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Applying grey systems to analyze water quality on the river Chira watershed

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ABSTRACT

Due to people's opposition to any mining company exploiting some ore deposit close to their community, these projects, in some cases, are never carried out properly, resulting in informal miners illegally exploiting these areas and polluting important river watersheds. Hence, a water quality assessment is necessary. In this work, to assess the water quality of the Chira river watershed was used the Grey Clustering method, which is based on grey systems, in which informal miners affected the activity in the Tambogrande area in Piura, Peru. In this case study, 17 monitoring points were determined (1-17), all of them were analyzed using 6 criteria of evaluation (C1-C6). The results of this study showed that there was some level of pollution due to the activity of informal miners, but this does not involve a great negative impact. These results could help to demonstrate that the expulsion of formal mining companies from ore deposits can cause pollution to a higher level than expected. Some monitoring points on the Ecuador – Peru boarder showed high pollution, which could mean illegal mining activity in that area and would be subject for future study.

Key words: Grey Clustering; Informal miners; Water quality assessment.

1. INTRODUCTION

It was in 1999 when Canadian company Manhattan Minerals Corp. received the concessions to drill and develop mines in the Tambogrande area, the result of which led them to develop plans to establish a gold and copper open pit mine [1]. This discovery and the consequent mine proposed by the company implied the relocation of over half the 16,000 residents in the town [2]. The mining company promised to give the inhabitants of the town better life conditions [2] as it's common in this kind of projects. However, people refused this proposal from the very beginning since it would pollute their water sources and, thus, their limes and mangoes crops would be also affected [2]. This fervent opposition came about through an elaborate strategy, which was joined by local authorities, a sector of the Catholic Church, social organizations, agricultural producers, national and international NGOs and the media [3]. In 2001, these protests were led and organized by the former mayor of the district and then president of the organization that represents local farmers called "Frente de Defensa deTambogrande y el Valle de San Lorenzo" Francisco Ojeda Riofrío. [4] In the same year, Villagers managed to convoke a referendum [2] and it resulted in 96% rejection by the local population. Later in 2003 [2], because of the national and international pressure, the Peruvian Government revoked the operating license of Manhattan Minerals Corp. in Tambogrande [1]. Definitely, this revocation generated great losses for the company and, in minor scale, the Peruvian State since if the project had been approved, the Peruvian state would have had the 25% of participation in benefits [3]. However, despite the belief that agriculture had triumphed in the town of Tambogrande. The exit of the Manhattan Minerals Corp. gave free passage for informal miners to exploit the deposits that were in the valley of San Lorenzo, which by using mercury to amalgamate gold polluted the waters of the Quiroz River, affecting the crops of mango and lemon in the area, and affecting the health of the people of Tambogrande. As a result, in 2015, the mayor of Tambogrande Gabriel Madrid Oré called attention to these informal miners to stop polluting the river with mercury because it is the main source of drinking water for the district [4].

To make this article, several methods were considered, which would be explained below. The first method to consider was the Delphi method, which the RAND Corporation in 1950. The method took into consideration surveying a selected group of people, all of whom must be experts in the related topic. In order to reduce the influenced that other people may cause on the experts, the survey must be anonymous. Then, a feedback will be sent and after a second round of surveying. Finally, the final analysis will be carried out [5]. The second method considered was Shannon's entropy. This is a method developed by Claude Shannon, which measures uncertainty or the degree of average disorder calculated from a probabilistic theory. Shannon uses an event of high uncertainty with two possible results, which occurs or does not occur, each with a probability of 50%, which is known as a bit and is handled using the logarithm in base 2 [6]. For the entropy calculation, Shannon defined an entropy equation which becomes maximum when the probability is 50% and becomes minimum (0), when the probability is 0 or 100%, since it is definitely known that the event will not occur or if it will occur [7]. And finally, it is considered to use the grey clustering method, which is a method developed by Deng that we use to study elements that are uncertain or incomplete, which are called Grey Systems [8]. The method tries to deal with the little-known information, generating and deepening in the little useful information that can be found in order to monitor and describe these systems correctly [9]. Likewise, the method based on fuzzy logic; therefore, it considers that the parameters that govern these systems are relative, evaluating the proximity of these parameters to certain borders and drawing a conclusion from this evaluation. Analyzing our options, the Delphi method is a valid option for topics, which are highly uncertain such as technology, elections or the realization of a project. Nevertheless, in the case of the study of a river, a more mathematical method, which can work with real and proved data, is required. Similar happens with Shannon Entropy, is not recommended to apply it to the study since it measures the uncertainty of an event, which only has two possible results and in the case of an analysis of water quality, there is no such randomness because it works with exact values. In addition to this method serves more to make a prediction and not a classification as required in this case. The method that better fits our available data and purposes is the Grey Clustering Method. Since This method, as its definition says, allows evaluating the proximity of the parameters of the grey systems to certain borders, which is just the procedure to examine the quality of water. To analyze its proximity with the values within the Peruvian legislation in order to classify the water of the monitoring points according to the degree of contamination of this one.

The confluence point of Macara and Catamayo rivers, which belong to Ecuadorian territory, marks the birth of Chira River. This river has a length of 170 km[10]. In its initial section it delimits the border between Peru and Ecuador, then, when entering the Peruvian territory, it passes through the province of Sullana, later by Paita and finally flows into the Pacific Ocean between Bayovar and Colan[11]. The activities carried out in this watershed are mainly agricultural, since it keeps productive soils under irrigation where rice, cotton and fruits such as bananas and coconut are grown, and mining. As it was mentioned, informal miners have taken advantage that Manhattan Minerals Corp. have left the ore deposit of Tambogrande. Because of this, Chira river watershed has been affected by them [11].

In this paper, the Gray Clustering Method evaluated the degree of contamination in Chira River. To determine the water classification (A1, A2, A3) of our object of study, the National Environmental Quality Standards (ECA) for Water described in Ministerial Resolution N°072-2017-MINAM will be used [12].

In this study, section 2 will present in detail the Grey Clustering Method, followed by section 3, which will describe the case study, and then section 4 will present the results and the discussion on these. Finally, section 5 will present the conclusions of the study

2. METHODOLOGY

Grey clustering method is part of the new mathematical approach known as grey systems theory, which includes several new analyses methods for evaluation, modeling, decision-making, prediction, control, and optimization techniques. The grey clustering method consisted on fuzzy mathematics, which were stablished in 1960. However, grey system analysis started to appear once Julon Deng developed the grey system theories in the 1980s. [9].

The comparison between the classical and these new mathematic is that the first approach consists of obtaining yes/no answers that lead to an absolute conclusion. With these grey systems are possible to achieve a result that implies a percentage of both answers (yes/no).

This method takes into consideration different steps to achieve a conclusion. The requirements needed are points or groups of study, which are classified as evaluation objects, then the criteria include chemic and physic parameters that characterize the study object; lastly, grey classes are taken out from the country legislation depending on the topic that has been chosen. For this research work the standard data was taken from the National Water Authority known as ANA for its acronym in Spanish, it has to be mentioned that to develop this method the CTWF (center-point triangular whitenization weight functions) technique is required [13].

After identifying the requirements, the next step was to realize a set of calculus that are listed as follow.

As stated before, the CTWF take into account 4 different elements: a group of “m” objects, “n” criterions, a set of “s” grey classes (and their values (λ) for each criterion), and a group of field values “Xij” (i=1, 2 ,…, m; j=1, 2, …, n).

1. Starting with changing the data from legislation (λ), which are the values from the different grey classes, and the field (x_ij) to non-dimensional values. This is a common stage during the process because it is probably that the collected data and the reference parameters, provided by the regulator institution, do not possess equivalent units (if the units are equal this step can be omitted).

2. Then, building triangular functions, which will depend on the number of grey classes (s) and their values (λ). Each gray class will have a different function according to the standard values assigned by the National Water Authority.

   In the case of any object and any criteria which grey class k = 1 the first function acquires the following structure.

$$f_j^1 = \begin{cases} 1 & , x \in [\lambda_0 : \lambda_1] \\ \dfrac{(\lambda_2 - x)}{(\lambda_2 - \lambda_1)} & , x \in]\lambda_1 : \lambda_2[\\ 0 & , x \in [\lambda_2 : +\infty[\end{cases} \quad (1)$$

   In the case of any object and any criteria which grey classes k ∈ [2, 3, 4, 5… s-1] the function acquires the following structure.

$$f_j^k = \begin{cases} \dfrac{(x-\lambda_{k-1})}{(\lambda_k-\lambda_{k-1})} & ,x \in [\lambda_{k-1}:\lambda_k] \\ \dfrac{(\lambda_{k+1}-x)}{(\lambda_{k+1}-\lambda_k)} & ,x \in]\lambda_k:\lambda_{k+1}] \\ 0 & ,x \not\ni [\lambda_{k-1}:\lambda_{k+1}] \end{cases} \quad (2)$$

In the case of any object and any criteria which final grey class k = s the last function acquires the following structure.

$$f_j^s = \begin{cases} 1 & ,x \in [\lambda_s:+\infty[\\ \dfrac{(x-\lambda_{s-1})}{(\lambda_s-\lambda_{s-1})} & ,x \in]\lambda_{s-1}:\lambda_s[\\ 0 & ,x \in [0:\lambda_{s-1}] \end{cases} \quad (3)$$

These functions would allow every non-dimensional value, taken from the collected data (x_ij), to match a value in each function f_j^k (x_ij); since only one criterion is being used for the example the same analysis applies for the rest of it [14].

3. The following step is to weight each criteria through an objective way in which it is applied the harmonic mean to the legislation data. The number of weights depends on the number of grey classes(s) and the number of criteria (n).

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

4. Every criteria has to be weighted taking into account the standard values obtained from the regulator institution that correspond to each grey class. The grey clustering coefficient will be obtained for every object of study "i"and grey class "s".

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}) * \eta_j^k \quad (5)$$

5. Finally, with this result, every study object ranked from the maximum value to the minimum.

3. CASE STUDY

The presented case involves a series of points from Chira River that were tested in 2016; the criteria chosen in this analysis are: pH, 〖DBO〗_5, DQO, coliforms, Cadmium and Iron. The Chira river watershed is located in the department of Piura on the north of Peru, as shown in Figure 1.

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Figure 1: Chira's river watershed location

Figure 2 shows the 17 monitoring points studied, which are detailed in Table I.

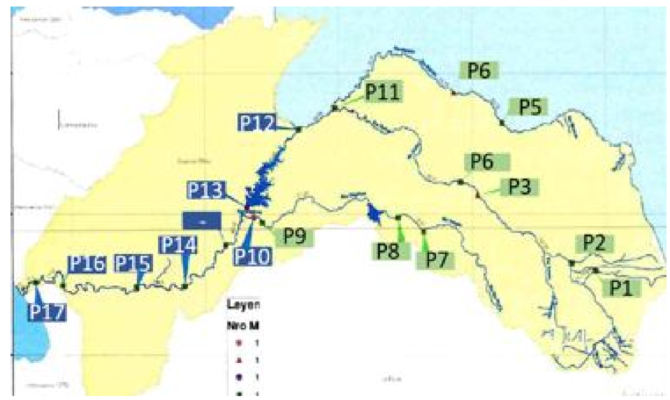

Figure 2: Monitoring points's location in the watershed

Table 1: Payroll Control and Monitoring System Specifications

Point	Name	Point	Name
1	138Palo1	9	138RChip2
2	138Sant1	10	138RChip3
3	138RQuir3	11	138RQuir2
4	138RQuir1	12	138RChir2
5	138RMaca1	13	138RChir3
6	138RMaca4	14	138RChir5
7	138QTimb1	15	138RChir6
8	138RChip1	16	138RChir7
		17	138RChir8

Phase 1: Non-dimensional data

The standard values obtained from the Supreme Decree N°004-2017-MINAM were transformed into non-dimensional values and are presented in Table 2.

Table 2: Non-dimensional Values taken from the legislation

Parameter	Code	Sub Category A		
		A1	A2	A3
pH	C1	1.034	1.000	0.966
Coliforms	C2	0.003	0.272	2.725
DBO_5	C3	0.500	0.833	1.667
DQO	C4	0.500	1.000	1.500
Cadmium	C5	0.500	0.833	1.667
Iron	C6	0.143	0.476	2.381

At the same time, the data obtained from the monitoring was transformed into non-dimensional values taking into account the standard values from the National Authority of Water (ANA) [15]; the data was presented in TABLE3.

Table 3: Non-dimensional Values taken from the field

Point	Name	C1	C2	C3	C4	C5	C6
1	138Palo1	7.9860	110	4	20	0.00006	0.3575
2	138Sant1	9.0290	230	4	16	0.00006	0.509
3	138RQuir3	9.1740	230	3	12	0.00006	0.254
4	138RQuir1	9.8900	1700	1	8	0.00006	0.834
5	138RMaca1	9.2900	4900	1	8	0.00006	1.183
6	138RMaca4	10.7910	17000	3	12	0.00045	2.409
7	138QTimb1	11.2820	13000	3	16	0.00006	3.982
8	138RChip1	11.5380	49000	1	8	0.00006	9.572
9	138RChip2	12.0290	23	1	8	0.00006	0.034
10	138RChip3	11.2610	790	4	2	0.00006	0.48
11	138RQuir2	8.7000	49000	1	18	0.00006	20.84
12	138RChir2	8.5000	79000	1	16	0.00006	13.64
13	138RChir3	7.8600	230	1	28.1	0.00006	0.368
14	138RChir5	7.9000	49000	7.1	15	0.00006	0.279
15	138RChir6	7.8500	2300	6	14	0.00006	0.15
16	138RChir7	7.9500	790	5	12	0.00006	0.837
17	138RChir8	7.6800	490	6	14	0.00006	0.453

Phase 2: CTWF functions and results

In this step, the values in the CTWF were replaced in order to obtain the values in table IV. As an example, the functions for the second criterion (Total Coliforms) and the graph of these are shown below.

$$f_1^2 = \begin{cases} 1 & ,x \in [0.000, 0.003[\\ \dfrac{0.272 - x}{0.269} & ,x \in]0.003, 0.272[\\ 0 & ,x \in [0.272, +\infty\ [\end{cases} \quad (6)$$

$$f_2^2 = \begin{cases} \dfrac{x - 0.003}{0.269} & ,x \in]0.003, 0.272] \\ \dfrac{2.725 - x}{2.453} & ,x \in]0.272, 2.725[\\ 0 & ,x \in [0, 0.003] \cup [2.725, +\infty[\end{cases} \quad (7)$$

$$f_3^2 = \begin{cases} \dfrac{x - 0.272}{2.453} & ,x \in]0.272, 2.725[\\ 1 & ,x \in [2.725, +\infty[\\ 0 & ,x \in [0.000, 0.272] \end{cases} \quad (8)$$

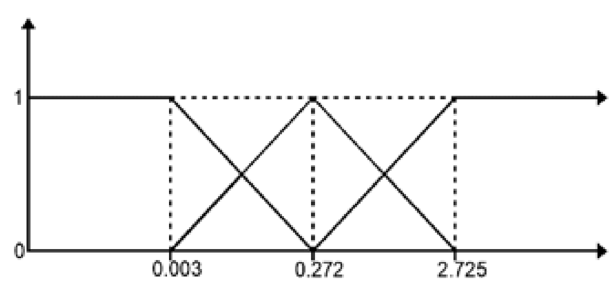

Figure 3: Graphics of the CTWF for criterion 2

Using the equations 6, 7, and 8, the CTWF values were calculated and shown in Table 4.

Table 4: Payroll Control and Monitoring System Specifications

P1	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.9545	0.5000	0.0000	1.0000	0.8926
f2j(x)	0.0000	0.0455	0.5000	1.0000	0.0000	0.1071
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P2	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.8939	0.5000	0.4000	1.0000	0.7014
f2j(x)	0.0000	0.1061	0.5000	0.6000	0.0000	0.2986
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P3	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.8939	1.0000	0.8000	1.0000	1.0000
f2j(x)	0.0000	0.1061	0.0000	0.2000	0.0000	0.0000
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P4	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.1515	1.0000	1.0000	1.0000	0.2371
f2j(x)	0.0000	0.8485	0.0000	0.0000	0.0000	0.7629
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P5	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	1.0000	1.0000	1.0000	0.0000
f2j(x)	0.0000	0.8389	0.0000	0.0000	0.0000	0.6478
f2j(x)	0.0000	0.1611	0.0000	0.0000	0.0000	0.3523
P6	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	1.0000	0.8000	1.0000	0.0000
f2j(x)	0.0000	0.1667	0.0000	0.2000	0.0000	0.9543
f2j(x)	0.0000	0.8333	0.0000	0.0000	0.0000	0.0458
P7	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	1.000	0.4000	1.0000	0.0000
f2j(x)	0.0000	0.3889	0.0000	0.6000	0.0000	0.2545
f2j(x)	0.0000	0.6111	0.0000	0.0000	0.0000	0.7455
P8	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	1.0000	1.0000	1.0000	0.0000
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
f2j(x)	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
P9	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	1.0000	0.9985	1.0000	1.0000	0.0000
f2j(x)	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table 5: Payroll Control and Monitoring System Specifications

P10	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.6111	0.5000	1.0000	1.0000	0.7429
f2j(x)	0.0000	0.3889	0.5000	0.0000	0.0000	0.2571
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P11	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	1.0000	0.2000	1.000	0.000
f2j(x)	0.0000	0.0000	0.0000	0.8000	0.000	0.000
f2j(x)	0.0000	1.0000	0.0000	0.0000	0.000	1.000
P12	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	1.0000	0.4000	1.0000	0.0000
f2j(x)	0.0000	0.0000	0.0000	0.6000	0.0000	0.0000
f2j(x)	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
P13	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.8939	1.0000	0.0000	1.0000	0.9029
f2j(x)	0.0000	0.1061	0.0000	0.1900	0.0000	0.0971
f2j(x)	0.0000	0.0000	0.0000	0.8100	0.0000	0.0000
P14	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	0.0000	0.6000	1.0000	1.0000
f2j(x)	0.0000	0.0000	0.8000	0.4000	0.0000	0.0000
f2j(x)	0.0000	1.0000	0.2000	0.0000	0.0000	0.0000
P15	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.0000	0.0000	0.6000	1.0000	1.0000
f2j(x)	0.0000	0.9833	0.8000	0.4000	0.000	0.000
f2j(x)	0.0000	0.0167	0.2000	0.0000	0.000	0.000
P16	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.6111	0.0000	0.8000	1.0000	0.2329
f2j(x)	0.0000	0.3889	1.0000	0.2000	0.0000	0.7671
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P17	C1	C2	C3	C4	C5	C6
f1j(x)	1.0000	0.7626	0.0000	0.8000	1.0000	0.2329
f2j(x)	0.0000	0.2374	1.0000	0.2000	0.0000	0.7671
f2j(x)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Phase 3: Criteria weight

Using the non-dimensional values from Table II the clustering weights (ηj) were calculated and presented in Table 6.

Table 6: Clustering weigthts

	Code	**A1**	**A2**	**A3**
η1	C1	0.003	0.098	0.281
η2	C2	0.963	0.361	0.099
η3	C3	0.005	0.118	0.163
η4	C4	0.005	0.098	0.181
η5	C5	0.005	0.118	0.163
η6	C6	0.018	0.206	0.114

Phase 4: Clustering coefficients

The final step was to calculate the clustering coefficients (σ_j^k) using equation (5). Table 7 showed the results.

Phase 5: Results summary

Then, we applied the rule that $\max_{1\le k\le s}\{\sigma_i^k\}=\sigma_i^{k^*}$, which symbolizes that the monitoring point "i" belongs to the grey class "k", and so on for each monitoring point. The following table shows a statistic of the results of this classification.

Table 7: Clustering weights

Point	A1	A2	A3
1	0.946	0.196	0.000
2	0.887	0.218	0.000
3	0.897	0.058	0.000
4	0.169	0.464	0.000
5	0.018	0.500	0.021
6	0.017	0.214	0.123
7	0.015	0.252	0.146
8	0.018	0.000	0.213
9	0.999	0.001	0.000
10	0.618	0.252	0.000
11	0.014	0.079	0.213
12	0.015	0.059	0.213
13	0.891	0.077	0.146
14	0.029	0.0118	0.168
15	0.029	0.489	0.034
16	0.605	0.436	0.000
17	0.760	0.265	0.033

Table 8: Number of max σ for each sub category

Sub Category	Number of max σ	Percentage
A1	7	41.18%
A2	6	35.29%
A3	4	23.53%
TOTAL	17	100.00%

4. RESULTS AND DISCUSSION

4.1 Case of study results

In this study, through the grey clustering method, it was possible to rate the study objects. In Peru Legislation, there are three categories to classify the water quality: A1, A2, and A3.

In Table 8, it is specified the numbers of points that belongs to each category. Therefore, 41.18% of monitored points had good quality water (A1), which means that the water only needs disinfection; 35.29% had moderate-quality water (A2) which involves a conventional treatment; and 23.53% has low-quality water (A3) which needs a special treatment[16].

In addition, from Table 7, the points most affected by the contamination were 8, 11, 12 and 14. When the points were located on the map, number 8 was near the influence area (Las Lomas). However, the other ones where located near the border Ecuador – Peru.

From these results, it was easy to found a similar case that is the Santa River. As follows, we would present a chart with it results.

Table 9: Number of max σ for each sub category for the study of the Santa River

Sub cartegory A	Number of max	Percentage
A1	10	47.6%
A2	7	33.3%
A3	4	19.1%
TOAL	21	100%

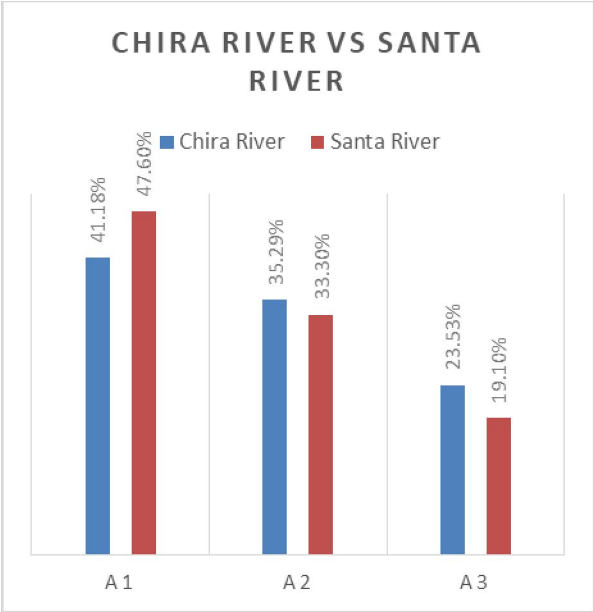

Figure 3: Comparison between Chira and Santa River

Figure 3 shows the similarities between the Chira River and the Santa River, both were affect by the mining industry so it was easy to say that this behavior was often see on Peruvian watershed.

4.2 Method results

The grey clustering method considered the uncertainty in this project by classifying each of the monitored points. If we had used another method such as Delphi or Analytic hierarchy process (AHP) the uncertainty in this study would not be examine.

The advantages that this method presented were that it cooperate to classify the study objects, so it helped to focus on the points more affected. In addition, the mathematic behind the results is simple and easy to understand[17].
The disadvantages were that the mathematic process would be very slow if a computer were not use. Furthermore, the results could not be specific because it depended on the country legislation, which may be or not be well define.

5. CONCLUSION

The objective behind this study was to show how illegal mining have influenced negatively on areas where there was not acceptance from the communities on legal mining. The results proved the water contamination, mainly by the point number 8, which was on the sphere of influence of the Manhattan Project. Furthermore, the contamination on other points, that are far from the area, probably indicate that the careless methods that illegal mining used caused the spare of the contaminants.

Regarding this method used for the elaboration of this paper, the grey clustering method is the most effective option to classify the water monitoring points based on the information of the legislation and the data collected from the water monitoring. Since it is capable of processing data from little information such as that available for this study. However, it is not efficient to use the Excel software to perform the calculations required by this method, so it would be advisable to design a software that allows applying this methodology more quickly and efficiently.

There are several points corresponding to monitoring zones along the Ecuador- Peru border that show signs of severe contamination; A2 and A3 ratings from environmental quality standards were obtained; this is an indicator of possible illegal mining groups in that area. It would be feasible to analyze this region more rigorously in the future to determine exactly which sources contaminated these zones.

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