

Estimation of the water footprint in a small scale gold ore beneficiation plant located in the municipality of Vetás, Santander, Colombia.

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Abstract

The aim of this work was the calculation of the water footprint and the assessment of the water usage in the gold ore beneficiation plant “Reina de Oro”, located in the town of Vetás (Santander) in Colombia. From the metallurgical standpoint, the environmental impact of the operations of concentration and gold recovery on nearby water streams was evaluated. Under local considerations, the water footprint of the “Reina de Oro” plant was calculated, and compared with similar operations in Segovia municipality (Antioquia, Colombia), being found to be favorable, due to the nature of the different processes involved.

Keywords: Water Footprint, Mercury, Ore Beneficiation, Gold Ore.

1. Introduction

In the Santander Region (Colombia), the Municipality of Vetás has been pioneer in the extraction of gold from vein deposits. There are several mining companies in the Vetás Municipality dedicated to the extraction of gold by hydrometallurgical and gravimetric methods. In this article, the beneficiation plant “Reina de Oro” is to be taken as a reference, in order to estimate the water footprint [1-17] for the small-scale mining industry in the afore-mentioned Colombian region. This region is of paramount importance, because the mining companies are located along the banks of the Suratá River, from which drinking water is extracted for the city of Bucaramanga (ca. 230.000 inhabitants). This study was conducted by the School of Metallurgical Engineering or the Industrial University of Santander (Colombia) and its aim is to propose alternatives to reduce the environmental impact of small-scale gold mining and maintain local sustainability.

2. Methods

The general scheme of the methodological approach of this work is shown in figure 1. The general view of the “Reina de Oro” beneficiation plant can be seen in figure 2. It must be noticed in figure 2, that the upper facilities correspond to the ore treatment installations, while the lower facilities are, in fact, housing buildings of the local villagers.

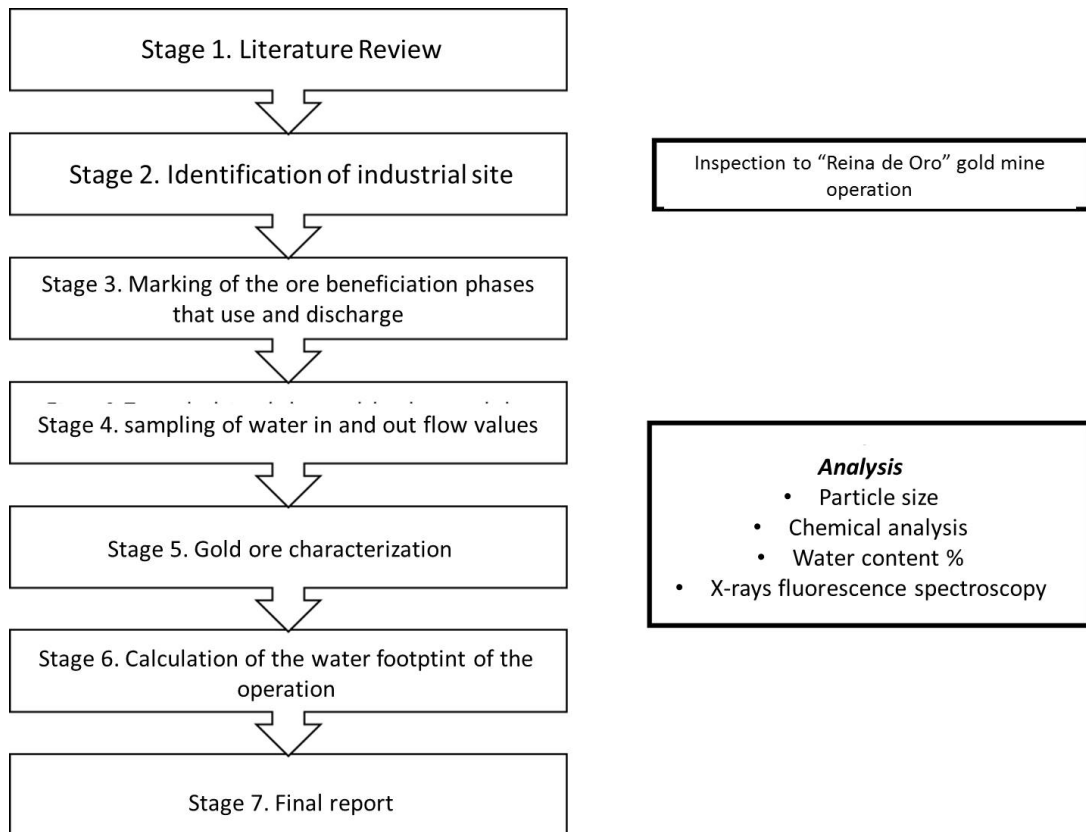


Figure 1 Methodology flow diagram followed in this work.



Figure 2 General view of the "Reina de Oro" gold ore beneficiation plant, located in Vetás Municipality, Santander, Colombia

3. Sampling at mining & processing site

In figure 3 the different stages required for the recovery of gold in the “Reina de Oro” plant are shown. The process begins with the extraction of coarse orebody from the mining tunnels. This run-of-mine product is then crushed and milled, to reduce its particle size. In the milling stage water is widely used, to facilitate the liberation of gold particles from the orebody. The milled ore is then passed through a series of Wilfley type shaking tables, which help to concentrate the gold particles by means of density differences between the gold and the gangue minerals present in the orebody. The Wilfley tables take advantage of a longitudinal vibratory movement, by which the ore particles can be segregated, forming arch bands, according to its specific gravity and particle size. This process is very effective, because great part of the gold in this region is native and can be liberated easily. For this reason, gravimetric gold concentrates in the “Reina de Oro” plant are very rich. The produced tailings still contain gold that cannot be recovered, unless a cyanide leaching stage is implemented. The final stage in the process is the smelting with fluxes, a procedure that grants the elimination of water and organic matter in the concentrate, as well as other companion elements. The final product is an impure gold ingot.

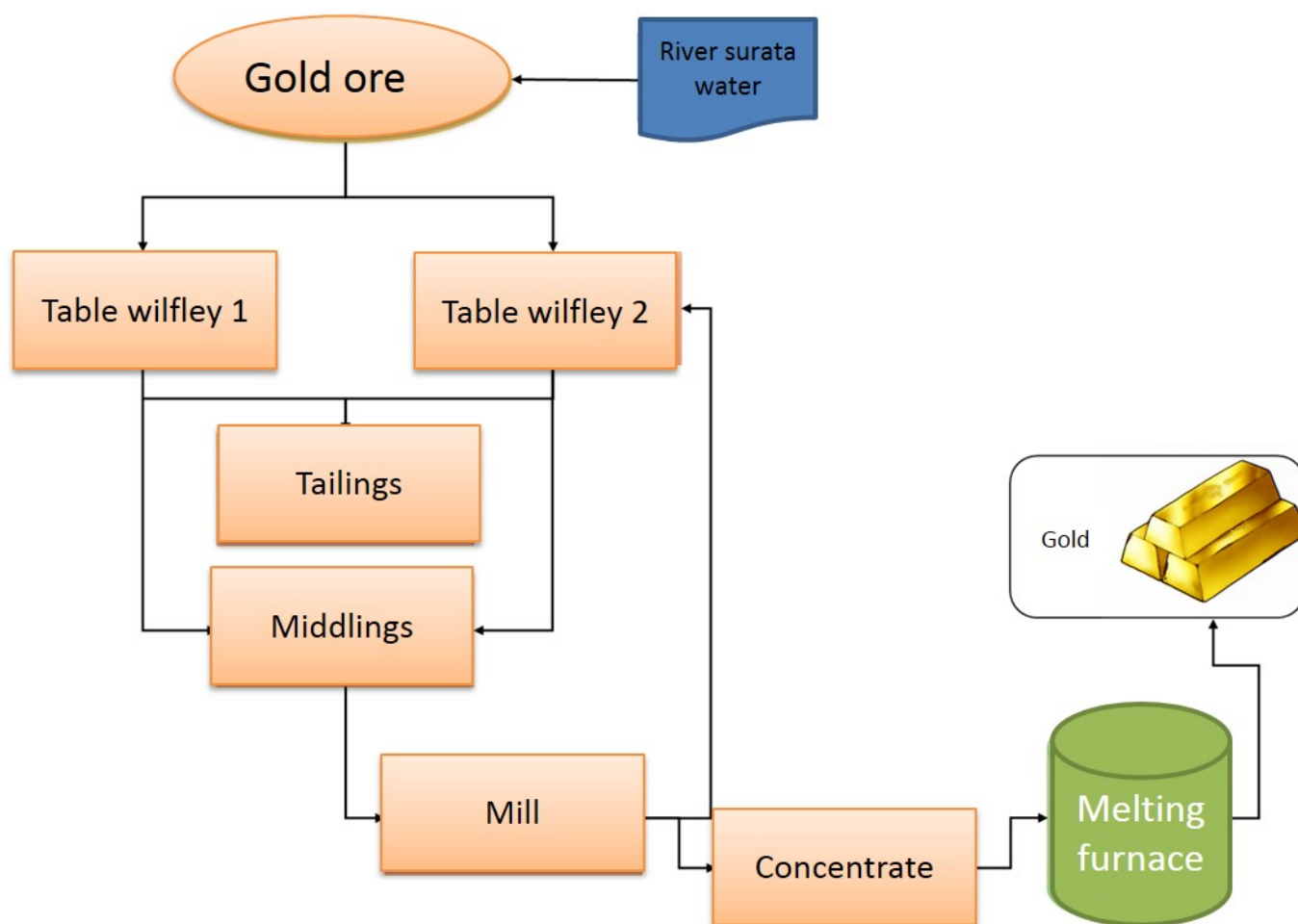


Figure 3 General process flow diagram of the gold ore beneficiation at “Reina de Oro” mining plant.

4. Results and Analysis

It must be stated that, to our knowledge, there is only one study conducted in Colombia to calculate the water footprint in gold mining operations [10]. The test was conducted in the Segovia Municipality, Antioquia Region. Although the mining procedures depicted were rather different than those found in Vetás, it is possible to establish, at least, a rough comparison between these two regions within Colombia, aiming to determine the national water consumption by gold mining in the country. According to [10], in Segovia (Antioquia) 200,778.5 m³ of water are consumed per year and the gold production is 3,421.1 kg. This sets a blue water footprint of 58,69 m³ per kilogram of gold. On the other hand, our results in “Reina de Oro” plant (Vetas, Santander) showed that the water consumption was 6.85 m³ of water per ton of dry ore (daily basis). If we consider that the gold content of this ore was 0,031 kg per ton of dry ore, it can be said that the “Reina de Oro” plant used a daily average of 21.79 m³ of water per kilogram of gold, being the yearly production of gold, estimated in 114.76 kg. So, the water consumption in the Santander Region, as compared to that of the Antioquia Region in Colombia, was much lower.

Besides the water usage, the volume of water affected by pollutants must also be estimated. According to [10], the gray water footprint for the gold mining in the Antioquia Region can reach 870.45 million m³ of water per annum, due to the use of mercury amalgamation in the concentration stages of the process. Since this procedure remains un-controlled, great amounts of Hg are accumulated in the water, which implies the use of more fresh water to ameliorate the environmental impact of the operation. In Santander, particularly in the “Reina de Oro” plant, neither mercury nor cyanide are employed to recover gold from the ore, that is why the grey water footprint in this zone can be considered to be zero. Nevertheless, this “environmentally friendly” procedure implies that an important part of the gold (i. e. fine gold) is lost within the tailings of the process.

Following, some of the physical, mineralogical and chemical analyses performed to the ore from “Reina de Oro” (Vetas, Santander) as well as the water flow measurements taken will be shown.

Results of the water flow measurements in the “Reina de Oro” plant.

In table 1 the measurements of pulp flow and mineral weight are shown, for the outlets of the two shaking (Wilfley) tables available in the layout of the “Reina de Oro” plant. The main consumptions of water are found in the stages of milling and gravity concentrations (shaking tables) are shown in table 2.

Calculation of water footprint

The sampling of flows was carried out by means of selected plastic flasks, of known calibrated volume (ml). The time of filling was measured using a chronometer and annotated as hundredths of a second (CS). For rock material with low water content, the water the flow was estimated from the weight percentage of water in the solid material. The time lapse related to the stream of solid material was obtained from production data available in the “Reina de Oro” plant.

Table 1 Pulp flow data related to the concentration stage in shaking tables, for “Reina de Oro” plant.

Sample number	Mineral Weight (gr)	Pulp flow at the outlet of Wilfley table #1 $\frac{ml}{CS}$	Pulp flow at the outlet of Wilfley table # 2 $\frac{ml}{CS}$
1	20,01	$\frac{1000}{117}$	$\frac{1000}{134}$
2	18,975	$\frac{1000}{116}$	$\frac{1000}{111}$
3	18,864	$\frac{1000}{103}$	$\frac{1000}{145}$
4	18,9863	$\frac{1000}{95}$	$\frac{1000}{146}$

The outlet pulp flow from the mil to the shaking tables were standardized to m³ per hour. The amount of water incoming from the water ponds was not possible to calculate, due to a lack of parameters. In consequence, this values will be estimated from the information available in other two sub-zones, so the blue water footprint is approximately determined for this sub-system.

Next, a calculation example is shown, to depict the unit conversion operation performed for each sample point, according to ISO 14001 normative (m³/h). The example shown explains how the flow is obtained from the water percentage in the solids (rocks) stream. The blue water footprint (BWF) in the “Reina de Oro” plant, equals the summation of the three sub-footprints determined before, accordingly:

$$BWF (m^3) = 1.14 + 0.55 + 5.16 = 6.85$$

Based on the above, and considering no variation in the mine process (10 tons of dry ore extracted per day, as an average), the behavior of the BWF parameter can be predicted, as shown in figure 4.

Report of the x-rays fluorescence results

Figure 5 and figure 6 show the chemical analysis of the “Reina de Oro” gold ore, as obtained by x-rays fluorescence spectroscopy. Several heavy metals can be identified. Following, a list of health issues concerning these heavy metals in polluted waters will be depicted.

Iron, lead and copper can easily migrate to water from mining environments. The excessive intake of contaminated water containing these elements may affect health conditions in humans. Big amounts of iron in water will change its taste and color, which may tend to me brown and sediment rich. This water will create problems, such as clogging, in the water pipe distribution system, and will stain the appliances in contact with the water. Too much iron in food and water may conduct the individual to a health condition known as hemochromatosis. This a serious condition, that may damage several organs. Its symptoms include: fatigue, weight loss and joint pain, heart and liver problems and diabetes [5].

Table 2 Water flow data in the mill and concentration stages of the process in “Reina de Oro” plant.

Sample number	Flow1 1 ¹ ($\frac{ml}{CS}$)	Flow1 2 ² ($\frac{ml}{CS}$)	Pulp Flow from the mill ($\frac{ml}{CS}$)	Pulp Flow in system tailings ($\frac{ml}{CS}$)	Pulp Flow in system middling's ($\frac{ml}{CS}$)	Water content in system concentrate (Weight %)
1	$\frac{500}{67}$	$\frac{120}{62}$	$\frac{1000}{117}$	$\frac{1000}{80}$	$\frac{500}{90}$	9.6
2	$\frac{500}{76}$	$\frac{120}{46}$	$\frac{1000}{116}$	$\frac{1000}{75}$	$\frac{500}{87}$	9.6
3	$\frac{500}{66}$	$\frac{120}{64}$	$\frac{1000}{103}$	$\frac{1000}{80}$	$\frac{500}{96}$	9.6
4	$\frac{500}{84}$	$\frac{120}{51}$	$\frac{1000}{95}$	$\frac{1000}{72}$	$\frac{500}{95}$	9.6
5	$\frac{500}{68}$	$\frac{120}{65}$		$\frac{1000}{80}$	$\frac{500}{93}$	
6	$\frac{500}{74}$	$\frac{120}{75}$		$\frac{1000}{92}$	$\frac{500}{95}$	
7	$\frac{500}{71}$	$\frac{120}{72}$		$\frac{1000}{75}$	$\frac{500}{92}$	
8	$\frac{500}{79}$	$\frac{120}{70}$		$\frac{1000}{90}$	$\frac{500}{94}$	
9	$\frac{500}{73}$	$\frac{120}{74}$		$\frac{1000}{91}$	$\frac{500}{91}$	
10	$\frac{500}{72}$	$\frac{120}{53}$		$\frac{1000}{80}$	$\frac{500}{92}$	

Copper, as an element in excess in water, when ingested by a person can cause harmful effects on human health such as: irritation of the nose, mouth and eyes, vomiting, diarrhea, stomach ache, nausea and even death, if ingested in high amounts [6].

On the other hand, lead ions in water have even more problems for human health. The type and effects depend on the amount of lead that has accumulated in the body over time. Children and fetuses are the most sensitive to the harmful effects of lead. Some children with too high a level of lead in the blood may not show any symptoms. At school age, learning and behavior problems appear. Other health effects include damage to the brain and kidneys, anemia and a decrease in newborn weight. There are also signs that lead can cause an increase in blood pressure. Symptoms of severe lead poisoning are stomach pains, vomiting, decreased appetite or nausea [7].

¹ From water pond, inlet to the first shaking table for pulp washing.

² From water pond, inlet to the table for final stage of pulp washing for middling's and concentrate.

Table 3 Flow data related to cyanide process in industrial plant.

Sample number	Outlet flow to Suratá River from the process ($\frac{ml}{cs}$)	Water content in the recovered concentrate by Wilfley tables 1 and 2 of the system (Weight %)	Water content in the cyanide concentrate of the system (Weight %)
1	$\frac{1000}{45}$	9.6	9
2	$\frac{1000}{40}$	9.6	9
3	$\frac{1000}{48}$	9.6	9
4	$\frac{1000}{48}$	9.6	9
5	$\frac{1000}{62}$		
6	$\frac{1000}{44}$		
7	$\frac{1000}{46}$		
8	$\frac{1000}{50}$		
9	$\frac{1000}{68}$		
10	$\frac{1000}{69}$		

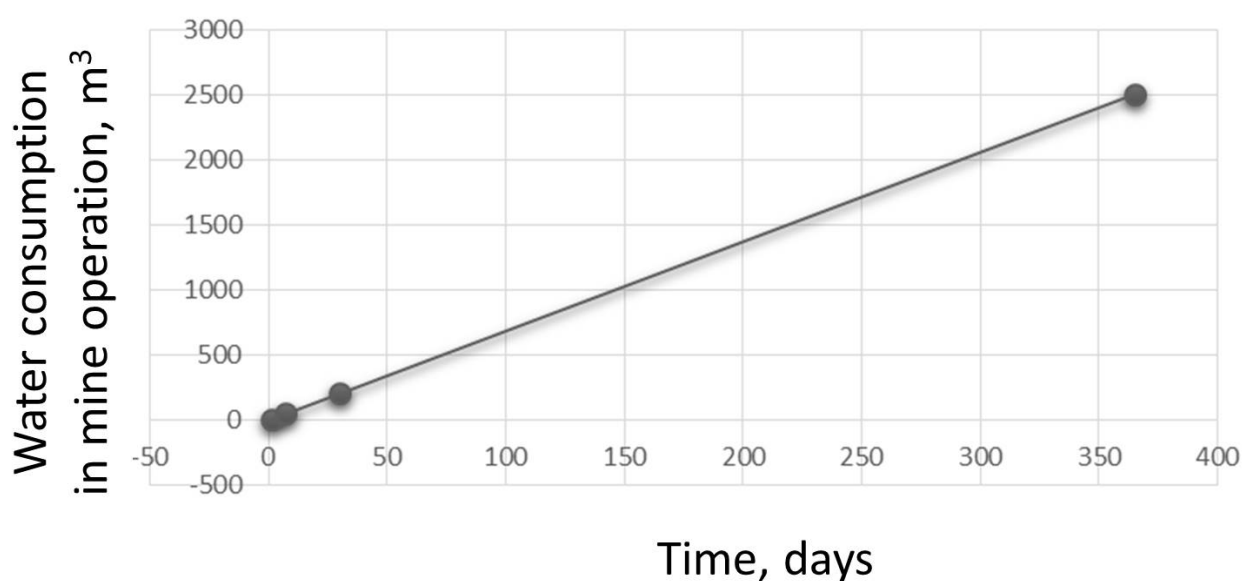


Figure 4 Variation of the blue water footprint (BWF) in the gold recovery at “Reina de Oro” plant, Vetas, Santander, Colombia.

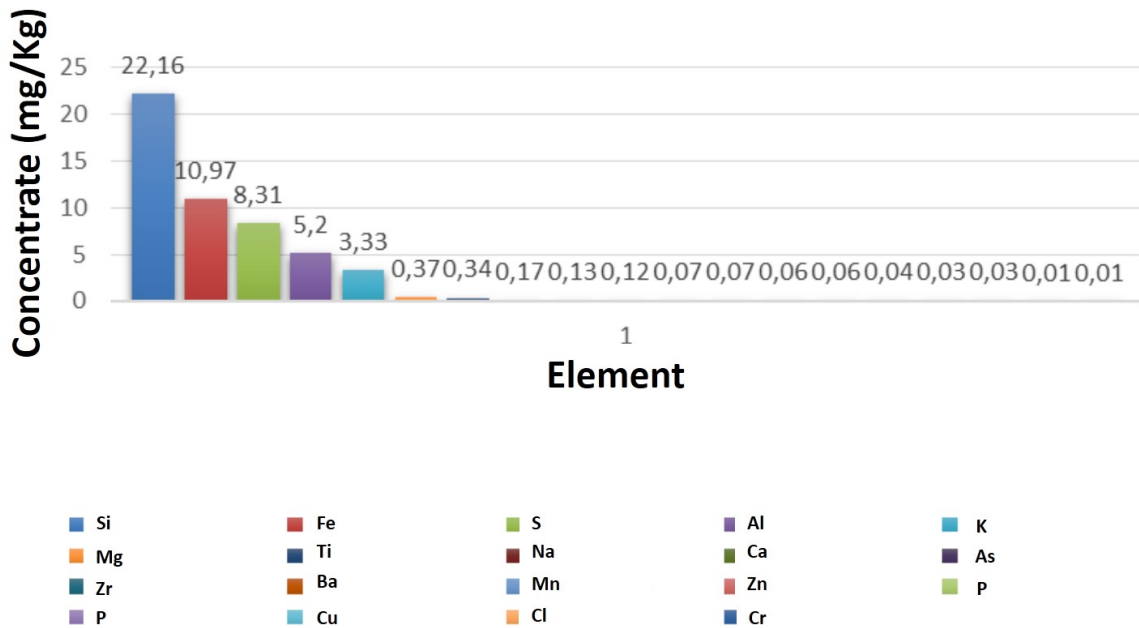


Figure 5 Quantification (weight %) of elements present in the gold ore from “Reina de Oro” plant, as obtained by x-rays fluorescence spectroscopy.

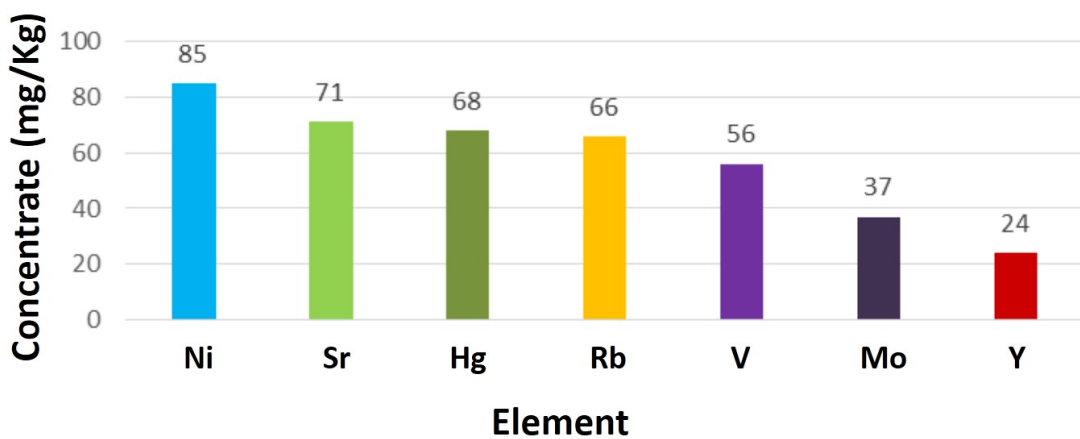


Figure 6 Quantification (mg/kg of sample) of minor elements present in the gold ore from “Reina de Oro” plant, as obtained by x-rays fluorescence spectroscopy.

The assessment of the quantity of these elements indicated in the final tributaries discharged to the river suratá shall be deducted by means of the atomic absorption test which shall yield, in ppm, the present quantity of each element in the water; As a verification of the quality of incoming water to the process from the green lagoon, the same test is carried out to know the initial amount of these elements in said tributary and to be certain of the contribution made by the gold ore to the possible contamination of water .

Figure 6 indicates that, as demonstrated by the results of the X-ray fluorescence test, the presence of a large percentage of silicon (22.16%), followed by elements such as iron (10.97%), sulfur (8.31%), Aluminum (5.2%), potassium (3.33%), among others. For the realization of the project considered the elements: iron, lead and copper; by the characteristics that they present when being diluted in water and how they affect the physical qualities and damages to the health of the people who ingest the liquid. Although elements such as lead and copper are found to be at a low percentage with respect to others as the same iron or as sulfur, which is the latter also a critical element, copper and lead were designed for the study to the conditions provided by the test laboratory since its presence in the water brings problems to human health, as already mentioned above.

Conclusions

It was possible to carry out the calculation of the water footprint of the gold recovery process of the Reina De Oro mine in the municipality of Vetas Santander. Likewise, it was possible to demonstrate that the values obtained are in favorable ranges as delivered by other studies of similar processes.

Although the results are partially statistically representative and not conclusive, the environmental impact demonstrated in the obtained analyzes managed to identify the tendency of the low impact caused by the use and dumping of the gold recovery process in the water sources of the Suratá River. These results may indicate that the mining of the Reina De Oro Mine in the municipality of Vetas could be regarded as friendly with the environment.

The determination of the flow rates corresponding to each unit operation shows that the operation of the mill as initial zone consumes a blue water sub-footprint equal to 1.14 m³ daily the two Wilfley tables located in the gold processing and recovery plant show a use of water for its process of 0.55 m³ per day and the final stages of sedimentation of the tails and media of the mineral, the subsequent shedding of process tailings to the Suratá River and the process of casting the obtained concentrates show a consumption equal to 5.16 m³ per day, which indicates that the final stage of the process in the gold mining plant is the one that requires a greater consumption of water in the treatment

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