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Applying grey systems to assess social impact on the extraction phase of the Palma mining project in Peru

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ABSTRACT

Nowadays, social impact assessment (SIA) is a very important factor in determining the viability and integration of a mining project. In this study, we analyzed the social conflict that the Palma project would have on the extraction phase using the grey clustering method, based on the grey systems theory. The case study was conducted in the town of Antioquia and its surroundings, where the mining project is located. Two stakeholder groups (rural and urban population) and six evaluation criteria (regarding the perception of social impact of the mining project) were identified. The results showed that in the future the project would have, for the rural group of study, a normal social impact, in the same way it would have a neutral impact over the urban stakeholder group. By applying the percentage system certain criteria it has been proved to be more negative or positive than others within each stakeholder group through a numerical quantifiable evaluation provided by such system. These results could help to the company in charge of the Palma project and local authorities to make the best decision about future conflicts in the extraction phase.

Key words : Grey Systems, Grey clustering, Mining project, Social impact assessment

1. INTRODUCTION

Due to the overexploitation of natural resources, social conflicts in the world have increased and Peru, as a mining country, is being seriously affected by this [1]. Therefore, social impact assessment (SIA) appears as an important tool, focused on social and cultural issues, which provides a series of data to be analyzed in order to determine the consequences of conflict on the development of the human environment [2]. However, strong stakeholder interests, time and type of circumstances can lead to the persistence of conflict [3].

For the social impact assessment (SIA), methods such as grey clustering [4], Shannon entropy [5], Delphi [6], AHP and FAHP can be used [7], among others has been used. However, in this study, we apply they grey clustering method to SIA, which is based on grey systems theory. Specifically, we use the center-point triangular whitenization weight functions (CTWF) method, since it allows us to classify defined objects into groups, called grey classes. Besides, the respondents have the facility of classifying their answers around the center point of the class interval as they tend to be more certain compared with other points of the grey class [8].It should be noted that SIA is an analysis with a high level of uncertainty [9], which is why grey clustering method is considered as a perfect fit for this type of problem as it is a tool with the advantage of considering the lack of certainty in its procedure. In the same way, it is applicable for environmental conflicts [9], [10], water quality assessment [11], lighting and noise concerns [12], etc.

On the other hand, stakeholder groups participation is important to improve the management of natural resources and the integrated evaluation of projects and programs. However, within the study area, social conflicts were created between stakeholder groups [13], [14]. Then, to avoid possible crisis, a SIA should be carried out for each group and a result from a general SIA will be presented at the end of the analysis[15]. Likewise, to perform the CTWF method, we conducted a SIA in a mining project of massive sulphide deposits (VMS) on the surroundings of Antioquia, Lima. Currently, the project is in an exploration phase to determine the total resources of the mineral deposit with the help of geochemical analyzes [16].

The aim of the current article is to apply the CTWF method on the SIA to evaluate the future extraction phase of the Palma mining project in Antioquia, Lima, Perú.

In this work, Section 2 will verify the application of the CTWF method to SIA. In Section 3, the case study will be described, followed by the results and discussions in Section 4. In Section 5, the conclusions are displayed.

2. METHODOLOGY

In this section we proceed to describe the steps to apply the grey clustering method and the SIA analysis to the social impact study.

2.1 Grey Clustering Method

First of all, we defined the requirements needed to start the application of the CTWF method: a set of o groups of study, a set of c criteria to assess the opinion of the groups, a set of g grey classes to qualify the populations´ overall response to the consequences of the future development of the Palma project and monitoring values $x_{ij}(i = 1,2,\dots,o;\ j = 1,2,\dots,c)$ to establish which group and which criteria related to such group is considered in the respective analysis each time [8], [17], [18].

*Step 1:*Since there are no standard values established by the Peruvian state legislation over social topics or studies we considered our own standard range of values for each grey class qualifying the total c criterions and the center – points $\lambda_1, \lambda_2, \dots, \lambda_g$ of each range.Also, and considering the c criteria used are all non-dimensional, the standard center-point values considered already lacking dimensions. Analogously, the data obtained for each group of study (i) for every criteria (j) was also non-dimensional.

*Step 2:*Center- point values are plotted in a triangular function graph as observed in Figure 1. Additional grey classes 0 and $g + 1$ and their respective center point values $\lambda_0$and λ_{g+1}were considered. Then, for the k^{th} grey class in the evaluation of the j^{th} criteria and i^{th} group of interest the explicit whitenization weight function [8] as shown in (1) is as follows:

$$f_j^k(x_{ij}) = \begin{cases} 0 & ; x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \frac{x-\lambda_{k-1}}{\lambda_k - \lambda_{k-1}}; & x \in [\lambda_{k-1}, \lambda_k] \\ \frac{\lambda_{k+1}-x}{\lambda_{k+1} - \lambda_k}; & x \in [\lambda_k, \lambda_{k+1}] \end{cases} \quad (1)$$

The new distribution for the center point values is shown in Figure 1.

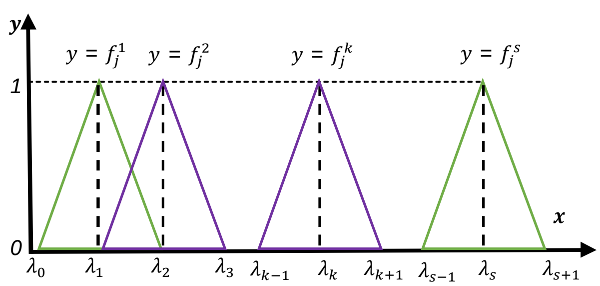

Figure 1: CTWF [8]

*Step 3:*After introducing field data (non-dimensional) in the shown functions for thei^{th} object of study and the j^{th} criteria for each grey class (up to g) for each case, the clusterization coefficient σ_i^k for the i object and k grey class can be expressed through (2):

$$\sigma_i^k = \sum_{j=1}^{c} f_j^k\left(x_{ij}\right) \bullet n_j^k \qquad (2)$$

Where n_j is the weight of criterion j.

Considering a social study includes a high level of uncertainty due to data being subjective and not supported by a quantitative or mathematical measurement or model an because it considers, in this case, field data based on future circumstances, the weight of any of the c criterions cannot be defined as more relevant then the weight of the other criterions considered. Thus, every weight is considered equal. For this study in specific then, the value of n_j^k can be calculated by (3)for every value given to k and j each time.

$$n_j^k = \frac{1}{c} \qquad (3)$$

*Step 4:*To locate an object of study in a specific grey class the maximum value of the clusterization coefficients calculated for each grey class within the i group of study must be considered.

Therefore, if the expression $\max_{1<k<g}\{\sigma_i^k\} = \sigma_i^p$, then the object i will belong to the grey class p [8]. Thus, if two or more objects belong to the same grey class, these will be ordered according to the needs of the study and to the values provides by the max function.

2.2 SIA analysis

SIA analysis comprehends the following steps [15]:

Step 1: Criteria and grey classes

A group of C_j $(j = 1,2,\dots,c)$ criteria is established as well as a set of $\lambda_k(k = 1,2\dots,g)$ grey classes to evaluate the SIA.

Step 2: CTFW and clusterization coefficient

By replacing the non-dimensional field data in (1), arranging the results and then utilizing the (2), the clusterization coefficient σ_i^k for the criteria j $(j = 1,2\dots,c)$ and object or stakeholder group j $(i = 1,2,\dots,o)$ regarding the grey class k $(k = 1,2,\dots,g)$ can be obtained.

Step 3: Percentage system

A percentage system is implemented and defined by the percentage factor $\alpha_k(k = 1,2,\dots,g)$ where k is the k^{th} grey class established. In this system α_g = 100, α_1= 100/g,α_2 = $\alpha_1 + \alpha_1$, $\alpha_3 = \alpha_1 + \alpha_2$,…, $\alpha_{g-1} = \alpha_1 + \alpha_{g-2}$. The results for each object are given by (4):

$$z_j^i = \sum_{k=1}^{g} f_j^k\left(x_{ij}\right) \bullet \alpha_k \qquad (4)$$

Where f_j^k is the whitenization value for the $j^{th}(j = 1,2,\dots,c)$ criteria of the $i^{th}(i = 1,2,\dots,o)$ object or stakeholder group.Meanwhile, the value z_j^i represents a result matrix established by (5):

$$z_j^i = \{z_j^i, i = 1,2,\dots,o;\ j = 1,2,\dots,c\} \qquad (5)$$

3. CASE STUDY

SIA was applied on a mining project located in the district of Antioquia, province of Huarochiri, department of Lima, Peru, located as shown in Figure 2. This project company, called Palma, proposes to conduct a mining process in 5 years, including 3 years of construction and 17 years of operation. It is predicted that the project operation will involve a massive use of water [1], energy, social licensing and qualified personnel. SIA was conducted in the surroundings of the project, which is composed of urban areas and rural areas [15]. According to various sources, the mining project has been active for more than 15 years in the exploration phase and many groups of people disagree with its presence and related activities.

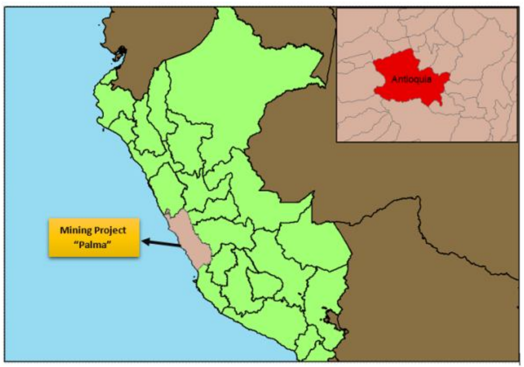

Figure 2: Mining project location

3.1 Stakeholder Groups

During the field phase, 2 stakeholder groups were identified. The composition of such groups was determined according to similarities found during the overall assessment of the exploration project [1]. The sample size in each group was determined by means of the principle of saturation of discourse, which establishes that information gathering should end when respondents do not produce new information relevant to object of study [1]. Table 1 will show the stakeholder groups:

Table 1: Stakeholder groups in the case study

Stakeholder group	Description
G1: Rural population	The rural population was composed by residents living around the project in rural areas. The group is collected by a total of twenty interviewees.
G2: Urban population	The urban population was composed by residents living in Antioquia. It is a small urban center near the project. The group was formed by a total of twenty interviewees.

3.2 Calculations using the SIA analysis

The study calculations that have been based on the 3-step based SIA analysis are as follow:

Step 1: Criteria and grey classes

The study criteria were based on factors that depend on the social and economic aspect of the rural and urban areas near the mining project in Lima, Peru. According to the characteristics of the area and the priorities of the residents, it was decided to consider 6 related criteria in economic activities that could affect them such as agriculture, employment, lack of water, education and health. These criteria will be shown in Table 2.

Table 2: Criteria in the case study

Criterion	Description
C1	Employment rate in rural and urban areas.
C2	Poverty rate in rural and urban areas.
C3	Health service in rural and urban areas.
C4	Development of agriculture and livestock in rural and urban areas.
C5	Access to drinking water in rural and urban areas.
C6	Education rate in rural and urban areas.

To know the evaluation of the social impact of the mining project, the following structured questionnaire was carried out: S1: Decrease noticeably, S2: Decrease, S3: No effect, S4: Increase, S5: Increase noticeably; in which S1= [0;2>, S2= [2;4>, S3= [4;6>, S4= [6;8>, and S5= [8;10]. Table 3 shows the questionnaire applied.

Table 3: Questions used in the case study

Questions		Grey Clases				
C1	How would you rate the impact in the future of the Palma mining project on job creation?	S1	S2	S3	S4	S5
C2	How would you rate the impact in the future of the Palma mining project on poverty reduction?	S1	S2	S3	S4	S5
C3	How would you rate the impact in the future of the Palma mining project on improving health service?	S1	S2	S3	S4	S5
C4	How would you rate the impact in the future of the Palma mining project on the development of agriculture and livestock?	S1	S2	S3	S4	S5
C5	How would you rate the impact in the future of the Palma mining project on the availability of drinking water?	S1	S2	S3	S4	S5
C6	How would you rate the impact in the future of the Palma mining project on improving education?	S1	S2	S3	S4	S5

With the information obtained in the field, the following results were calculated using an arithmetic formula. Table 4 shows each criterion and their respective results:

Table 4: Data collected from the stakeholder groups

Stakeholder	C1	C2	C3	C4	C5	C6
G1	5.29	5.48	5.29	3.57	3.76	4.81
G2	5.84	6.05	5.42	4.68	4.26	5.42
Total	5.57	5.77	5.36	4.13	4.01	5.12

Step 2: CTFW and clusterization coefficient

The data obtained from the groups of interest will be processed using CTWF. The grey classes were divided from extra negative to extra positive with additional center points λ0 and λ6. The sequence was defined as λ0, λ1, λ2, λ3, λ4, λ5 and λ6 as shown in Table 5 and Figure 3:

Table 5: Center-points of the extended grey classes

Criterion	Center-points of the extended grey classes						
	Extra negative impact (λ_0)	***Verynegativeimpact (λ_1)***	***Negative impact (λ_2)***	***Normal impact (λ_3)***	***Positive impact (λ_4)***	***Very positive impact (λ_5)***	***Extra positive impact (λ_6)***
C1	0	1	3	5	7	9	10
C2	0	1	3	5	7	9	10
C3	0	1	3	5	7	9	10
C4	0	1	3	5	7	9	10
C5	0	1	3	5	7	9	10
C6	0	1	3	5	7	9	10

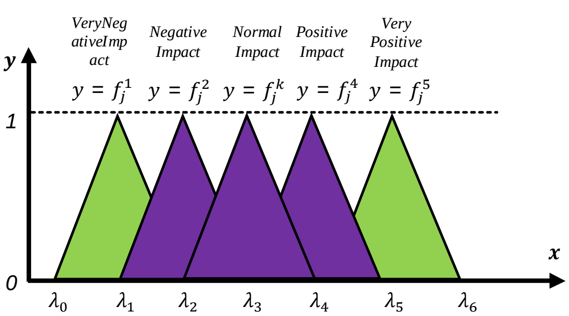

Figure 3: CTWF for the case study

The values indicated in Table 4 were replaced in the following (6) to (10) to obtain the CTWF of the five grey classes:

$$f_j^1(x) = \begin{cases} 0 & ; x \notin [0,3] \\ \frac{x-0}{1}; & x \in [0,1] \\ \frac{3-x}{2}; & x \in [1,3] \end{cases} \quad (6)$$

$$f_j^2(x) = \begin{cases} 0 & ; x \notin [1,5] \\ \frac{x-1}{2}; & x \in [1,3] \\ \frac{5-x}{2}; & x \in [3,5] \end{cases} \quad (7)$$

$$f_j^3(x) = \begin{cases} 0 & ; x \notin [3,7] \\ \frac{x-3}{2}; & x \in [3,5] \\ \frac{7-x}{2}; & x \in [5,7] \end{cases} \quad (8)$$

$$f_j^4(x) = \begin{cases} 0 & ; x \notin [5,9] \\ \frac{x-5}{2}; & x \in [5,7] \\ \frac{9-x}{2}; & x \in [7,9] \end{cases} \quad (9)$$

$$f_j^4(x) = \begin{cases} 0 & ; x \notin [7,10] \\ \frac{x-7}{2}; & x \in [7,9] \\ \frac{10-x}{2}; & x \in [9,10] \end{cases} \quad (10)$$

The values obtained in Table 4 were replaced into (6) to (10) to calculate the CTWF values of each criterion. Additionally, (2) was used to obtain the clusterization coefficient for each grey class within the rural and urban group. These are shown in Tables 6 and 7:

Table 6: Values of CTWF for each criterion of G1

G1	C1	C2	C3	C4	C5	C6	σ_i^k
f_j^1	0	0	0	0	0	0	0
f_j^2	0	0	0	0.715	0.620	0.095	0.238
f_j^3	0.855	0.760	0.855	0.285	0.380	0.905	0.673
f_j^4	0.145	0.240	0.145	0	0	0	0.088
f_j^5	0	0	0	0	0	0	0

Table 7: Values of CTWF for each criterion of G2

G2	C1	C2	C3	C4	C5	C6	σ_i^k
f_j^1	0	0	0	0	0	0	0
f_j^2	0	0	0	0.160	0.370	0	0.088
f_j^3	0.580	0.475	0.790	0.840	0.630	0.790	0.684
f_j^4	0.420	0.525	0.210	0	0	0.210	0.228
f_j^5	0	0	0	0	0	0	0

Step 3: Percentage system

In the final stage of SIA for the percentage system it was defined by the values α_1, α_2, α_3, α_4, and α_5; where α_5=100, α_1=100/5=20, $\alpha_2=\alpha_1+\alpha_1$=40, $\alpha_3=\alpha_1+\alpha_2$=60, and $\alpha_4=\alpha_1+\alpha_3$=80 according to five grey classes established, as shown in Table 8 [8]:

Table 8: Percentage system

Social ImpactClass	Interval	α_k
Verynegative	[20,30]	20
Negative	[30,50]	40
Normal	[50,70]	60
Positive	[70,90]	80
Very Positive	[90,100]	100

Then, (4) was used to calculate the SIA matrix. Tables 9 and 10 show the results obtained for G1 and G2 respectively.

Table 9: SIA results for group G1

Impact	α_k	C1	C2	C3	C4	C5	C6	Total
Verynegative	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Negative	40.00	0.00	0.00	0.00	28.60	24.80	3.80	9.53
Normal	60.00	51.30	45.60	51.30	17.10	22.80	54.30	40.40
Positive	80.00	11.60	19.20	11.60	0.00	0.00	0.00	7.07
Very positive	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SIA	62.90	64.80	62.90	45.70	47.60	58.10	57.00
		Normal	Normal	Normal	Negative	Negative	Normal	Normal

Table 10: SIA results for group G2

Impact	α_k	C1	C2	C3	C4	C5	C6	Total
Verynegative	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Negative	40	0.00	0.00	0.00	6.40	14.80	0.00	3.53
Normal	60	34.80	28.50	47.40	50.40	37.80	47.40	41.05
Positive	80	33.60	42.00	16.80	0.00	0.00	16.80	18.20
Very positive	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SIA	68.40	70.50	64.20	56.80	52.60	64.20	62.78
		Normal	Positive	Normal	Normal	Normal	Normal	Normal

Table 11 show the final results of the stakeholder groups according to (4).

Table 11: Results of SIA for groups G1 and G2

Group	C1	C2	C3	C4	C5	C6	Total	Impact
G1	62.90	64.80	62.90	45.70	47.60	58.10	57.00	Normal
G2	68.40	70.50	64.20	56.80	52.60	64.20	62.78	Normal

4. RESULTS AND DISCUSSION

The result and discussion are presented in 2 two parts:

4.1 Case Study

Total SIA has shown that the Palma mining project would have a normal social impact, meaning that the mining project would not generate nor negative nor positive social impact according to the opinion of the involved population. In addition, the result of the social impact for both stakeholder groups (urban and rural population) is normal; which indicates that the Palma mining project would not have positive or negative effect in the project influence zone.

Nevertheless, there has been a contrast of opinions, as the rural population (G1) believes that the Palma mining project would have a negative impact in the development of agriculture and livestock (C4) and access to drinking water (C5), due to consider the mining company activities responsible for producing environmental pollution on water and farmland, affecting the availability of both of these. Meanwhile, according to the urban population group (G2) criteria C4 and C5 would have a normal impact, as the mining company does not use its hydric resources. This last stakeholder group also considers a positive impact on the reduction of poverty (C2) given the economic growth that it could provide to the region.

4.2 CTWF method in SIA analysis

Social impact assessment (SIA) has a high uncertainty, which is why is important to choose a method that considers such uncertainty [9]. The best method that approaches this aspect is the CTWF method, given its uncertainty within its analysis. In addition, grey clustering is the best method to resolve a SIA, due to the facilities the method provides when collecting information from the affected population and the good level of objectivity and quantification given by the mathematical theory in which it is based [8]. Comparison with other methods shows that Delphi method has a clear disadvantage for SIA as a result of the use of descriptive statistics in the treatment of data entailing a decrease in the capacity of quantification as well as AHP method since its mathematical basis is relatively simple so that it requires complementation with other theories to achieve a more objective SIA [7].

In addition to the CTWF, a way to establish a ranked order for each stakeholder group in a social impact assessment can be achieved through a percentage system which provides numerical objectively comparable information that allows a

more accurate comparison between stakeholder groups [19]-[21]. This numerical system also allows ranking and comparison between criteria affecting each stakeholder group in a more precise manner.
In conclusion, the CTWF is a powerful mathematical method in order to produce an objective SIA compared to the others methods mentioned before, as CTWF considers the uncertainty in its analysis and the process to collect information is rather easy to accomplish.

5. CONCLUSIONS

After obtaining qualitative field information from the surveys carried out involving stakeholder groups, the CTWF method was used, allowing quantification of this data for its usage in SIA analysis. The results obtained could help the company in charge of the Palma mining project to avoid conflicts with local communities and make better decisions on its social responsibility.
Likewise, CTWF method has demonstrated to have an advantage over other methods (for example, statistical models) as it considers uncertainty in the analytical process; in addition, it does not need a large sample size which facilitates its application by its lower cost. Therefore, and according to the results, the Palma mining project would have a normal social impact as proven by the percentages system showing that both stakeholder groups, G1 and G2, predict the same degree of impact with little difference of opinion in very specific criteria.
Finally, the CTWF method applied in the SIA analysis has demonstrated to have a wide range of flexibility which is why it can be applied to assess the social impact of others types of programs or projects regarding environmental quality, hydrocarbons, civil infrastructure, etc.

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