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How to determinate water quality using an artificial intelligent model based on grey clustering?

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ABSTRACT

Water quality is an important topic for countries like Peru, where the mining sector is one of the main economic activities, so the study of its impact on water quality is also necessary to have a regular control of benefits and dangers. In this way, to achieve this objective, the chosen methodology was grey clustering, which is based on artificial intelligent theory. Specifically, the central point triangular whitening weight function better known as CTWF, which is an approach from grey clustering, was used. The case study was focused on the Mashcon and Chonta rivers, located in the province of Cajamarca, Peru, these rivers are directly affected by an open pit mine. The study was carried out taking into account thirteen monitoring points taken by National Water Authority (ANA). The results showed that all the points considered were classified as not contaminated, A1 category, this using the parameters of the Peruvian government. With these results, the mining company was able to demonstrate that they are taking the water quality into account and that they are making an effort to keep these rivers as healthy as possible.

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1. INTRODUCTION

The gold mining company in the north of Peru is considered to be the largest group of epithermal high sulphidation deposits in the world [1], its operations began in 1993. However, in recent years mining in this region it has been the cause of social conflicts between the mining company and the surrounding communities [2], due to an issue of water quality and quantity that have put on the agenda the question of whether or not to continue mining, mainly in the headwaters of the basin. Therefore, it is considered appropriate to study the impact of the mining activity on the bodies of water that is directly related to the company and thus determine if they comply with Peruvian regulations and standards.

For the development of the research, the grey clustering method, which is based on artificial intelligent theory, was used. Exactly, the central point triangular whitening functions (CTWF), which is an approach from grey clustering. The grey clustering method was initially developed by Deng that focuses on the study of problems with small samples of information limited with the use of artificial intelligence [3], it also allows the quantification of qualitative information and the classification of the observed objects into definable classes, in the same way it allows to verify whether the observed objects belong or not to predetermined classes called grey classes [4]. Therefore, it is widely applied as for example in evaluation of security management [5], evaluation of air quality [6], problems of decision on investment risk [7], and for socio-environmental problems [8].

The case study is located in the department of Cajamarca in Northern Peru. Where the mining company whose operations are located in the upper part is located, and therefore, they have a direct relationship with two rivers that are: Mashcon and Chonta whose waters are used for different activities such as: agriculture, cattle raising and human consumption [9]. The analysis will be done with 13 monitoring points taken by the National Water Authority (ANA) in 2019. Therefore, our specific objective with this research is to determine the water quality, using an artificial intelligent model based on grey clustering, of the 13 monitoring points based on 5 inorganic parameters and thus to know if mining has an impact on the water quality of the two rivers mentioned and based on from the results to know if the water can be used for the production of drinking water according to the Peruvian water quality standards (ECA) established in decretory supreme (DS) N °004-2017-M-Environment Ministry [10].

In the present investigation, a new case study is developed applying the grey clustering methodology used by [11], [12]. Where the water quality was analyzed for category 3 (water intended for irrigation of vegetables and for animal consumption) according to with the Peruvian standard of environmental quality, on the other hand [13] used the grey clustering methodology to determine air quality and [14] used it with physicochemical parameters. The contribution of our research is the identification of the monitoring points that present high concentrations of heavy metals product of the mining activity, and thus be able to classify them according to category 1, subcategory A (water intended for the production of drinking water) based on the Peruvian standard. This study provided useful information to the company and the population, to improve knowledge about the scope of the water quality problem that exists in the study area and thus take actions to prevent and solve it. The structure of this work is organized as follows: in section 1 we have the introduction, in section 2 the explanation of the CTWF methodology is made, in section 3 the case study is presented, the results and the discussion of the research are presented in section 4, and finally in section 5 the conclusions are presented.

2. METHOD

In this section explain the steps we follow to applied the CTWF method, including the math operations. Then, the steps of the grey clustering methodology are presented in Figure 1. This method is one of the most used in subjects such as water quality. There are some considerations that we need to follow [15]:

- First, define a set of "m" groups that will be represented as O_i, where i=1,2,3...m.
- Then set a quantity of criteria "n" which will be coded as C_J, where j=1,2, 3...n.
- And an specific number of classes "s" called λ_k, where k=1,2,3...s.
- Standard values coded as λ_j^k , for the j^{th} value categorizes as λ_k, for this research, the standards of "Decretory supreme N° 004-2017" of the Ministry of the Environment (MINAM acronym in Spanish) are used [10]. For the value of the samples xij (i=1, 2..., m; j=, 2..., n) known as xij referred to the value j^{th} and the parameter j^{th}.

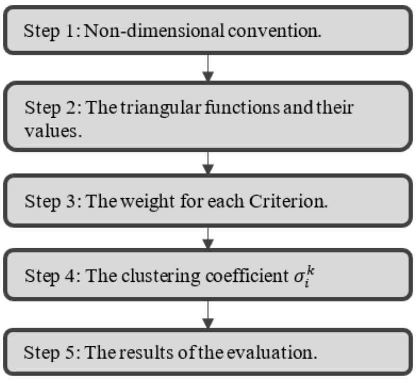

Figure 1. Scheme of the methodology

2.1. Step 1: non-dimensional convention

The grey clustering method is applied with non-dimensional values to create the grey classes. So, a conversion of the values is necessary using (1). Where λ_i^k represent the values for each parameter *i* and grey class k.

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

2.2. Step 2: calculation of the triangular functions and their values

It is necessary to obtain the values of CTWF by calculus for each class obtain. The (2)-(4) show how to obtain them [16], [17].

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

$$f_j^k(x_{ij}) = \begin{cases} \frac{x - \lambda_j^{k-1}}{\lambda_j^k - \lambda_j^{k-1}}, x \in [\lambda_j^{k-1}, \lambda_j^k] \\ \frac{\lambda_j^{k+1} - x}{\lambda_j^{k+1} - \lambda_j^k}, x \in (\lambda_j^k, \lambda_j^{k+1}) \\ 0, x \in \left[0, \lambda_j^{k-1}\right] \cup \left[\lambda_j^{k+1}, \infty\right) \ k \neq \{1, s\} \end{cases} \tag{3}$$

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

Then number of functions is defined by number of levels for our research we have three levels, Figure 2 shows the graph of the triangular functions.

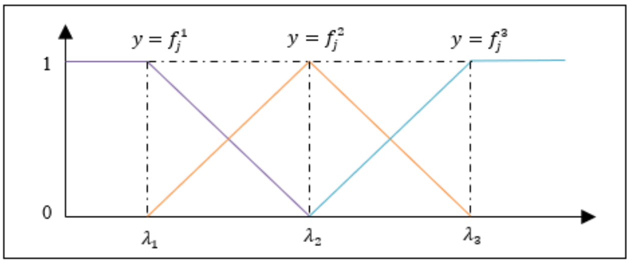

Figure 2. CTWF representation

Where:
f_j^1 = A1: water that can be purified with disinfection.
f_j^2 = A2: water that can be purified with conventional treatment.
f_j^3 = A3: water that can be purified with advanced treatment.

2.3. Step 3: calculation of the weight for each criterion

In this step, to give objective weight to each criterion, the Shannon entropy or the harmonic mean can be used, the following research used the harmonic mean expressed in (5).

$$n_j^k = \frac{\frac{1}{\lambda_j^k}}{\sum_{j=1}^{n} \frac{1}{\lambda_j^k}} \tag{5}$$

Where: n_j^k is the value of clustering weight of j^{th}parameter of each grey class λ_k, this weight is calculated with the standard values non-dimensional?

2.4. Step 4: Calculation of the clustering coefficient σ_i^k

The clustering coefficient for each monitoring point i, $i = 1,2,3 \ldots m$ with its respective class grey k, $k = 1,2,3 \ldots s$. Represents the value of the sum of each evaluated function multiplied with the weight obtained in the fourth step, is calculated with (6).

$$\sigma_i^k = \sum_j^n f_j^k(x_{ij}) * \eta_j \qquad (6)$$

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

2.5. Step 5: The results of the evaluation

Finally, between the grouping coefficients, the maximum is chosen following (7). These values will determine the class of the sample. In this way you can define and choose the maximum value.

$$\forall \sigma_i^k : \sigma_i^{k*} = \max_{1 \le k \le s}\{\sigma_i^k\} \rightarrow objet\ i\ belongs\ to\ \lambda_k \qquad (7)$$

2.6. Case study

2.6.1. Context description

This water quality research was developed between the rivers Mashcon and Chonta, located in Cajamarca, Peru at 3400 (MASL). These rivers are around the mine [18], there direct districts which are affected by this mine are La Encañada, Baños del Inca, Cajamarca and Tumbaden. Some years ago there was an incident with this mine and a project they were developing the main problem was with surround community people who lives near to the mine, the main problem was about the water and related to it [2]. Figure 3 shows the Cajamarca region, where the mining company is located.

Figure 3. Cajamarca-Perú

2.6.2. Definition of study objects

The information of the 13 monitoring points was published by Peru's the National Water Authority (ANA) through technical report N° 024 -2019-ANA [9]. The Table 1 shows the points (P1-P13) that are considered for the present study and are quite relevant to the case. The Figure 4 shows the location of the mining company and the monitoring points.

Table 1. Codification and location of the study points

River	N°	Code	Coordinates (WGS84)	
			North	East
Mashcon	P1	RQUILL 1	9 220 901	766 920
	P2	RQUILL 2	9 216 458	767 783
	P3	RPORC 1	9 214 183	771112
	P4	RMASH 1	9 212 710	773 157
	P5	RGRANG 3	9 215 817	773 823
	P6	RGRANG 2	9 221 923	771854
Chonta	P7	Q CALL 1	9 223 042	771286
	P8	Q ENCA 1	9 223 551	772 066
	P9	Q ARNA 1	9 227007	780 689
	P10	Q OCUN 1	9 227 057	779 437
	P11	Q CHAQ 1	9 224 459	780 760
	P12	MVENT 1	9 222 367	787 251
	P13	R CHON 1	9 216 458	787130

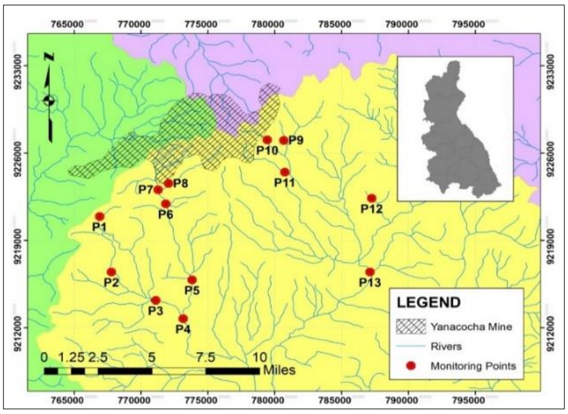

Figure 4. Map with study points

2.6.3. Definition of assement creteria or parameters

This research will evaluate 5 inorganic water quality parameters and were taken from DS-N °004-2017-MINAM [9]. Table 2 details the quality ranges of the water intended for the production of drinking water, indicating the limits of the 5 metals used in the study, some parameters were modified to be able to apply the methodology. For example, in the case of aluminum, the norm for category 1 subcategory A2 tells us that the limit is 5 mg/L [9]. For the research 3 mg / L was used, being even more strict.

2.6.4. Definition of the grey classes

The grey classes are chosen based on DS- 004-2017 of the Ministry of the Environment of Peru [10]. For category 1, subcategory A, waters intended for the production of drinking water Table 2. Where *A1* indicates treatment with disinfection, *A2* with conventional treatment and *A3* with advanced treatment.

Table 2. Parameters and grey classes

Parameter	Code	Levels			Average
		A1	A2	A3	$\bar{x}$
Aluminum (mg/L)	C1	0.9	3	5	2.95
Arsenic (mg/L	C2	0	0.1	0.2	0.08
Barium (mg/L)	C3	0.7	1	1.3	1
Iron (mg/L)	C4	0.3	1	5	2.1
Manganese (mg/L)	C5	0.4	0.45	0.5	0.45

2.6.5. Calculations using the CTWF method

Step 1: First, Table 2 shows the values of the dimensioned standards, for any environmental quality modeling system the first thing is to convert the data to non-dimensioned. Table 3 shows the non-dimensioned values for the present research. That is why A1, A2 and A3 change to λ_1, λ_2 y λ_3.

Table 3. Non-dimensioned standard values for each parameter

Parameter	Code	λ_1	λ_2	λ_3
Aluminum	C1	0.305	1	1.695
Arsenic	C2	0.125	1	1.875
Barium	C3	0.7	1	1.3
Iron	C4	0.143	0.476	2.381
Manganese	C5	0.889	1	1.111

Then, using the average obtained in Table 2, the non-dimensioned values for the monitoring points are calculated, which is the result of dividing the original value by the average ($\bar{x}$), for the present research the results are shown in Table 4.

Table 4. Non-dimension data for the monitoring points

Point N°	Parameters				
	C1	C2	C3	C4	C5
P1	0.0451	0.0004	0.0153	0.1016	0.0434
P2	0.6763	0.0129	0.0414	0.9267	0.6412
P3	1.4037	0.0166	0.0674	1.6090	0.6558
P4	0.5753	0.0119	0.0560	0.6157	0.3431
P5	0.1678	0.0100	0.0438	0.2046	0.1694
P6	0.8576	0.0399	0.0274	0.1514	0.1283
P7	1.4708	0.0638	0.0243	0.1408	0.0542
P8	0.2620	0.0226	0.0286	0.0696	0.1483
P9	0.3742	0.0955	0.0317	0.8686	0.0220
P10	0.2824	0.0474	0.0119	0.0599	0.0409
P11	0.2200	0.0715	0.0362	0.1488	0.0804
P12	0.0007	0.0004	0.0254	0.0002	0.0001
P13	0.2108	0.0203	0.0485	0.2899	0.1306

Step 2: The values obtained ($\lambda_1, \lambda_2\ y\ \lambda_3$) in Table 3 of each parameter (aluminum, arsenic, barium, iron and manganese) are replaced in (2)-(4), obtaining the triangular whitening functions (CTWF), as an example in (4)-(6) show the results for arsenic and Figure 5 shows its graph.

$$f_j^1(x_{ij}) = \begin{cases} 1, x \in [0, 0.125] \\ \frac{1-x}{1-0.125}, x \in (0.125,1) \\ 0, x \in [1, \infty] \end{cases} \quad (4)$$

$$f_j^2(x_{ij}) = \begin{cases} \frac{x-0.125}{1-0.125}, x \in [0.125,1] \\ \frac{1.875-x}{1.875-1}, x \in (1,1.875) \\ 0, x \in [0,0.125] \cup [1.875, \infty) \end{cases} \quad (5)$$

$$f_j^3(x_{ij}) = \begin{cases} \frac{x-1}{1.875-1}, x \in [1,1.875) \\ 1, x \in [1.875, \infty) \\ 0, x \in [0,1] \end{cases} \quad (6)$$

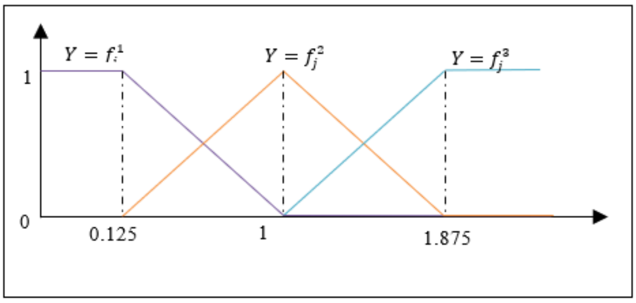

Figure 5. CTWF for arsenic

Then, the values of Table 4 are evaluated in the triangular whitening functions of the three classes of grey, this is done for the 5 parameters (aluminum, arsenic, barium, iron and manganese). Table 5 shows as an example the results obtained for 5 monitoring points.

Table 5. CTWF values of five sudy points

Code	Criteria	Al	As	Ba	Fe	Mn
	$f_1^1(x)$	1.0000	1.0000	1.0000	1.0000	1.0000
P1	$f_1^2(x)$	0.0000	0.0000	0.0000	0.0000	0.0000
	$f_1^3(x)$	0.0000	0.0000	0.0000	0.0000	0.0000
	$f_1^1(x)$	0.4659	1.0000	1.0000	0.0000	1.0000
P2	$f_1^2(x)$	0.5341	0.0000	0.0000	0.7635	0.0000
	$f_1^3(x)$	0.0000	0.0000	0.0000	0.2365	0.0000
	$f_1^1(x)$	0.0000	1.0000	1.0000	0.0000	1.0000
P3	$f_1^2(x)$	0.4190	0.0000	0.0000	0.4053	0.0000
	$f_1^3(x)$	0.5810	0.0000	0.0000	0.5948	0.0000
	$f_1^1(x)$	0.6112	1.0000	1.0000	0.0000	1.0000
P4	$f_1^2(x)$	0.3888	0.0000	0.0000	0.9268	0.0000
	$f_1^3(x)$	0.0000	0.0000	0.0000	0.0733	0.0000
	$f_1^1(x)$	1.0000	1.0000	1.0000	0.8147	1.0000
P5	$f_1^2(x)$	0.0000	0.0000	0.0000	0.1853	0.0000
	$f_1^3(x)$	0.0000	0.0000	0.0000	0.0000	0.0000

Step 3: The grey grouping weight for each parameter is calculated by replacing the values ($\lambda_1, \lambda_2\ y\ \lambda_3$) from Table 3 in (5). For the present research the results are shown in Table 6.

Table 6. Clustering weight for the parameters

Code	Parameters	Subcategory A		
		A1	*A2*	*A3*
C1	Aluminum	0.1573	0.1639	0.1837
C2	Arsenic	0.3840	0.1639	0.1660
C3	Barium	0.0686	0.1639	0.2394
C4	Iron	0.3360	0.3443	0.1307
C5	Manganese	0.0540	0.1639	0.2802

Step 4 and 5: To calculate the clustering coefficient σ_i^k, in (5) is used, the results for the 13 monitoring points in this study are shown in Table 7. The highest coefficients are chosen from the values obtained, in the Table 7. The numbers highlighted in grey color are the highest coefficients.

Table 7. Clustering coefficient values for each monitoring point

N°	Code	λ_1	λ_2	λ_3
P1	RQUILL1	1	0	0
P2	RQUILL2	0.5799	0.3504	0.0309
P3	RPORC1	0.5066	0.2082	0.1845
P4	RMASH1	0.6028	0.3828	0.0096
P5	RGRAN 3	0.9377	0.0638	0
P6	RGRAN2	0.8663	0.1392	0
P7	QCALL1	0.8427	0.0529	0.1244
P8	QENCA1	1	0	0
P9	RARNA1	0.6483	0.2897	0.0269
P10	QOCUN1	1	0	0
P11	QCHAQ1	0.9940	0.0061	0
P12	MVENT1	1	0	0
P13	RCHON1	0.8518	0.1518	0

3. RESULTS AND DISCUSSION

3.1. About case study

After performing the calculations using the grey clustering methodology, the results are shown in Table 8 and will be analyzed and supported in the following paragraphs. From the results shown in Table 8, both the water bodies that belong to the Mashcon River and the Chonta River are within level A1, this indicates that only water disinfection is necessary for human consumption, coinciding with the report of the ANA corresponding to the eighth participatory carried out and published in May 2019 and with the ninth participatory monitoring carried out and published in February 2020, the two reports show that the points chosen for our study do not present contamination by heavy metals, only that unlike from monitoring point 3 (P3), it presents a small amount of excess manganese [8], but it is not due to mining activity but to the geological constitution of the area as it is a mineralized zone and the removal of land by the extraction of haulage material in the riverbed [17].

Table 8. Water quality results

Rivers	N°	Maximum coefficient	Level
Mashcon	P1	1	λ1
	P2	0.579920968	λ1
	P3	0.506619678	λ1
	P4	0.602794041	λ1
	P5	0.93773807	λ1
	P6	0.866296079	λ1
	P7	0.842651681	λ1
	P8	1	λ1
Chonta	P9	0.64830992	λ1
	P10	1	λ1
	P11	0.993999429	λ1
	P12	1	λ1
	P13	0.851809887	λ1

The good quality of the water may be due to the good environmental management of the mining company, the company carries out its operations in 4 basins, within which is the Chonta river basin and the Mashcon river basin [9], and as the operations are in the upper part, it has even more reason to take care of the water that follows its course through of streams and rivers to the communities, that is why the company has good environmental management complying with national and international standards (the latter case, those of the world bank), taking into account both the dry times where it is recirculated and reused water within the operation such as wet times where excess water requires adequate treatments for discharge to streams, adequate treatment and discharge of good quality water, in compliance with current regulations, treatment is carried out through three major programs:

- Permanent monitoring of water quality (internal and participatory).
- Water treatment (excess water, acidic water, vehicle washing).
- Erosion and sediment control program.

The gold mining company has conventional and reverse osmosis water treatment plants to treat excess water, it also has treatment plants for acidic waters, and sewage treatment plants and vehicle washes, in 2018, it is highlighted the construction and commissioning of the Quinua treatment plant, applying reverse osmosis technology whose design capacity is 250 m^3/h, in 2019 this treatment plant increased its treatment capacity to 500 m^3/h [19], demonstrating the company commitment and responsibility and efficient water management, that is why the water in the monitored points does not present contamination by heavy metals according to Peruvian regulations.

3.2. About the method

The grey clustering method, which is based on artificial intelligent theory [20], is a very useful mathematical model to determine the quality of surface water [17]. In addition, to work with the CTWF method, some changes had to be made in the standards of Peruvian law, when we find some parameters that are not very well defined, we choose to do some operations or we complete it with values from other legislations, unlike other methodologies such as: Delphi [21] or AHP hierarchical analytical process [22] the grey clustering method has advantages such as: its low cost due to the little information needed to do it [3], on the other hand, the grey clustering method allows the use of different standards and includes uncertainty within its analysis [23]. Therefore, the CTWF method turns out to be an excellent methodology to determine the quality of the water [24]-[26], that and due to the aforementioned advantages can allow the company to demonstrate its efficient environmental management, reducing costs versus other methodologies.

4. CONCLUSION

The water quality of the rivers Chonta and Mashcon were evaluated using the grey clustering method with this it was possible to classify the thirteen points of those rivers. Taking into account the Peruvian legislation (DS 040-2014-EM) these ones were classified as A1 so these rivers have the enough concentration of the metals that were studied, to be considered as suitable for human consumption also this can be used for other activities related with the water. About the methodology, the grey clustering method was used in this study to help to have a better understanding of the information given about the metal concentration of the rivers. With this it was possible to give a correct classification to them. In order to do that this method used equations and calculations for each point studied. Finally, this paper could be the basis for a major study of the water quality in Cajamarca, which takes into account other rivers from the region. It would be useful to the Peruvian state to make decisions about the water quality and the environmental impact. Also, the results shown by the grey clustering method could be compared to another method and having a comparison between them can help to improve the accuracy of them.

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