

# Water quality assessment after the spill of the former mining company in Peru using the grey clustering method

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## I. INTRODUCTION

In June 14th of 2019, the Pelagatos ravine located in the department of Ancash, Peru, were affected by the spill of tailings from the former Pushaquilca mine (LME Pushaquilca) [1], which generated that the National Water Authority of Peru (ANA by its spanish acronym) carried out an analysis of pollutants in the water near the accident area, according to the National Protocol for Monitoring the quality of Water Resources [2]. Therefore, in this work, we seek to determine the level of contamination of five points in the affected area using the grey clustering method [3], [4] with the Prati Scale [5], [6] in order to classify the points and register the damage; as a water assessment is crucial for the correct development and welfare of the nearby communities and animals, as well as the ecosystem of the surrounding areas [7].

The grey clustering method is based on grey systems theory and is part of artificial intelligence, which was developed in 1985 by Deng [8], [9]. This method consists of developing a series of equations called whitening functions (CTWF), which will allow classifying what is observed with the name of grey classes to determine the level of contamination of the object analyzed [9]–[12].

The study area corresponds to the Pelagatos ravine [13], in which 5 monitoring points located downstream from where the mining effluent flowed [2] will have the following codes: Qpush 01, Qpush 02, Lpesc 03, Lpesc 02 and Lpesc 01.

The main objective of the work study is to classify the water quality level of the Pelagatos ravine after the tailings spill occurred in the area, using the CTWF method in order to have a registry of the water quality, as a foundation to analyze in future studies and see the impact in case a remediation has been applied or not in the mentioned area by the company in charge of closing the liabilities. By using the method, the Prati scale will classify the points as: excellent (drinking water), acceptable (water for agriculture), polluted (not usable) and highly polluted (harmful to life) in order to have a scale of the contamination if any.

In the following section, a literature review is given in order to obtain a better understood of the benefits of the methodology. Likewise, the presentation of the methodology of the present article is described in details by its equations and steps to be performed in section III. Then the case study will be displayed in section IV, where the location of the affected area, the control points, and the parameters to be taken will be found. In section V, the results of the application along with its discussions can be seen. Lastly, the conclusions are shown in section VI.

## II. LITERATURE REVIEW

The evaluation of water quality plays an important role in environmental science [14], [15]. Due to several factors, a rational pattern must be chosen to objectively describe the quality of the environment.

The first study to be evaluated is in the Tambobamba district, Cotabambas province, in the Apurímac region [3]. Las Bambas mine is operating in this area, which influences the Challhuahuacho and Ferrobamba rivers. Through the monitoring of 6 points carried out by the ANA it was possible to know the degree of contamination of these rivers. Carrying out the grey clustering methodology and the water parameters by the peruvian DS N ° 004-2017-MINAM. This paper concluded that the water in the Ferrobamba river has high water quality, while the Challhuahuacho river has poor quality associated with spills in the area.

Another case reference of the use of the chosen methodology is the Fuyang River, which has great value for industrial and agriculture in Handan [16]. However, in recent years monitoring of water in this river has indicated

contamination. Given this, the grey clustering evaluation of the water quality was established using aquatic plants that purify the water of the FuYang River. For this evaluation, the Grey Clustering method was used, analyzing 7 monitoring points where the plants were located, the method allowed to distinguish the level of water quality, which indicates that the river has a gradually good water purification cycle, but in some months it is different and may be due to the change in the temperature of the climate and the decomposition of the aquatic plant itself.

On the study [17], the Fenchuan River is a level 1 tributary of the Yellow River that flows from the eastern slope of Jiu Long Spring Lao Mountain in Nanniwan. This river is an important resource for the industry and agriculture in the Baota area, and it was decided to carry out a quality evaluation of this river through the application of Grey Clustering, therefore samples were collected from the upstream, midstream, downstream and leaving boundary spot of Fengchuan River respectively in October 2008. The evaluation in this article is classified into five levels, is based on water quality standard in Environmental Quality Standards for Surface Water (GB3838-2002), that is, in five grey classes. The result indicated that the quality of the Fengchuan water in the Baota area was contaminated to different degrees and different solutions were proposed that can counteract the degree of contamination of the river.

Finally, in [18], the Grey Clustering Method has been used to evaluate the water quality of 20 sections of the Suzhou River in Jiangsu Province, China in order to do a comparison with the results obtained by the traditional method.

Consequently, once we have analyzed the variety of studies that have used the Grey Clustering methodology (which cannot be analyzed in its full width since it exceeds the possibilities of the present article), we conclude that the method is completely adjustable to the field of study with the objective of evaluating water quality.

### III. METHODOLOGY

In this section, we explain the Grey Clustering method, which will be applied in the evaluation of the water quality of 5 monitoring points belonging to sectors of the Pelagatos ravine. For which we begin with information from works that present the same methodology considered in the literature review.

First, a set of  $n$  monitoring points, a set of  $m$  water quality parameters, a set of  $s$  grey classes and a set of real monitoring data  $x_{ij} (i = 1, 2, \dots, m; j = 1, 2, \dots, n)$  will be defined. Then, the steps of the CTWF method are presented as follows [9], [14], [16]–[19].

*Step 1:* The non-dimensional standard values for each water quality parameter ( $j$ ) are established, according to the Prati scale [5]. Subsequently, monitoring data is obtained from all the non-dimensional study points of each water quality parameter, for each monitoring point to be evaluated ( $i$ ).

*Step 2:* The five grey classes from Prati scale are shown in Fig. 1.

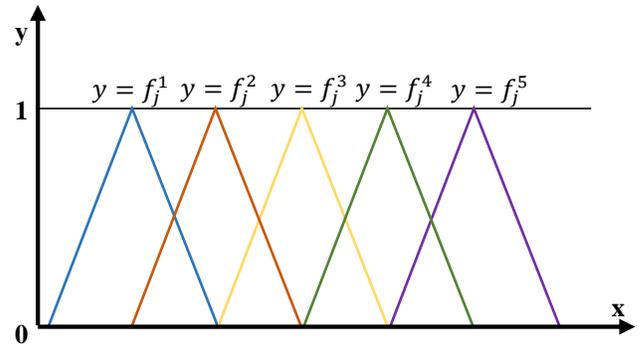


Fig. 1 CTWF according to Prati scale [20]

Where:

$y = f_j^1$ : Uncontaminated.

$y = f_j^2$ : Acceptable.

$y = f_j^3$ : Moderately contaminated.

$y = f_j^4$ : Contaminated.

$y = f_j^5$ : Highly contaminated.

Then, the grey classes or criteria will be denoted by the letter  $k$  where ( $k = 1, 2, 3, 4, 5$ ) of the  $j^{th}$  parameter ( $j = 1, 2, \dots, n$ ) for a monitoring value  $x_{ij}$ ; the CTWF will be calculated by (1) – (3).

$$f_j^1(x_{ij}) = \begin{cases} 1, [0, \lambda_j^1] \\ \frac{\lambda_j^2 - x}{\lambda_j^2 - \lambda_j^1}, x < \lambda_j^1, \lambda_j^2 > \\ 0, x [\lambda_j^2, +\infty > \end{cases} \quad (1)$$

$$f_j^k(x_{ij}) = \begin{cases} \frac{x - \lambda_j^{k-1}}{\lambda_j^k - \lambda_j^{k-1}}, x [\lambda_j^{k-1}, \lambda_j^k] \\ \frac{\lambda_j^{k+1} - x}{\lambda_j^{k+1} - \lambda_j^k}, x < \lambda_j^k, \lambda_j^{k+1} > \\ 0, x [0, \lambda_j^{k-1}] \cup [\lambda_j^{k+1} + \infty > \end{cases} \quad (2)$$

$$f_j^5(x_{ij}) = \begin{cases} \frac{x - \lambda_j^4}{\lambda_j^5 - \lambda_j^4}, x < \lambda_j^4, \lambda_j^5 > \\ 1, x [\lambda_j^5, +\infty > \\ 0, x [0, \lambda_j^4] \end{cases} \quad (3)$$

*Step 3:* The clustering weight ( $\eta_j$ ) of each parameter is obtained, according to the values of the Prati scale, which is calculated by (4).

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

*Step 4:* The integral clustering coefficient  $\sigma_i^k$  for each monitoring point  $i, i = 1, 2, \dots, m$ , with respect to the grey class  $k, k = 1, 2, \dots, s$ , is calculated by (5).

$$\sigma_j^k = \sum_{i=1}^n f_j^k(x_{ij}) \cdot \eta_j \quad (5)$$

Where  $f_j^k(x_{ij})$  is the value of grey clustering and  $\eta_j$  is the weight of parameter  $j$ .

*Step 5:* The maximum clustering coefficient value is analyzed;  $\max\{\sigma_i^k\} = \sigma_j^k$ , and it is decided which object  $i$  belongs to the grey class  $k$ .

#### IV. CASE STUDY

On June 14th of 2019, there was a spill of an Environmental Mining Liabilities left by the former mine Pushaquilca that damaged the Pelagatos ravine and empties into the Santa River. For this reason, the National Water Authority from Peru (ANA by its Spanish acronym) performed a contaminant analysis in the water near the accident zone.

The affected area was delimited by 5 monitoring points to carry out water control from different parameters. For this, the Grey Clustering method will be carried out to evaluate the values of the results.

##### A. Context Description

The context of this area is regarding a spill of environmental liabilities of the former mine Pushaquilca located in the Pampas district, Pallasca, Ancash near the Pelagatos ravine where this environmental mining pollution could affect it considerably. The location is close to the coordinates  $-77.89977$ ;  $-8.16469$  (WGS84); for a better appreciation see Fig. 2.



Fig. 2 Location of the area where the mine tailings collapse occurred

As mentioned before, 5 control points were made in order to make a more-in-detail analysis, such control point are located in the ravine of Pelagatos which is displayed in Fig. 3.



Fig. 3 Satellite image of the monitoring point

In addition, the coordinates of such control points are displayed in Table I.

TABLE I  
MONITORING POINTS

Monitoring point	Code	Description	Coordinates	
			East	North
1	QPush1	Quebrada Pushaquilca 1	190943	9096181
2	QPush2	Quebrada Pushaquilca 2	190583	9095384
3	LPesc3	Laguna Pescuezona 3	189922	9095620
4	LPesc2	Laguna Pescuezona 2	189651	9095597
5	LPesc1	Laguna Pescuezona 1	189234	9095588

##### B. Calculations using the Grey Clustering Method

The calculations for the case study are presented below, in order to do the analysis through the Grey Clustering Method, the steps presented in section 3 will be followed.

*Step 1:* First, the parameters of the dimensioned standard values, according to the Prati scale is presented in Table II.

TABLE II  
STANDARD DIMENSIONED DATA

	$\lambda_1$	$\lambda_2$	$\lambda_3$	$\lambda_4$	$\lambda_5$
Basic pH	1.350	1.164	1.024	0.829	0.633
OD	0.672	0.797	0.925	1.177	1.429
SS	0.082	0.247	0.577	1.557	2.537
Fe	0.044	0.177	0.531	1.593	2.655
Mn	0.052	0.231	0.702	1.572	2.442

The monitoring data obtained by the National Water Authority (ANA) for each parameter of each control point, the results of which were dimensioned, are presented in Table III.

TABLE III  
MONITORING DATA

	QPush1	QPush2	LPesc3	LPesc2	LPesc1
pH	0.63	0.63	1.56	1.45	1.55

OD	0.04	0.05	0.05	0.05	0.05
SS	0.12	0.09	0.008	0.03	0.02
Fe	9.91	5.33	0.20	1.54	0.64
Mn	4.1048	3.667	0.203	0.493	0.284

Step 2: The values of the Table of standardized data (Table I) added are used to perform the following equations in order to obtain the grey clustering of the 5 points. As an example, the equations of the fourth parameter (Fe) are shown from (6) – (10).

$$f_4^1(x_{ij}) = \begin{cases} 1, & x \in [0,0.044] \\ \frac{0.177-x}{0.177-0.044}, & x \in \langle 0.044, 0.177 \rangle \\ 0, & x \in [0.177, +\infty] \end{cases} \quad (6)$$

$$f_4^2(x_{ij}) = \begin{cases} \frac{x-0.044}{0.177-0.044}, & x \in \langle 0.044, 0.177 \rangle \\ \frac{0.531-x}{0.531-0.177}, & x \in \langle 0.177, 0.531 \rangle \\ 0, & x \in [0,0.044] \cup [0.531, +\infty] \end{cases} \quad (7)$$

$$f_4^3(x_{ij}) = \begin{cases} \frac{x-0.177}{0.531-0.177}, & x \in \langle 0.177, 0.531 \rangle \\ \frac{1.593-x}{1.593-0.531}, & x \in \langle 0.531, 1.593 \rangle \\ 0, & x \in [0,0.177] \cup [1.593, +\infty] \end{cases} \quad (8)$$

$$f_4^4(x_{ij}) = \begin{cases} \frac{x-0.531}{1.593-0.531}, & x \in \langle 0.531, 1.593 \rangle \\ \frac{2.655-x}{2.655-1.593}, & x \in \langle 1.593, 2.655 \rangle \\ 0, & x \in [0, 0.531] \cup [2.655, +\infty] \end{cases} \quad (9)$$

$$f_4^5(x_{ij}) = \begin{cases} \frac{x-1.593}{2.655-1.593}, & x \in \langle 1.593, 2.655 \rangle \\ 1, & x \in [2.655, +\infty] \\ 0, & x \in [0, 1.593] \end{cases} \quad (10)$$

Step 3: The weight of the criteria according to grey clustering for each parameter, in each value of the Prati scale, according to (4) is calculated. The results are shown in Table IV.

TABLE IV  
CLUSTERING WEIGHT OF THE PARAMETERS

	$\lambda_1$	$\lambda_2$	$\lambda_3$	$\lambda_4$	$\lambda_5$
Basic pH	0.01	0.05	0.14	0.30	0.46
OD	0.03	0.08	0.15	0.21	0.20
SS	0.22	0.25	0.24	0.16	0.11
Fe	0.40	0.35	0.27	0.16	0.11
Mn	0.34	0.27	0.20	0.16	0.12

Step 4: The clustering coefficients were obtained by means of (5), such results are displayed in Table V.

TABLE V

VALUES OF CTWF AND  $\sigma_i^k$  FOR EACH PARAMETER

QPuSh1	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$\sigma_i^k$
$f_j^1(x)$	0.00	1.00	0.75	0.00	0.00	0.189
$f_j^2(x)$	0.00	0.00	0.25	0.00	0.00	0.054
$f_j^3(x)$	0.00	0.00	0.00	0.00	0.00	0.000
$f_j^4(x)$	0.00	0.00	0.00	0.00	0.00	0.000
$f_j^5(x)$	1.00	0.00	0.00	1.00	1.00	0.757
QPuSh2	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$\sigma_i^k$
$f_j^1(x)$	0.00	1.00	0.95	0.00	0.00	0.232
$f_j^2(x)$	0.00	0.00	0.05	0.00	0.00	0.011
$f_j^3(x)$	0.00	0.00	0.00	0.00	0.00	0.000
$f_j^4(x)$	0.00	0.00	0.00	0.00	0.00	0.000
$f_j^5(x)$	1.00	0.00	0.00	1.00	1.00	0.757
LPeSc3	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$\sigma_i^k$
$f_j^1(x)$	1.00	1.00	1.00	0.00	0.15	0.308
$f_j^2(x)$	0.00	0.00	0.00	0.95	0.85	0.670
$f_j^3(x)$	0.00	0.00	0.00	0.05	0.00	0.022
$f_j^4(x)$	0.00	0.00	0.00	0.00	0.00	0.000
$f_j^5(x)$	0.00	0.00	0.00	0.00	0.00	0.000
LPeSc2	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$\sigma_i^k$
$f_j^1(x)$	1.00	1.00	1.00	0.00	0.00	0.256
$f_j^2(x)$	0.00	0.00	0.00	0.00	0.44	0.151
$f_j^3(x)$	0.00	0.00	0.00	0.05	0.56	0.209
$f_j^4(x)$	0.00	0.00	0.00	0.95	0.00	0.384
$f_j^5(x)$	0.00	0.00	0.00	0.00	0.00	0.000
LPeSc1	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$\sigma_i^k$
$f_j^1(x)$	1.00	1.00	1.00	0.00	0.00	0.256
$f_j^2(x)$	0.00	0.00	0.00	0.00	0.89	0.302
$f_j^3(x)$	0.00	0.00	0.00	0.90	0.11	0.400
$f_j^4(x)$	0.00	0.00	0.00	0.10	0.00	0.041
$f_j^5(x)$	0.00	0.00	0.00	0.00	0.00	0.000

Step 5: Finally, the condition "if  $\max_{1 \leq k \leq s} \{\sigma_i^{k*}\}$ " is applied, then the objective  $i$  belongs to grey class  $k$ . For each monitoring point; the results are shown in the following table.

TABLE VI  
RESULTS OF EACH MONITORING POINT AND ITS DESCRIPTION

Poin ts	$\lambda_1$	$\lambda_2$	$\lambda_3$	$\lambda_4$	$\lambda_5$	Ma x- val ue	$\lambda$	Description
QPu sh1	0.1 9	0.0 5	0	0	0.7 6	0.7 6	$\lambda_5$	Highly contaminated
QPu sh2	0.2 3	0.0 1	0	0	0.7 6	0.7 6	$\lambda_5$	Highly contaminated
LPe sc3	0.3 1	0.6 7	0.0 2	0	0	0.6 7	$\lambda_2$	Acceptable
LPe sc2	0.2 6	0.1 5	0.2 1	0.3 8	0	0.3 8	$\lambda_4$	Contaminated
LPe sc1	0.2 6	0.3	0.4	0.0 4	0	0.4	$\lambda_3$	Slightly contaminated

## V. RESULTS AND DISCUSSION

The discussion of the water quality evaluation, according to the specific objectives set for this study, is as follows:

Firstly, from Table VI we can conclude that 20% of the monitoring points have an "Acceptable" quality; 20% of the monitoring points have a "Slightly Contaminated" quality; 20%

of the monitoring points have a “Contaminated” quality; and 40% of the monitoring points have a “Highly Contaminated” quality, according to the Prati scale. The monitoring points can be ordered in the following increasing order of contamination (by considering the higher value  $\sigma_i^k$ ):

$$LPesc3 < LPesc1 < LPesc2 < QPush1 = QPush2$$

LPesc3 presents the lowest degree of contamination, being classified in the  $\lambda_2$  “Acceptable” category. In contrast, points QPush1 and QPush2 are the most contaminated and have the same affinity with category  $\lambda_5$  “Highly contaminated”.

Secondly, the heterogeneity in the results may be due to the limitation of the water to reach all the monitoring points at the same time and in the same quantity. In addition, diffusion factors that limit the permanence of certain pollutants in certain areas of the affected hydrographic system should not be discarded.

Thirdly, more evaluations are required for a correct design of remediation methods. The present study can only confirm or discard the degree of affection that water quality has had in a specific monitoring point.

Finally, the results are compatible with the ANA report [2], which indicates environmental damage to the water quality of the study area. It was observed that for the points Qpush1 and Qpush2 (which are the closest to the tailings spill), metallic contents respect to iron and manganese are the most critical and exceed the permissible limit according to Prati scale [5].

## VI. CONCLUSIONS

The surface waters of the Pelagatos ravine, which meets the Santa River, has a low quality level of water. Likewise, it is important to note that the area affected by the former mining company has nearby communities (Pampas’s community) that use surface water for their activities. In this sense, Activos Mineros S.A.C., the company in charge of closing the mining liabilities, must execute the necessary and prompt measures to avoid negative effects on the health of the inhabitants, as well as another possible spill. In this sense, the results obtained in this study could help the organisms in charge of the supervision of surface waters and the local authorities to make the best decisions regarding the treatment and management to be applied to the waters that have suffered the impact of the tailings spill.

On the other hand, regarding the Grey Clustering method, it has been proven that it evaluates and classifies the monitoring points according to the water quality parameters reported by the ANA in an optimal manner. In addition to consider the difference in the influence of the water quality indicators established by the ANA, it also assigns the weights to each parameter depending on the degree of contamination of the different variables applied, and according to legislation or chosen scale.

In future studies, the Grey Clustering method could be used to assess to do a comparison of the impact before and after having carried out remediation treatments to improve the quality of water in the study area.

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