n_j^k = \frac{1/\lambda_j^k}{\sum_{j=1}^{m} 1/\lambda_j^k} \qquad (4)$$

Step 4: The clustering coefficient is calculated integrally for each monitoring point in each study sector, using Equation 5:

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k\left(x_{ij}\right).n_j \qquad (5)$$

Step 5: Establish $max_{l \le k \ge s}\left\{\sigma_i^k\right\} = \sigma_i^{k^*}$ which defines the classification and decides which object i belongs to grey class k*.

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IV. CASE STUDY

A. Description of the context

The analysis of soil quality was carried out in the industrial park of the district of Ventanilla - Mi Perú belonging to the constitutional province of Callao, in Peru. As shown in Figure N° 3, the study area is made up of three Areas of Potential Interest (API): Mercado Virgen de Guadalupe - CS-MVG (0.30 Ha), AAHH Las Casuarinas - CS-LC (0.87 Ha) and the I.E.P. Arturo Padilla Espinoza - CS-APE (1.47 Ha). The first two are located in the district of Mi Perú and the third in the district of Ventanilla. These three areas were selected because of their proximity to the industrial zone of Ventanilla, which could be directly affected by metal contamination in the soil due to the activity that takes place in the industrial zone.

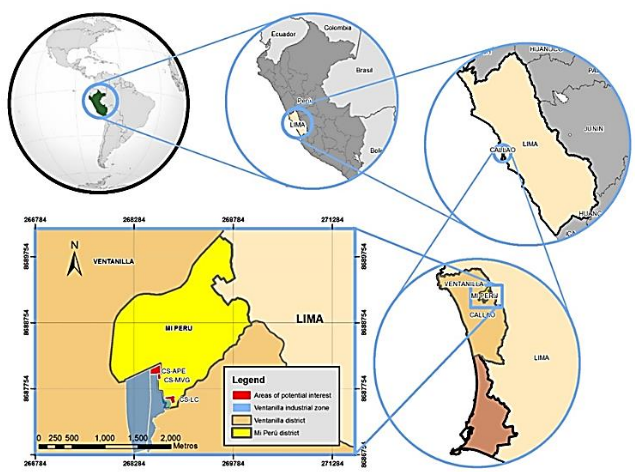

Fig. 3. Location of Areas of Potential Interest (API)

Figure 2 shows that the three areas of potential interest (API) analysed are located next to the industrial zone, and it should also be noted that the wind direction is from windward (industrial zone) to leeward (API), which may contribute to particulate matter from the industrial zone being deposited on the soils in these areas.

B. Definition of the objects of study:

For the evaluation of soil quality to address the environmental problems in the Ventanilla Industrial Zone - My Peru, information was collected from the soil quality monitoring of three (3) areas of potential interest (API) carried out from 3 to 21 March 2017 by the Coordination of Environmental Assessments in Fisheries, Industry and Others - CEAPIO of the Directorate of Environmental Assessment of the Environmental Assessment and Enforcement Agency [3], which are detailed in the following Table I and are represented in Figure 4.

TABLE I.
MONITORING POINTS AT SELECTED APIS IN THE VENTANILLA INDUSTRIAL ZONE - MI PERÚ

PI	Sampling point
Mercado Virgen de Guadalupe (CS-MVG)	CS-MVG-1
	CS-MVG-2
	CS-MVG-3
	CS-MVG-4
AA.HH. Las Casuarinas (CS-LC)	CS-LC-1
	CS-LC-2
	CS-LC-3
	CS-LC-4
	CS-LC-5
	CS-LC-6
Patio de La I.E.P. Arturo Padilla Espinoza (CS-APE)	CS-APE-1
	CS-APE-2
	CS-APE-3
	CS-APE-4
	CS-APE-5
	CS-APE-6
	CS-APE-7
	CS-APE-8
	CS-APE-9
	CS-APE-10

EXPLORING RESEARCH AND INNOVATIONS

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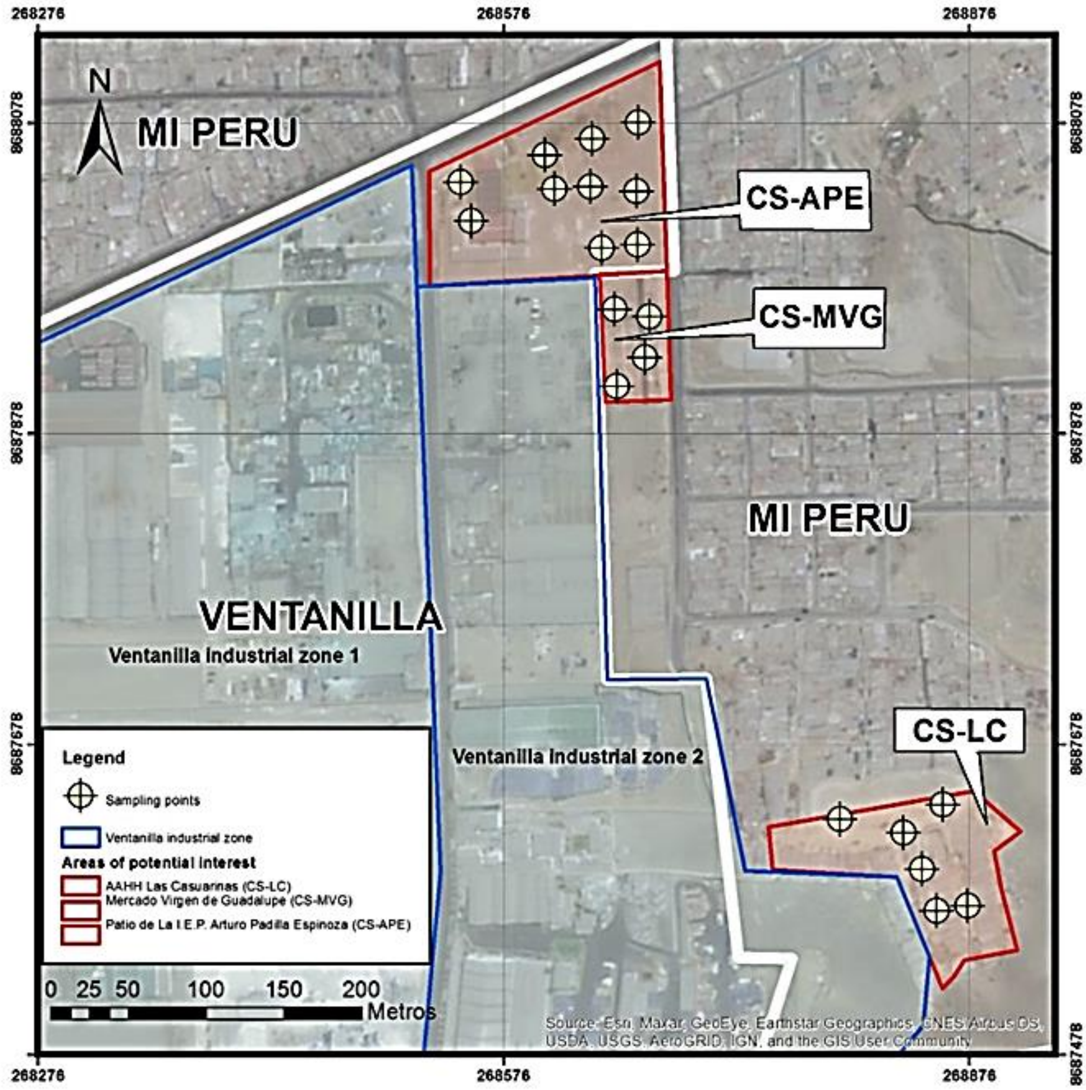

Fig. 4. Sampling points in the Areas of Potential Interest

C. Definition of the objects of study:

In the present research work, the evaluation criteria are the soil quality parameters shown in Table II.

TABLE II.
ASSESSMENT CRITERIA FOR SOIL QUALITY

Criteria	Units	Notation
Cd	mg/l	C_1
Pb	mg/l	C_2
Hg	mg/l	C_3

D. Definition of the objects of study:

Five grey classes are defined which are based on the Liangqian[6] soil quality standard, as presented in Table III, for the three criteria defined in 4.3.

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TABLE III.
GREY CLASSES BASED ON STANDARD USED BY LIANGQIAN[6] FOR FLOORING QUALITY.

	λ1 (mg/L)	λ2 (mg/L)	λ3 (mg/L)	λ4 (mg/L)	λ5 (mg/L)
C1	0.1204	0.2523	0.6	1.4	2
C2	23.35	36.09	150	500	211.888
C3	0.092	0.2592	0.45	1.05	1.5

λ_1: Very well, λ_2: Well, λ_3: Moderate, λ_4: Wrong, λ_5: Very wrong

E. Calculations using the CTWF method

The calculations for the case study are presented below:

Step 1: Based on the values presented by the standard used by Liangqian[6], these values are dimensioned, as well as the monitoring data for each soil quality parameter. The results are presented in Table IV.

TABLE IV.
DIMENSIONING OF THE GREY CLASSES OF SOIL QUALITY STANDARDS

	λ1	λ2	λ3	λ4	λ5
C1	0.1377	0.2885	0.6861	1.6008	2.2869
C2	0.1102	0.1703	0.7079	1.6518	2.3597
C3	0.1373	0.3867	0.6714	1.5666	2.238

λ_1: Very well, λ_2: Well, λ_3: Moderate, λ_4: Wrong, λ_5: Very wrong

Similarly, based on the results of the Environmental Assessment Report on the Ventanilla Industrial Zone - My Peru, Constitutional Province of Callao in 2017, developed by the Environmental Evaluation and Oversight Agency (OEFA), the data of the 20 monitoring points of the three Areas of Potential Interest (API) are dimensioned. The results of the sizing are presented in Table V.

TABLE V.
MONITORING DATA DIMENSIONING

API	Sampling point	Parameters		
		Total cadmium	Total lead	Total mercury
Mercado Virgen de Guadalupe (CS-MVG)	**CS-MVG-1**	6.7887	0.3898	0.0448
	CS-MVG-2	2.1314	0.1732	0.0448
	CS-MVG-3	4.3086	0.3813	0.0448
	CS-MVG-4	3.9598	0.4262	0.0746
AAHH Las Casuarinas (CS-LC)	**CS-LC-1**	4.4	0.0087	0.0597
	CS-LC-2	4.0524	0.1402	0.0448
	CS-LC-3	2.5533	0.2426	0.0895
	CS-LC-4	4.1988	0.2813	0.0448
	CS-LC-5	3.0393	0.0944	0.0448
	CS-LC-6	9.2552	0.2355	0.0448
Patio de La I.E.P. Arturo Padilla Espinoza (CS-APE)	**CS-APE-1**	4.7019	0.429	0.0448
	CS-APE-2	5.7916	0.3676	0.0448
	CS-APE-3	6.5532	0.3846	0.0448
	CS-APE-4	5.4943	0.2506	0.0448
	CS-APE-5	0.7705	0.2709	0.0448
	CS-APE-6	7.6292	0.3455	0.0448
	CS-APE-7	2.9661	0.176	0.0448
	CS-APE-8	3.276	0.1354	0.0448
	CS-APE-9	11.2528	0.1623	0.0448
	CS-APE-10	8.2192	0.2487	0.0448

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Step 2: Based on equations 1-3, the CTWFs of the 5 grey classes are calculated for the 3 selected parameters. As an example, equations 6-10 and Figure 4 are presented for the first parameter C_1 (Cadmium).

$$f_j^1(x_{ij}) = \begin{cases} 1 & x\,\epsilon[0\,;0.1377] \\ \frac{0.2885-x}{0.1508} & x\,\epsilon\langle 0.1377;0.2885\rangle \\ 0 & x\,\epsilon[0.2885\,;+\infty\rangle \end{cases} \quad (6)$$

$$f_j^2(x_{ij}) = \begin{cases} \frac{x-0.1377}{0.1508} & x\,\epsilon\langle 0.1377,0.2885] \\ \frac{0.6861-x}{0.3976} & x\,\epsilon\langle 0.2885,0.6861\rangle \\ 0 & x\,\epsilon[0,0.1377]\ U\ [0.6861,+\infty\rangle \end{cases} \quad (7)$$

$$f_j^3(x_{ij}) = \begin{cases} \frac{x-0.2885}{0.3976} & x\,\epsilon\langle 0.2885,0.6861] \\ \frac{1.6008-x}{0.9148} & x\,\epsilon\langle 0.2885,1.6008\rangle \\ 0 & x\,\epsilon[0,0.2885]\ U\ [1.6008,+\infty\rangle \end{cases} \quad (8)$$

$$f_j^4(x_{ij}) = \begin{cases} \frac{x-0.6861}{0.9148} & x\,\epsilon\langle 0.6861,1.6008] \\ \frac{2.2869-x}{0.6861} & x\,\epsilon\langle 1.6008,2.2869\rangle \\ 0 & x\,\epsilon[0,0.6861]\ U\ 2.2869+\infty\rangle \end{cases} \quad (9)$$

$$f_j^5(x_{ij}) = \begin{cases} \frac{x-1.6008}{0.6861} & x\,\epsilon\langle 1.6008,2.2869\rangle \\ 1 & x\,\epsilon\langle 2.2869,+\infty\rangle \\ 0 & x\,\epsilon[0,0.16008] \end{cases} \quad (10)$$

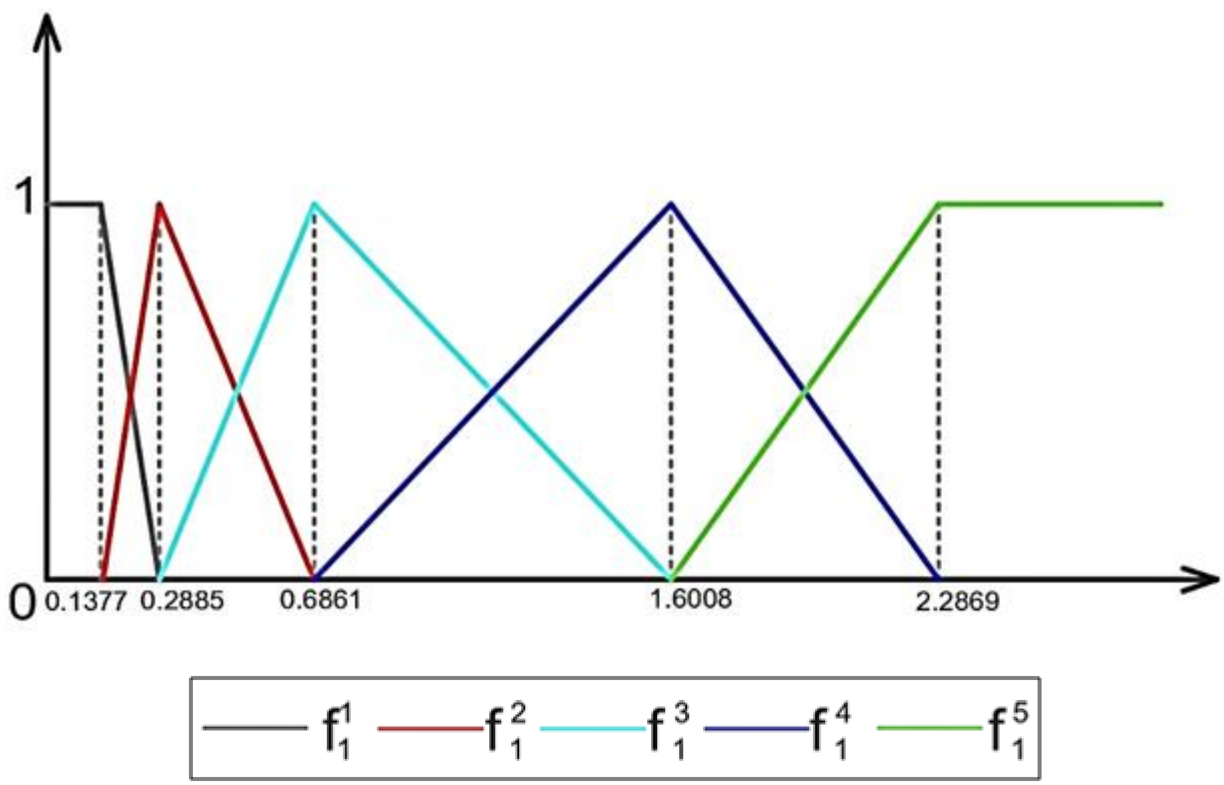

Figure N°4: CTWF for the first parameter C_1

Subsequently, the values in Table V were replaced in the triangular whitening functions for each parameter.

Table VI shows the results obtained for the API Mercado Virgen de Guadalupe in its 4 monitored points.

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TABLE VI.
VALUES OF THE TRIANGULAR WHITENING FUNCTIONS (CTWF) FOR THE FIRST 4 MONITORING POINTS, BELONGING TO THE "MERCADO VIRGEN DE GUADALUPE" (CS-MVG).

CS-MVG-1			
Criteria	**C_1**	**C_2**	**C_3**
$f^1_j (x)$	0	0	1
$f^2_j (x)$	0	0.5917	0
$f^3_j (x)$	0	0.4083	0
$f^4_j (x)$	0	0	0
$f^5_j (x)$	1	0	0
CS-MVG-2			
Criteria	**C_1**	**C_2**	**C_3**
$f^1_j (x)$	0	0	1
$f^2_j (x)$	0	0.9946	0
$f^3_j (x)$	0	0.0054	0
$f^4_j (x)$	0.2266	0	0
$f^5_j (x)$	0.7734	0	0
CS-MVG-3			
Criteria	**C_1**	**C_2**	**C_3**
$f^1_j (x)$	0	0	1
$f^2_j (x)$	0	0.6075	0
$f^3_j (x)$	0	0.3925	0
$f^4_j (x)$	0	0	0
$f^5_j (x)$	1	0	0
CS-MVG-4			
Criteria	**C_1**	**C_2**	**C_3**
$f^1_j (x)$	0	0	1
$f^2_j (x)$	0	0.524	0
$f^3_j (x)$	0	0.476	0
$f^4_j (x)$	0	0	0
$f^5_j (x)$	1	0	0

Step 3: Equation (4) is used to calculate the clustering weight (nij) of each parameter, according to the standard used by Liangqian[6]. Table VII shows the results.

TABLE VII.
CALCULATED WEIGHTS OF THE CRITERIA

Criteria	Clustering weights (nij)				
	λ_1	λ_2	λ_3	λ_4	λ_5
C_1	0.3075	0.2907	0.3343	0.3343	0.3343
C_2	0.3842	0.4924	0.324	0.324	0.324
C_3	0.3084	0.2169	0.3416	0.3416	0.3416

Step 4: The values of the clustering coefficients were calculated by applying equation 5.

Table VIII shows the results of the first 2 monitoring points for each area of potential interest.

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TABLE VIII.
VALUES OF THE TRIANGULAR WHITENING FUNCTIONS (CTWF) AND THE CLUSTERING COEFFICIENTS

API	Results by Monitoring Point				
Mercado Virgen de Guadalupe (CS-MVG)	CS-MVG-1				
	Criteria	**C_1**	**C_2**	**C_3**	**Result**
	$f^1_i(x)$	0.0000	0.0000	1.0000	0.3084
	$f^2_i(x)$	0.0000	0.5917	0.0000	0.2914
	$f^3_i(x)$	0.0000	0.4083	0.0000	0.1323
	$f^4_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^5_i(x)$	1.0000	0.0000	0.0000	0.3343
	CS-MVG-2				
	Criteria	**C_1**	**C_2**	**C_3**	**Result**
	$f^1_i(x)$	0.0000	0.0000	1.0000	0.3084
	$f^2_i(x)$	0.0000	0.9946	0.0000	0.4897
	$f^3_i(x)$	0.0000	0.0054	0.0000	0.0017
	$f^4_i(x)$	0.2266	0.0000	0.0000	0.0758
	$f^5_i(x)$	0.7734	0.0000	0.0000	0.2585
Patio de La I.E.P. Arturo Padilla (CS-APE)	CS-APE-1				
	Criteria	**C_1**	**C_2**	**C_3**	**Result**
	$f^1_i(x)$	0.0000	0.0000	1.0000	0.3084
	$f^2_i(x)$	0.0000	0.5188	0.0000	0.3262
	$f^3_i(x)$	0.0000	0.4812	0.0000	0.2368
	$f^4_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^5_i(x)$	1.0000	0.0000	0.0000	0.5078
	CS-APE-2				
	Criteria	**C_1**	**C_2**	**C_3**	**Result**
	$f^1_i(x)$	0.0000	0.0000	1.0000	0.3084
	$f^2_i(x)$	0.0000	0.6330	0.0000	0.3980
	$f^3_i(x)$	0.0000	0.3670	0.0000	0.1806
	$f^4_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^5_i(x)$	1.0000	0.0000	0.0000	0.5078
AA.HH. Las Casuarinas (CS-LC)	CS-LC-1				
	Criteria	**C_1**	**C_2**	**C_3**	**Result**
	$f^1_i(x)$	0.0000	1.0000	1.0000	0.8638
	$f^2_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^3_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^4_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^5_i(x)$	1.0000	0.0000	0.0000	0.5078
	CS-LC-2				
	Criteria	**C_1**	**C_2**	**C_3**	**Result**
	$f^1_i(x)$	0.0000	0.5008	1.0000	0.5866
	$f^2_i(x)$	0.0000	0.4992	0.0000	0.3139
	$f^3_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^4_i(x)$	0.0000	0.0000	0.0000	0.0000
	$f^5_i(x)$	1.0000	0.0000	0.0000	0.5078

Step 5: The conditional classification of the monitoring points is carried out according to the maximum clustering coefficient, as shown in Table IX.

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TABLE IX.
CALCULATED COEFFICIENT AND CLASSIFICATION

Study Objects	Sampling Points	Very well	Well	Moderate	Wrong	Very wrong
Mercado Virgen de Guadalupe (CS-MVG)	CS-MVG-1	0.3084	0.2914	0.1323	0	0.3343
	CS-MVG-2	0.3084	0.4897	0.0017	0.0758	0.2585
	CS-MVG-3	0.3084	0.2991	0.1272	0	0.3343
	CS-MVG-4	0.3084	0.258	0.1542	0	0.3343
Patio de La I.E.P. Arturo Padilla Espinoza (CS-APE)	CS-APE-1	0.3084	0.3262	0.2368	0	0.5078
	CS-APE-2	0.3084	0.398	0.1806	0	0.5078
	CS-APE-3	0.3084	0.3781	0.1962	0	0.5078
	CS-APE-4	0.3084	0.5348	0.0735	0	0.5078
	CS-APE-5	0.3084	0.5111	0.553	0.0469	0
	CS-APE-6	0.3084	0.4239	0.1604	0	0.5078
	CS-APE-7	0.3084	0.6221	0.0052	0	0.5078
	CS-APE-8	0.6309	0.2636	0	0	0.5078
	CS-APE-9	0.3823	0.5451	0	0	0.5078
	CS-APE-10	0.3084	0.5371	0.0718	0	0.5078
AAHH Las Casuarinas (CS-LC)	CS-LC-1	0.8638	0	0	0	0.5078
	CS-LC-2	0.5866	0.3139	0	0	0.5078
	CS-LC-3	0.3084	0.5443	0.0661	0	0.5078
	CS-LC-4	0.3084	0.4989	0.1016	0	0.5078
	CS-LC-5	0.8638	0	0	0	0.5078
	CS-LC-6	0.3084	0.5525	0.0597	0	0.5078

V. RESULTS AND DISCUSSION

A. *About the case study*

Table X shows that for each study object the soil quality is very varied due to the location (proximity to the industrial area), wind direction and relief of the site.

In addition, the degree of quality of the soil samples has been determined, where a smaller bar means that the quality is very poor, while a larger bar represents good soil quality.

EXPLORING RESEARCH AND INNOVATIONS

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TABLE X.
RESULTS OF SAMPLING POINTS

Objetos de Estudio	Sampling Points	Values	Soil quality	Quality Grade Very well Well Moderate Wrong Very
Mercado Virgen de Guadalupe	CS-MVG-1	0.3343	Very wrong	
	CS-MVG-2	0.4897	Well	
	CS-MVG-3	0.3343	Very wrong	
	CS-MVG-4	0.3343	Very wrong	
Patio de La I.E.P. Arturo Padilla Espinoza (CS-APE)	CS-APE-1	0.5078	Very wrong	
	CS-APE-2	0.5078	Very wrong	
	CS-APE-3	0.5078	Very wrong	
	CS-APE-4	0.5348	Well	
	CS-APE-5	0.553	Moderate	
	CS-APE-6	0.5078	Very wrong	
	CS-APE-7	0.6221	Well	
	CS-APE-8	0.6309	Muy bueno	
	CS-APE-9	0.5451	Well	
	CS-APE-10	0.5371	Well	
AAHH Las Casuarinas (CS-LC)	CS-LC-1	0.8638	Very well	
	CS-LC-2	0.5866	Very well	
	CS-LC-3	0.5443	Well	
	CS-LC-4	0.5078	Very wrong	
	CS-LC-5	0.8638	Very well	
	CS-LC-6	0.5525	Well	

At the Mercado Virgen de Guadalupe (CS-MVG) it was determined that 75% of the sampling points indicate that the soil quality is in the "Very wrong" condition. This is due to the fact that the "Mercado Virgen de Guadalupe" is located on the slopes of an elevation, functioning as a natural barrier for particulate matter, with heavy metal content, coming from the industrial zone Ventanilla-Mi Perú. Likewise, the emissions generated could have reached the soil by dry and/or wet deposition, which would have been favoured by the wind direction from windward (industrial area) to leeward (study area). In addition, the already settled particles could be re-suspended by wind action (saltation) and re-settled on the ground[3].

In the case of the courtyard of the Arturo Padilla Espinoza Private Educational Institution, it was found that it is the area with the greatest variability of soil quality states, as 40% has a very poor quality, another 40% has good quality, 10% has a very good quality and finally another 10% represents a moderate quality. This distribution of qualities within the same API may be due to soil conditioning activities to provide suitable conditions for planting and growth of ornamental plant species in the free areas of the educational institution where the monitoring activities were carried out.

Finally, for the "AA.HH. Las Casuarinas" it was determined that 50% and 33.3% of the samples analysed had very good and good soil quality, respectively.

International Journal of Emerging Technology and Advanced Engineering
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This is due to the fact that the human settlement is located behind a geological formation (hill) that acts as a barrier to the flow of emissions generated by the industrial zone of Ventanilla.

B. About the methodology

The grey binning method is a very appropriate method for soil quality assessment as it performs a comprehensive analysis of the selected parameters[6] and considers the degree of uncertainty present in the environment[5] and therefore has advantages over fuzzy exhaustive analysis[16], multiple indicator assessment[17], and multivariate statistical analysis[18]. The grey binning method applied to soil quality assessment is less studied compared to those applied to the quality assessment of other components such as water and air. Furthermore, grey systems are not widely used compared to other approaches based on statistical or fuzzy logic models[15].

TABLE XI.
COMPARISON OF METHODS FOR MODELLING UNCERTAINTY

Methods	Advantages	Disadvantages
Diffuse mathematics	-Analyses research objects that possess the characteristic of clear intention and unclear extension.	- It is difficult to work with small samples and little information. -For the problem of cognitive uncertainty with clear intent and unclear extent, use is made of experience and the so-called membership function.
Statistical method	-They study the phenomena of stochastic uncertainty with emphasis on revealing historical statistical laws	-They need the availability of large samples that are required to satisfy a certain typical form of distribution.
Grey systems	- Allows for analysis of cognitive uncertainty problems with clear intent and unclear extent. - Allows analysis of small sample uncertainty problems and limited information. - It features an objective weighting system - It allows a comprehensive analysis between the different parameters.	- Grey systems are not widely used.

Source: Adapted from Liu, S. & Lin, Y. Introduction to grey systems theory.

C. Proposed solutions

In the case of the "Mercado Virgen de Guadalupe" (CS-MVG), which has a large percentage of soil with a "very poor" quality condition, and taking into account its geographical location, very close to a natural barrier that causes greater deposition of particulate material, it is necessary to propose solutions aimed at remediating soils contaminated by heavy metals.

Due to its proximity to human populations and the impertinence of more advanced and costly techniques, phytoremediation is proposed, which is a method for eliminating contaminants from the soil through the use of living plants and their associated micro-organisms, which have the ability to extract and concentrate contaminants from the soil[19]. The species "Lolium perenne" known as "ryegrass" is suggested, which can improve its remediation efficiency through the application of electrokinetics by increasing its capacity to accumulate a proportion of metals mobilised from the treated soil through the introduction of an electric field [20].

VI. CONCLUSIONS

The points evaluated within the areas of potential interest, the "Mercado Virgen de Guadalupe" presents 75% of points with very bad quality, the "I.E.P. Arturo Padilla Espinoza" presents 40% and 10% of analysed samples with bad and very bad quality respectively, likewise, the "AAHH Las Casuarinas" presents the best soil quality with 50% and 33.3% of the analysed samples with very good and good quality, respectively. The variability of the results obtained for each object of study on soil quality could be due to the dependence of the movement of these pollutants on the meteorological conditions of the area, precisely the intensity and direction of the wind, the natural or artificial barriers, the physical and atmospheric processes that allow dry and/or wet deposition, suspension of particulate material and its wide distribution in the area.

International Journal of Emerging Technology and Advanced Engineering
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The variability of the results obtained for each object of study on soil quality may be due to the dependence of the movement of these pollutants on the meteorological conditions of the area, precisely the intensity and direction of the wind, the natural or artificial barriers, and the physical atmospheric processes that allow dry and/or wet deposition, resuspension of particulate matter and its wide distribution in the area.

The results of the present study can be of great use to the competent authorities related to the surveillance and monitoring of soil quality, as well as the health of the nearby population for decision making on the control of nearby industrial activities. It should also be noted that grey systems are not widely disseminated in comparison to other approaches, which leaves the possibility for related institutions to integrate this methodology in their studies to assess the quality of components such as soil.

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