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# Conceptual Model Applied to the Selection of Wastewater Treatment with Mercury in Gold Mining in Colombia

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**Abstract**

The Artisanal and Small-Scale Gold Mining (ASGM) developed in Colombia which represents between 50 and 60% of the gold mining in the country creates a serious hazard for human health and the ecosystem as well, this is mainly caused due to the impact on water resources by dumping toxic metals such as mercury (Hg). This project looked for the right choice of gold mining wastewater treatment, using a model selection of alternatives from the Analytic Hierarchy Process, applied in a study made in the municipality of Segovia in Antioquia. As a result, it was found that under the conditions of mining in this municipality and the selection criteria taken into account, the most appropriate tertiary treatment is the biosorption, with a 21% of favorability.

**Keywords:** Artisanal gold mining, hierarchical analysis, mercury treatment.

## INTRODUCTION

The gold exploitation performed in Colombia which presents a large percentage of illegal mining (87 %) (Guiza & Aristizabel, 2013) has a significant negative outside

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effects, on ecosystems with a deterioration of quality resources and impact on fauna and flora, and also on human populations who see mining waste in the waters of nearby rivers and they cannot use it safely for human consumption or even for agricultural activities due to problems associated with the toxicity of mercury and other pollutants such as cyanide and zinc (UNEP, 2013).

The term "artisanal and small-scale mining" refers to informal activities carried out in developing countries which utilize low-tech machinery practiced by individuals, groups or communities, (usually illegal) (Hentschel, et al., 2002). In this process the step of beneficiation and transformation gold, consist in the separation, grinding, crushing, mixing and homogenization as well as the washing and concentration which has to submit the mineral extracted for further processing and the use (MME-MMA, 2002). One of the most used alternatives to separate gold from extracted materials is called amalgamation, the process in which gold comes into contact with the mercury forms an amalgam; gold particles adhere to mercury to be later manually separated by distillation techniques (Guiza & Aristizabel, 2013).

Thus in the ASGM developed in Colombia, in which there are about 200,000 miners who officially produce 30 tons of Au/year and have between 50 and 60% of the national production (Cordy, et al., 2011), the use of mercury for the gold beneficiation process has extended, a situation attributed to the easy handling of these inputs which require no special technical knowledge, the most economical cost compared to other methods and the availability of these compounds even in remote regions and for its illegal mining (Guiza & Aristizabel, 2013). Therefore, regulations on the mercury use as No. 1658 of 2013 Law (República de Colombia, 2013), are not enforced in the country.

According to the "Sinopsis Nacional de la Minería Aurífera Artesanal y de Pequeña Escala - Colombia" (MADS, 2012), the improper mercury use in gold amalgamation in the ASGM has generated a download of this metal to the environment in the country, (wastewater and emissions) have become up to 298,2 tons/year. This 34.6% unloading exceeded the calculated data in the inventory of mercury released in 2009 (103 tons/year) (MAVDT – Universidad de Antioquia, 2010) and a 50% value reported in the study by Cordy et. al., in (2011) (150 tons/year).

Several technologies have been applied in industries to the treatment of liquid effluents containing mercury and other heavy metals which are commonly classified into physical-chemical (adsorption, ion exchange, reverse osmosis and chemical precipitation, etc.) and biological (phytoremediation, bioaccumulation, bio mineralization, biotransformation and bio sorption) (Oehmen, et al., 2014).

Regarding to the selection model alternatives applied in this case, the Analytic Hierarchy Process (AHP) first introduced by Saaty in (1988), useful for managing multiple objectives, criteria and alternatives in the process of the decision making. The AHP helps analysts to organize the critical aspects of a problem similar to a hierarchical family tree structure. The aim of using this method is to identify the preferred alternative and determine a ranking of alternatives when all decision criteria are considered simultaneously (Karimi, et al., 2011).

In this context, the objective of this paper is to show the results of the study conducted on the construction of a conceptual model using the method of the AHP applied to the selection of water treatment contaminated with mercury by ASGM in Colombia, considering technical, social, environmental and economic aspects. Applying and validating the model in the ASGM in the municipality Segovia department of Antioquia.

## STUDY AREA

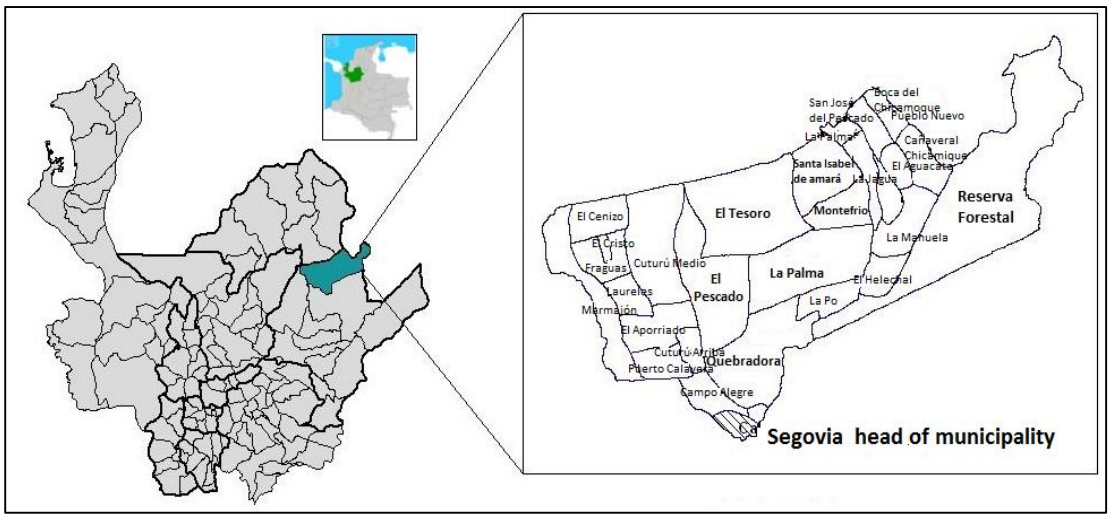


**Figure 1**: Location Segovia within Antioquia Department Source: (SANEAR, 2005).

The municipality of Segovia is located in northeastern of Antioquia department (Colombia - South America) (
***Figure* 1**). Its municipality Centre with 274 hectares is located 650 (m.a.s.n) at 7° 04' 28" latitude north of the equator and 74 ° 41' 56" longitude west of Greenwich Mean Time. The 1231 $Km^2$ of the municipal territory of Segovia is warm weather (SANEAR, 2005).

## METHODS

### Structuring the model

The proposed methodology for structuring and validation of the conceptual model is illustrated in ***Figure 2***.

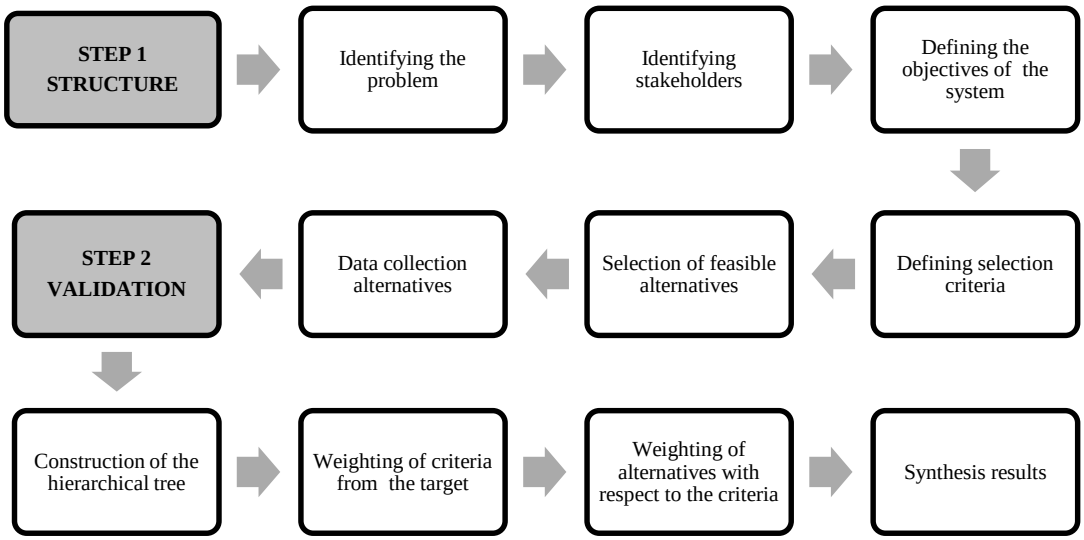


**Figure 2 :** Structuring and validation methodology model
*Source: self-elaboration*

## Implementation and validation of the model

### *Description of the gold beneficiation process in the study area*

The reconnaissance stage was conducted in "*entables"* or Processing Centers, in the municipality of Segovia (July 2014), in order to have primary information about the activity, identify procedures for the gold beneficiation process and evidence the handling of water resources. Secondary sources like government reports and academic papers, were also consulted.

### *Conceptual Model Validation*

The phases for the AHP validation model were as follows:

***a.*** *Hierarchy tree:*

A graphical representation of the problem in terms of the overall objective decision criteria and alternatives were made (Figure 3).

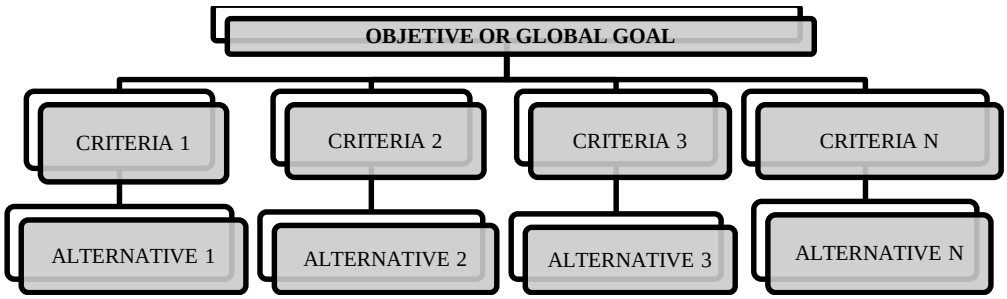


**Figure 3** : Hierarchy tree
*Source:* (Saaty, et al., 1988)

***b.*** *Weighting of criteria :*

For the criteria identification and classification, the perceptions of stakeholders in Segovia were taken into account. Surveys for 20 owners of the processing centers, representatives of the Mayor's Office of Segovia, Antioquia Government, and Corporación Autónoma Regional de Antioquia (CORANTIOQUIA), were prepared. In these surveys the level of importance assigned to each evaluation criteria based on the achievement of the objective, was scored. From this information the rate by the scale of paired comparisons (
***Table*** **1**) was made, obtaining the matched criteria matrix (***Table 2***).

**Table 1**: Scale for paired comparisons

| Intensity | Definition |
|---|---|
| **1** | Equally important |
| **3** | Moderate importance of one over another |
| **5** | Strong or essential importance |
| **7** | Very strong and demonstrable importance |
| **9** | Extremely important |
| **2,4,6,8** | Intermediate values or commitment |
| **Reciprocal or inverse** | Reverse comparison |

*Source: (Saaty, et al., 1988)*

**Table 2**: Paired comparison matrix of criteria

| | Criteria 1 | Criteria 2 | Criteria 3 |
|---|---|---|---|
| **Criteria 1** | **1** | | |
| **Criteria 2** | | **1** | |
| **Criteria 3** | | | **1** |

*Source: (Da Silva, 2014)*

Then, in order to compare the weights of the criteria evaluated, the matrix was normalized. This was to ensure that all data was in the same numerical order (Ibáñez, et al., 2014).

Finally, the eigenvector matrix of criteria which represents the relative importance of the criteria compared in each of the matrices was calculated. This step was performed by calculating the average of the elements of each row of criteria obtained in the normalized matrix.

***c.*** *Alternative weighting:*

At this stage, the matrices of alternatives comparison based on each criterion analyzed, were prepared (Table **3**)

**Table 3**: Matrix paired alternative for each criteria

| CRITERIA N | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|
| **Alternative 1** | **1** | | |
| **Alternative 2** | | **1** | |
| **Alternative 3** | | | **1** |

*Source: (Da Silva, 2014)*

This assessment was also performed by the pair wise comparison scale of preferences (**Table 1**). The rate was made based on scientific and technical information gathered in the literature review. Finally, the eigenvectors of each matrix was calculated with the same methodology used for the paired comparison matrix criteria.

***d.*** *Consistency ratio:*

In order to guarantee the consistency of the results in each matrix, a Consistency Proportion *(CP)* (which had to be less than 10%) was measured, using the Equation (1) (Karimi, et al., 2011)

$$CP = CI \div RI \quad (1)$$

Where: *CP* = Consistency Proportion; CI = Consistency Index and *RI* = Random Index.

The consistency index *(CI)* is equal to Equation (2):

$$CI = \frac{\lambda_{Max} - n}{n - 1} \quad (2)$$

Where: $\lambda_{Max}$ = Average values of each matrix eigenvector and *n* = Size of the matrix.

The random index *(RI)* is a consistency index of a random matrix; *RI* for different matrix size as shown in **Table 4**.

**Table 4** : Average random consistency index (RI) for various n

| **Matrix size (n)** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Random index (RI)** | 0 | 0.5 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 |

*Source: (Karimi, et al., 2011).*

***e.*** *Final result :*

An eigenvector of the criteria and an eigenvector for each alternative were obtained, wherewith a unified matrix from alternatives and criteria was formed. Finally both matrices were multiplied, giving the weight of alternatives according to all criteria and their importance. The final column vector indicated the weight of each alternative and as a result it allowed choosing the best.

## RESULT

### Structuring the hierarchical model of the AHP

In **Figure 4** summarizes the results of structuring the hierarchical model of the AHP:

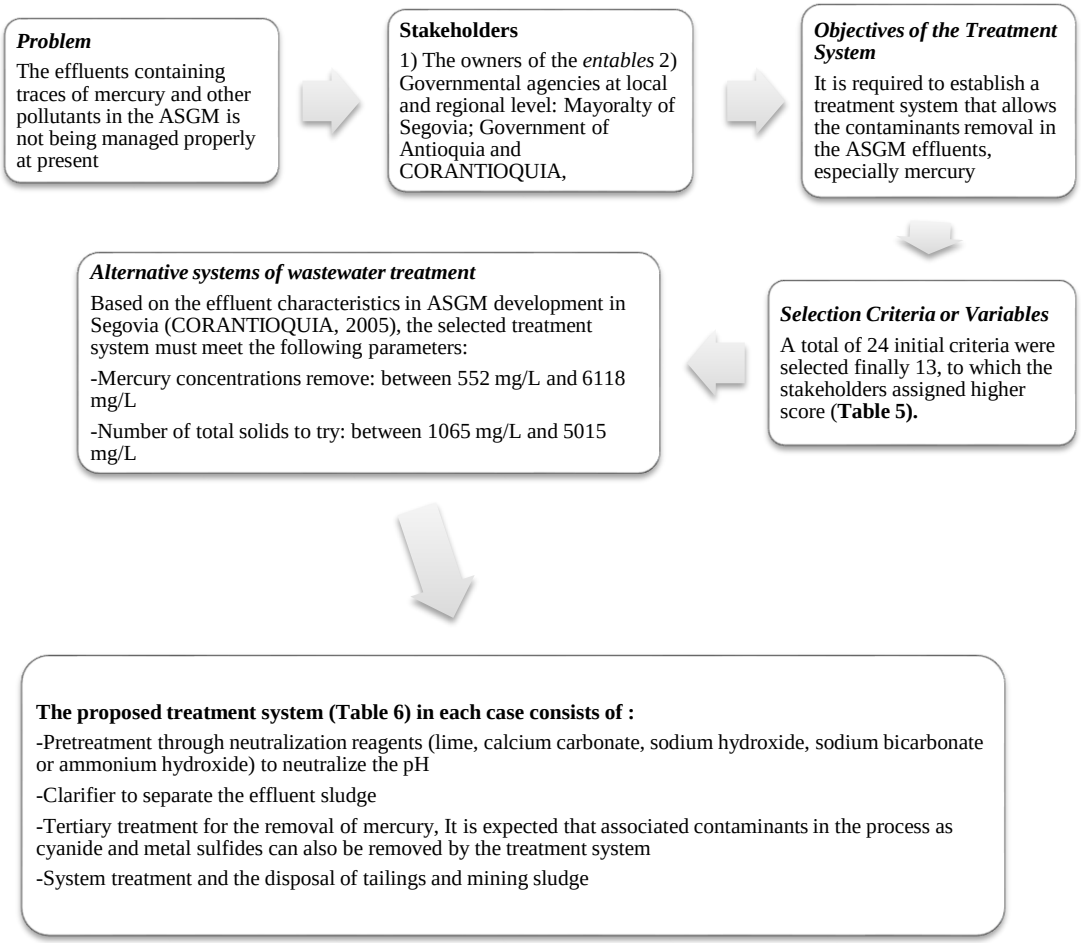


**Figure 4:** Structuring the hierarchical model of the AHP

The **Table 5** shows the criteria used in this study according to the literature review and the perception of stakeholders. The **Table 6** shows the proposed treatment system.

**Table 5** : Selection criteria used in the study

| Aspect | No | Criteria | Description |
|---|---|---|---|
| Tecnic | 1 | System Reliability | Possibility of achieving adequate performance over a specific period of time under specific conditions |
| | 2 | Technology easy to build and install | Compatibility with existing processes, level of automation and operational familiarity with the process |
| | 3 | Type of materials for operation | Complexity of the materials and equipment required for system construction |
| | 4 | Mercury removal efficiency | Determining the degree of removal of mercury present in the wastewater |
| | 5 | System replicability | The technical expert's participation should be required for the first implementations only. Since then, the technology must be easily replicated elsewhere without relying on specific expertise |
| Socioeconomic | 6 | Initial construction costs | Monetary expenditures for the system construction |
| | 7 | Annual cost for operation and maintenance | Costs related to the management of the treatment system |
| | 8 | Labor required | Required personnel and the ability of this for the operation and maintenance stage |
| | 9 | Social acceptability | The technology is accepted by the affected community |
| Environmental | 10 | Continuity ease of operation and maintenance | The system allows you to provide for continuity of the ease operation and maintenance over the lifetime of the same |
| | 11 | Possibility of water recirculation | The alternative should be able to reuse treated wastewater in the process of the ASGM |
| | 12 | Increased amount and/or toxicity of the sludge generated | The technology increases the quantity and / or toxicity of the sludge generated in the process |
| Regulator | 13 | Compliance with environmental regulations | Determine the value of mercury removal with respect to the permissible limit for mercury discharges, established by Decree 1594 of 1984 (Ministerio de Agricultura, 1984). Which is 0,02 mg/l. |

*Source: Adapted from Karimi, et al., (2011) and Meerholz & Brent,. (2013).*

**Table 6 :** Evaluated Treatment Systems

| No | Treatment system | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | Neutralization | Clarification | PREFILTRATION Ionic exchange | Treatment and disposal of mining sludge |
| 2 | | | Chemical precipitation – Flocculation | |
| 3 | | | Adsorption on activated carbon (variety of carbonaceous materials) | |
| 4 | | | PREFILTRATION. Reverse osmosis | |
| 5 | | | Biological process in bioreactor | |
| 6 | | | Biosorption with material from algae, bacteria, fungus or plant material | |
| 7 | | | Phytoremediation | |
| 8 | | | PREFILTRATION –Nanotechnology | |
| 9 | | | Electro coagulation | |

*Source: self-elaboration*

**Implementation and Validation**

***Description of the gold beneficiation process in "entables" of Segovia***

It was found that the gold beneficiation process begins by grinding the material by miners into small ball mills *or "Cocos Amalgamadores"* ***(Figure 5)***, in which a bucket of material is added with 3-4 ounces of mercury and water. After that, miners remove the amalgam formed by mercury and gold and carry it to the smelting process using the "*retorta"*, in which they recover some of the mercury.

Subsequently, the excess material in form of sludge passes through trenches to the sedimentation tanks in which large amounts of sludge is precipitated and put into the tanks where the cyanidation process is made, followed by the precipitation process in which Zinc and peroxide are added. Later on, the material is melted in the "*retorta"* (device used in burning gold amalgam) in order to recover gold. Finally, some "*entables"* add $H_2O_2$ or Ca ($ClO_2$), to recover part of the cyanide used in the process. This process is carried out by 102 "*entables*" (87 in the urban area).

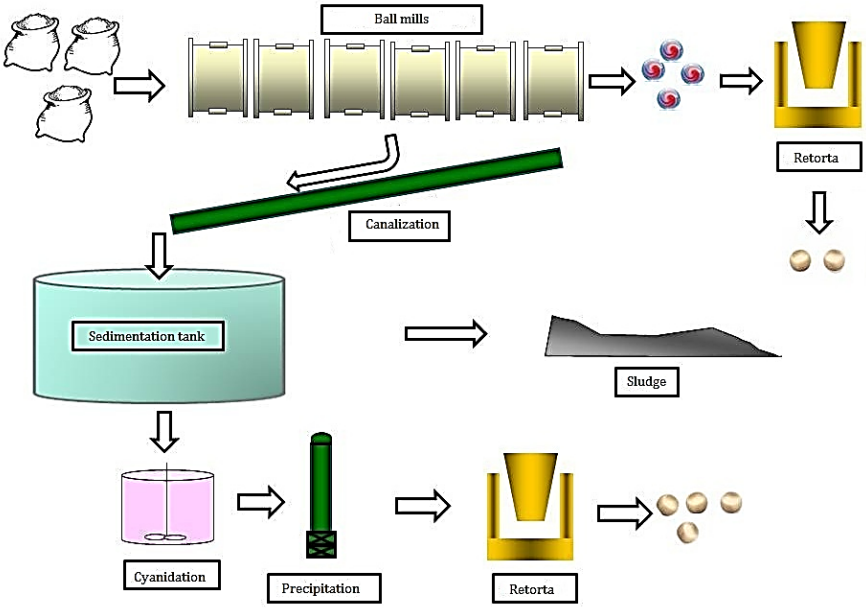


**Figure 5** : Flowchart of the gold beneficiation process in "entables" of Segovia
*Source: Adapted from Cordy, et al., (2011)*

***Hierarchy Tree***

The hierarchy tree obtained for this study is shown in ***Figure 6***.

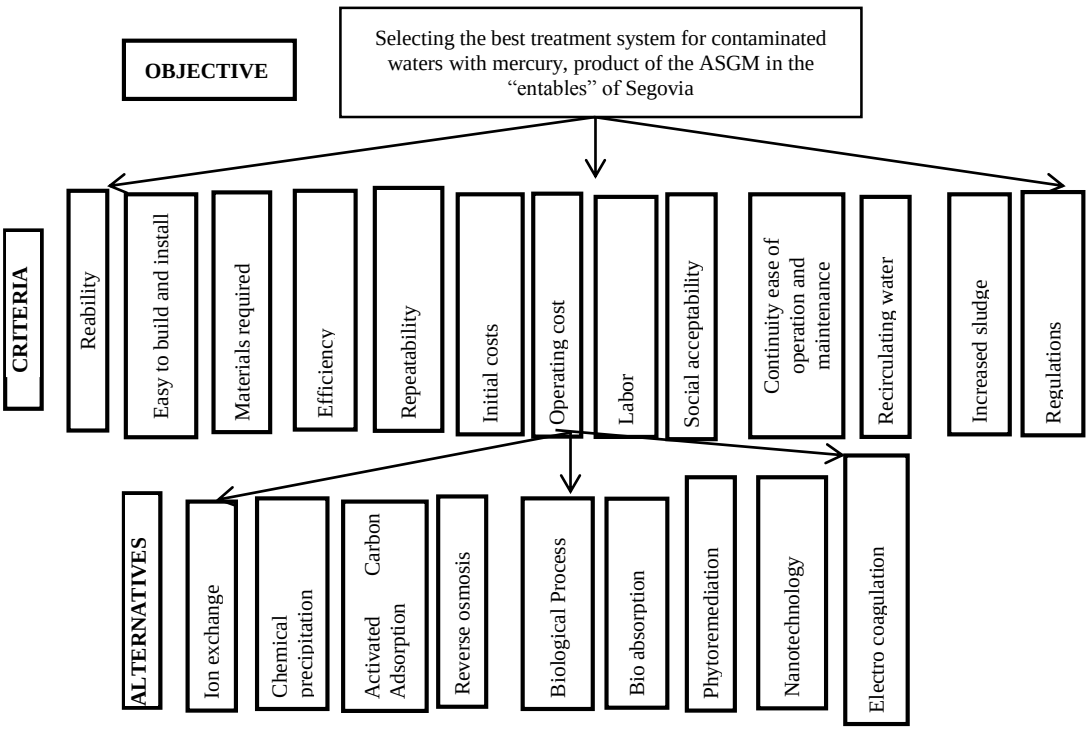


**Figure 6 :** Study hierarchy tree
*Source: self-elaboration*

***Weighting of criteria***

Once the weighting of each criterion in the matrix of paired comparisons, the eigenvectors of the matrix is obtained **(**see **Table 7**) which were plotted in Figure 6, where it is evident that the most relevant criteria are the initial costs built with 15%, followed by annual operating costs 12%, which reflects the perception of the owners of the *"entables"* in the town of Segovia. It is also important that the technology is easy to build and install (12 %) represented in the ease with which building materials can be searched and the compatibility with existing processes and the level of automation as well.

The remaining criteria obtained similar scores inwardly. It was possible to establish that contribute almost on equal terms to the fulfillment of the stated objective.

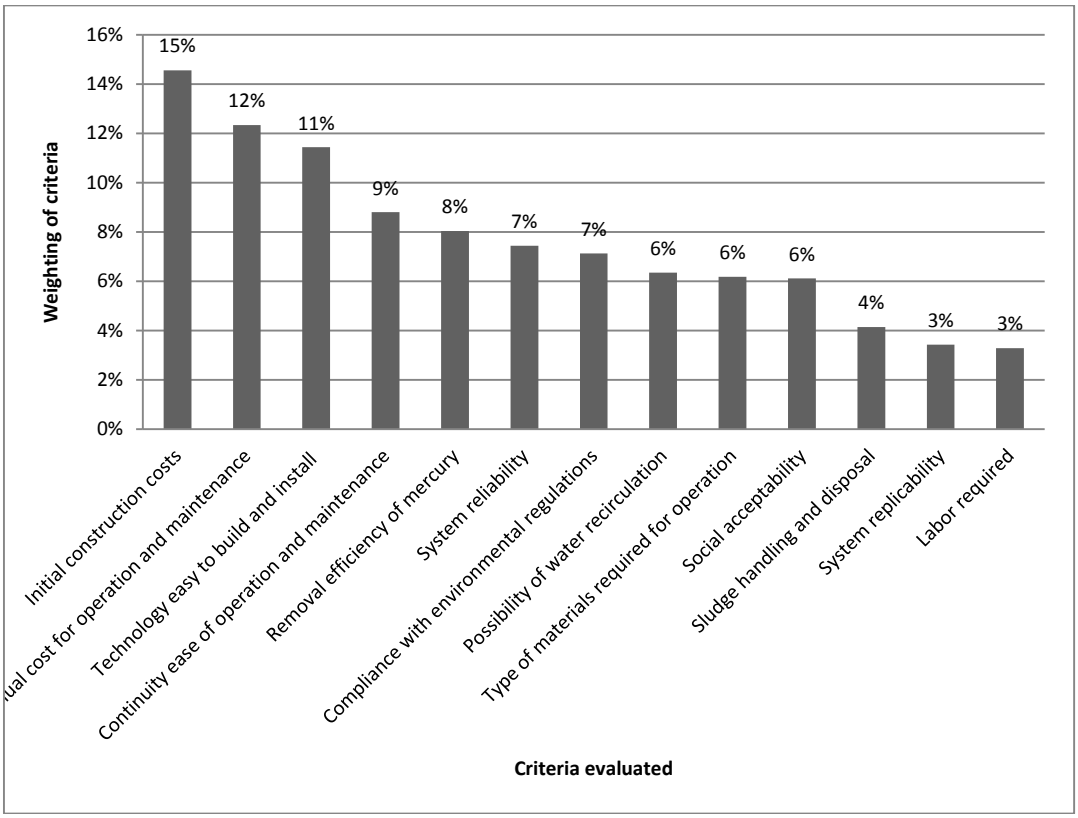


**Figure 7 :** Weighting of criteria
*Source: self-elaboration*

***Alternative weighting***

At this stage the weights of the alternatives or proposed treatments were performed with respect to the criteria, thereby obtaining 13 matrixes with their corresponding final vector (***Table 7***), which were used to obtain the final result in the next stage.

***Finale result***

Alternatives order was obtained from the final results matrix as evidenced by ***Figure* 8**, where the results were plotted, it was found based on the characteristics of the gold beneficiation process in the Segovia and the stakeholders preferences which was the best alternative was the biosorption (21%) followed by chemical precipitation (17,6%), phytoremediation (16,8%), adsorption on activated carbon (11%), biological process on bioreactors (7,9%), nanotechnology (7.3%), ion exchange (6.7%), electro coagulation (5.5%) and reverse osmosis (5.1%).

**Table 7:** Results matrix

| OWN VECTOR CRITERIA MATRIX | ALTERNATIVES | OWN VECTOR CRITERIA 1 MATRIX | OWN VECTOR CRITERIA 2 MATRIX | OWN VECTOR CRITERIA 3 MATRIX | OWN VECTOR CRITERIA 4 MATRIX | OWN VECTOR CRITERIA 5 MATRIX | OWN VECTOR CRITERIA 6 MATRIX | OWN VECTOR CRITERIA 7 MATRIX | OWN VECTOR CRITERIA 8 MATRIX | OWN VECTOR CRITERIA 9 MATRIX | OWN VECTOR CRITERIA 10 MATRIX | OWN VECTOR CRITERIA 11 MATRIX | OWN VECTOR CRITERIA 12 MATRIX | OWN VECTOR CRITERIA 13 MATRIX | MODEL RESULT AHP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0,074 | Ion exchange | 0,041 | 0,023 | 0,023 | 0,065 | 0,048 | 0,082 | 0,048 | 0,031 | 0,031 | 0,116 | 0,177 | 0,153 | 0,065 | **7%** |
| 0,114 | Chemical precipitation | 0,347 | 0,200 | 0,158 | 0,301 | 0,285 | 0,063 | 0,188 | 0,035 | 0,276 | 0,103 | 0,028 | 0,022 | 0,301 | **18%** |
| 0,062 | Adsorption on activated carbon | 0,059 | 0,116 | 0,128 | 0,080 | 0,136 | 0,136 | 0,044 | 0,218 | 0,141 | 0,228 | 0,064 | 0,061 | 0,080 | **11%** |
| 0,080 | Reverse Osmosis | 0,042 | 0,023 | 0,026 | 0,054 | 0,025 | 0,050 | 0,030 | 0,036 | 0,027 | 0,031 | 0,177 | 0,171 | 0,054 | **5%** |
| 0,034 | Biological process in bioreactors | 0,076 | 0,039 | 0,082 | 0,062 | 0,076 | 0,024 | 0,188 | 0,071 | 0,054 | 0,158 | 0,059 | 0,056 | 0,062 | **8%** |
| 0,146 | Biosorption | 0,211 | 0,153 | 0,293 | 0,265 | 0,146 | 0,304 | 0,188 | 0,178 | 0,217 | 0,253 | 0,076 | 0,056 | 0,265 | **21%** |
| 0,123 | Phytoremediation | 0,070 | 0,297 | 0,245 | 0,090 | 0,221 | 0,291 | 0,166 | 0,160 | 0,192 | 0,057 | 0,064 | 0,092 | 0,090 | **17%** |
| 0,033 | Nanotechnology | 0,130 | 0,075 | 0,022 | 0,034 | 0,026 | 0,025 | 0,133 | 0,135 | 0,031 | 0,027 | 0,177 | 0,166 | 0,034 | **7%** |
| 0,061 | Electro coagulation | 0,024 | 0,075 | 0,022 | 0,049 | 0,038 | 0,025 | 0,014 | 0,136 | 0,031 | 0,027 | 0,177 | 0,222 | 0,049 | **5%** |
| 0,088 | | | | | | | | | | | | | | | |
| 0,063 | | | | | | | | | | | | | | | |

*Source: self-elaboration.*

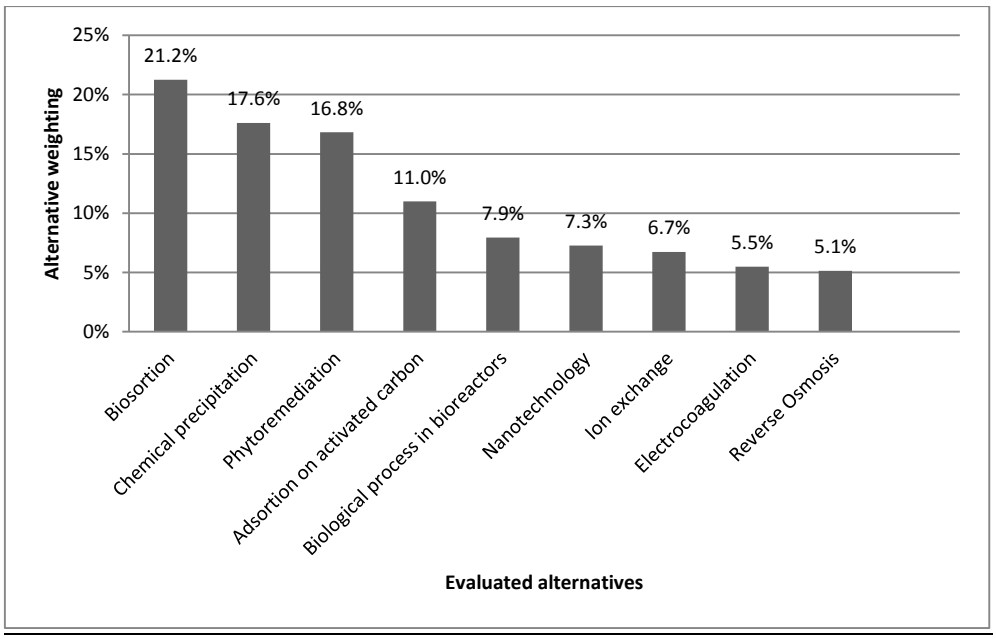


**Figure 8 :** Alternative selection model results
*Source: self-elaboration*

## DISCUSSION

### Model application

The results obtained allowed to establish that the information collected in a specific municipality, can provide data to select the most successful alternatives considering the technical, economic, environmental and social aspects in the conceptual model proposed, to ensure that the treatment system is applied in a specific context, taking into account the population and the environment, while being simple and inexpensive to maintain. So that it takes place in a framework of environmental management that achieves effective management of wastewater.

However, it should be noted that these results will be influenced by the perceptions of the stakeholders which in each case should set their preferences in order to guarantee that the proposed alternatives meet their expectations and that they are actually implemented by the miners in their process.

### Weighting results

The results obtained indicated that the complexity of the problem with the use of mercury in the Segovia ASGM, the mercury concentrations reported (up to 6118 mg Hg/L) and the presence of other pollutants associated with the gold beneficiation process as well as the characteristics of the mining population which are responsible for implementing treatment systems and improvements in their processes, indicated that the best technology that can be applied to remove the mercury before being dumped is the biosorption as tertiary treatment with a 21% of favorability.

This occurred because the relevance of the selection criteria was strongly influenced by the perception of the owners of the "*entables"* who would accept a treatment system as long as the installation, operation and maintenance costs were affordable for them, and the installation and operation were ease as well, factors on which the bio sorption has advantages over the other methods discussed.

In this context, the biosorption that uses natural polymers obtained from biological origins such as vegetable waste, algae, cultures of micro-organisms and fungi, turns out to be an efficient alternative at a low cost. This is because obtaining biosorbent material is considered economic, since little treatment is required for use, it is abundant in nature or it is a byproduct of industrial and agricultural operations. At the same time for being a technique that uses material of biological origin that can be inactive or inert, it eliminates the toxicity problem not only caused by dissolved metals but also by adverse operation conditions; in addition to its economic component of maintenance and including the fact that the supply of nutrients and the ability to regenerate by relatively simple treatments for reuse is not necessary (Volesky & Naja, 2007).

Other important criteria, such as efficiency and system reliability also obtained a high weighting for biosorption technology, because there have been reported effective removal levels of Hg (90-98 %) (Dos Santos, et al., 2004), as well as other heavy metals (Pauro, et al., 2009).

The effluent mining characteristics where significant concentrations of other pollutants such as zinc and cyanide are expected makes the biosorption one of the best alternatives and also because this process continues acting under a wide range of

physic-chemical conditions like: (temperature, pH and the presence of other ions) and has a high retention capacity of ions such as: (bio sorption capabilities up to 384 mg Hg/g of bio adsorbent, reported in the revised history) (Tejada & Villabona, 2012). However, a specific research is needed for the removal of mercury bioadsorbents easy to collect or produce in mining areas.

Furthermore, one of the major limitations of this and other bioremediation technologies, is that on the market there are already conventional technologies (physical, chemical), difficult to replace. Nevertheless, it is considered that as the application of the biosorption technology proves to be more economic and competitive, it will increase its marketing; especially in developing countries.

In this sense, the bioremediation has several technologies to remove metal contaminants in mine effluents that provide technical, economic and environmental advantages over others as the ion exchange or the use of membranes (Oehmen, et al., 2014). However, other biological methods analyzed in this study, including the biological process in bioreactor and phytoremediation, obtained less weighting than the biosorption and the precipitation.

Phytoremediation was in the third place with 16.7% and has some disadvantages related to its limitations by seasonality and the rate of plant growth which may be affected by high concentrations of contaminants that may inhibit their growth and therefore limit its application in treatment of ASGM effluents. The management of phytoremediation plants has been insufficiently studied and it must be ensured that the use of bio accumulator plants does not promote the dispersion of pollutants to the environment, or are distributed along the food chain (Gallardo & J.F, 2007).

Regarding to the use of bioreactors ranked fifth with 7.9%, it was found to have high installation costs compared to other alternatives (despite having operating and maintenance costs lower than standard chemical treatments), because this technique requires specific conditions for the proper growth of microorganisms. Therefore, the difficulty also lies on the need to develop crops and special conditions for maintaining its biomass (EPA, 2007), (EPA, 2014 ). Thus the weight obtained on criteria such as ease of construction, installation, operation and maintenance turned out to have one of the lowest scores among the technologies evaluated, that explains its low final score.

Precipitation is in the second place with a17.5% of favorability, considering that this system has an advantage over the other alternatives and even though that the installation of this system has significant costs, it is a system which the miners are already familiar, with as stated in developing surveys, some use reagents such as CaO, $H_2O_2$ and $ClO_{2-}$ in the process, in this case in order to recover some used cyanide.

While the precipitation process has marked environmental disadvantages compared to other alternatives, particularly in the amount of sludge generated, it is considered that the effectiveness of this technology is less likely to be reduced by features or contaminants that could affect other technologies such as the presence of other ions (EPA, 2007). The possibility of integrating this system in the existing process also favored the weighting obtained.

On the other hand, in the case of the activated carbon adsorption ranked fourth with a weighting of 11%, this occurred due to the high cost of activated carbon which although has numerous studies on more economic and effective materials for

obtaining the same results from natural materials, industrial waste and farming, but still has high costs on the activation and regeneration of the activated carbon in the process.

Systems using activated carbon adsorption have low scores on the criterion of reliability because the adsorption process for treating mercury is more likely to be affected by the characteristics of media and other contaminants. Therefore adsorption tends to be used more often when the mercury is the only contaminant to be treated (EPA, 2007).

Other technology evaluated was nanotechnology which had a weighting of 7.3%. It was ranked sixth. This technology is being evaluated experimentally in Colombia at present by several research groups through the *"*Red Colombiana de nanociencia y la nanotecnología*"*. They are looking to replace the use of mercury and the contaminated remediation sites from this technology. However, commercial application is still poorly addressed today, mainly because there is not enough available information about its material handling and potential effects on health and on the environment, In addition to the analysis of life cycle of processes and materials at a commercial level (EPA, 2014 ).

The ion exchange is one of the technologies with less weight, (6.7%) and also the reverse osmosis with (5.1%), despite they are commercially well established as technologies for treating industrial wastewater. The costs involved in the manufacture and supply of raw materials such as resins based on hydrocarbon polymers derived to ion exchange and reverse osmosis membranes are high (Volesky & Naja, 2005). It is difficult for these treatments to be applied in the small-scale mining process because the costs cannot be assumed.

There are also problems with the reliability and efficiency of these systems because they require pre filtration, specific conditions to avoid saturation and they also require constant maintenance. The reverse osmosis is used less frequently for mercury treatment because its cost tends to be higher and produces a greater volume of waste removal (EPA, 2007).

Finally, electrocoagulation obtained a low weight (5.5%) and was in the eighth place because even compared with reverse osmosis and nanofiltration it does not have a competitive cost and besides it requires more capital investment and pretreatment care (EPA, 2014 ). In addition, it presents high cost of electricity consumption which together with the electricity used in the ball mills, it would be untenable.

## CONCLUSIONS

The conceptual model application to the alternative wastewater with mercury treatment selection by hierarchical analysis methodology considering its technical, economic, social and environmental criteria in the activity of the ASGM in Segovia, allowed us to have primary information for the construction thereof, as well as verify and validate the relevancy of the information required for structuring and validation, while the application results were obtained in a real situation, looking for that

implementation of any selected treatment system to be actually carried out by the artisanal and small-scale gold miners in Colombia.

It was established that for the complexity of the use of mercury in the ASGM in Segovia and the characteristics of the mining population who are responsible for implementing any treatment system, the best technology that can be applied to remove mercury before it is being poured is biosorption as tertiary treatment, with a 21% of favorability.

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