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# Propose the surface flow constructed wetland in the treatment of acid drainage in the closure of a tailings deposit

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## I. INTRODUCTION

Peru is an important mineral producer and exporter for different trading partners. However, in the mining sector there are always mishaps or problems that can cause a delay in the mining work or in the closure of some work. One of these frequent problems is the formation of acid drainage in various mining operations, such as, for example, in the concentrator plant, tailings deposit, waste deposit, in underground or surface workings and others. The Acid Mine Drainage (DAM) is characterized by low pH and having a high concentration of sulfates, heavy metals and other toxic elements, which have a negative effect around the mining area [1]. One of the common and major formation minerals in the DAM is pyrite, which is typically found in sediments, mineral deposits, mineralized veins, hydrothermally altered rocks, and soils [2]. However, as mining operations expose pyrite and other sulfide-containing minerals to oxygen and water, they lead to the formation of acidic waters [3].

For this reason, the need for an adequate treatment to control acid mine drainage during and after carrying out mining activities. Currently, the DAM problem has two types of solutions, active treatment and passive treatment.

On the one hand, the active treatment applies the use of metals that generate alkalinity with the purpose that the metals precipitate, the use of adsorbents, ionic exchange and membrane technology, among others [4]. This method is typically used for the treatment of DAM with high acidity levels while the system adjusts to the different chemical properties that these drainages contain. However, these treatments are limited by their high cost and by their formation of sludge, which is unsustainable in the long term [5].

Passive treatment is considered a cost-effective technique for use in closed and abandoned mining sites, due to the stable chemistry of the area and the accessible soil for the DAM treatment system [6]. In these passive treatments they usually use inputs that generate alkalinity such as limestone, lime, among others, in order to neutralize the pH.

Acid drainages are observed in abandoned mining liabilities, where the proper closure process has not been carried out and there is no control over these mining liabilities.

The closure of a mining operation is important, since the physical and chemical stability of the specific area is sought. Likewise, prevent any incident towards workers or the generation of emissions or leaks of any kind. The Ministry of Energy and Mines defines mine closure as the implementation of activities throughout the life cycle of the mine, in order to comply with environmental and social standards. In addition, the activities used for the closure of mines influence the development and updating of the Closure Plan [7].

For this reason, in this investigation it is proposed to consider the constructed wetland of surface flow in the treatment of acid drainage in the closure of a tailings deposit in the former Huampar mining unit.

## II. STATE OF THE ART

The closure of a mining operation or a mining liability is a complex activity that needs to be evaluated with various studies in order to seek the physical and chemical stability of the specific area, and apply corresponding methods to control acid drainage.

Mining liabilities are usually abandoned or inactive, in Peru there are countless of these liabilities that little by little are beginning to be properly closed. A mining liability is considered according to Law No. 28271, "those facilities, effluents, emissions, remains or waste deposits produced by

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mining operations, which are currently abandoned or inactive and constitute a permanent and potential risk to the health of the population, the surrounding ecosystem and property" [8]. The closure of a mine or mining work is important for the safety of workers or people, anticipating emissions, leaks, leaks of any emission or fluid that could be generated inside or outside the mining work. According to Law No. 31347, the holders of mining activities are obliged to submit their Mine Closure Plan to the Ministry of Energy and Mines or the competent Regional Government in order to be approved, establishing the studies, actions and works to be carried out to mitigate and eliminate the polluting and harmful effects on the population and the ecosystem in general, at the conclusion of its operations [9].

However, when evaluating the closure of a liability or mining work, it is important to take into account various problems that could arise. One of the most common problems is the generation of acid emissions in the mines. Due to the nature and extent of its environmental impacts, AMD has been a topic of interest in the mining industry for many years [10]. In particular, when minerals containing associated sulfides, such as pyrite and arsenopyrite, which form part of the surrounding geological environment, are mined, the area is exposed to oxidizing conditions [11]. During rainfall and runoff, sulfides and minerals come into contact with water and oxygen, creating acid mine drainage [12]. However, if the water has a certain acidity, there is the possibility of the presence of the bacterium called Thiobacillus Ferrooxidans, which accelerates the oxidation and acidification process of metals [13]. These acid drainages occur in different mining activities, such as: tailings deposits, waste deposits and mining works.

In this case, the investigation focuses on the tailings deposits, which is the place where the liquid waste from the mineral concentrator plant is dumped. These liquid wastes are called tailings and contain a variety of toxic metals. The development of acid drainage in the tailings facility is usually very limited during operation and develops slowly over time after accumulation ceases. The occurrence of oxidation reactions is limited by the continuous accumulation of fresh layers of saturated and alkaline residues during operation. Once buildup is complete and the tailings begin to drain exposing the sulfides to oxygen, resulting in the initiation of oxidation. An oxidation reaction requires oxygen and water; Acid formation usually begins on the surface and sides of the dam, which drains first. Thus, oxidation begins at the surface of the dam and continues downstream as leachate drains and the water table moves deeper into the reservoir. Shallow drying and cracking of tailings can increase the supply of oxygen to the depth of the tailings and lead to deeper oxidation [14].

That is why it is convenient to consider new and innovative technologies that can achieve positive results in the treatment of these acid waters. One of the options is to consider passive treatment, in this case constructed wetlands, which have low operation and maintenance costs. In addition, there are two types of constructed wetlands: underground and surface [15]. This treatment of constructed wetlands has been studied for the last 50 years [16]. Likewise, there is evidence that in recent years, constructed wetlands have been developed and investigated, as a means of primary treatment at the pilot level (in the laboratory) and in some cases on a large scale [17].

Constructed wetland designs are often different, due to the use of different aquatic plant species and substrates. For example, common reed, modified iron ore drainage sludge, and constructed wetlands were used to understand the efficacy of this treatment for arsenic and heavy metal removal in lead-zinc mines [18].

In the investigations of this passive treatment, scale prototypes are usually developed, in order to study the efficiency of wetlands and substrates in these treatments. Also, scale treatment systems have been built with cells based on limestone or zeolite rocks. The system consisted of twelve acrylic cells, six of which use limestone as the main medium and the other six use zeolite as the main medium [19]. In addition, gravels were placed at the entrance and exit areas to help with circulation and the flow of water from left to right. Some of the materials used in passive acid drainage treatments are those that generate alkalinity such as lime, hydrated lime, quicklime in pebbles, magnetite, dolomite, fly ash, caustic soda, or also the best known limestone, among others, for what metals are precipitated and the pH is neutralized [20].

Regarding the efficiency of passive treatment with constructed Wetlands, it will depend on various factors such as the chemical composition of acid drainage, the degree of acidity, the accumulation of toxic metals and the organic material used [21]. Likewise, organic materials have been used for the treatment of DAM in constructed wetlands, such as cow dung, guano, eggshell, bamboo chips, among others [22].

However, in wetland systems the association of groups of microorganisms and plants that promote bacterial oxidation, fixation of trace elements, precipitation and absorption of metals such as iron, manganese, arsenic, aluminum, copper, zinc, cadmium, selenium, nickel and lead have been observed [23].

It should be noted that wetlands have mechanisms for removing heavy metals that include the chemical precipitation of metals and adsorption in the sediments by aquatic plants, metal retention in plant tissues through filtration, adsorption, cation exchange, and induction among roots, as well as the direct absorption of metals by plant roots. This benefits wetlands, as they can adapt to and resist environments with low pH and areas with high concentrations of heavy metals [24]. The most commonly used aquatic plants for this method are bulrushes, reeds, or cattails, due to their high resistance to low pH values.

During the experimentation process of this type of passive treatment, various results have been displayed that have been satisfactory for each proposed approach. On one hand, the constructed wetland has greatly improved water quality, and it could be affirmed that low-grade minerals can be removed with a percentage of up to 99% for Fe and Al, 94% for Ni, and 93% for sulfate, but the pH only increased from 2.21 to 5.36 [25]. The combined implementation of wetlands and limestone as substrate has also been studied, which achieved metal removal rates of up to 99% (Al, As, Cd, Co, Cu, Ni, and Mn); 67.5% for Zinc; around 60% for sulfates, and pH increases of 2.6 units or up to 9.5 units [26]. Lastly, another experimental result from this treatment showed that the constructed wetland, in combination with limestone, improved the pH and acidity of the effluent, achieving a pH increase between 4.4 and 6.3 units and reducing the acidity between 31 and 52%. Additionally, it registered an average removal of total iron between 54 and 67%, sulfur removal between 16 and 35%, nickel removal between 25 and 50%, and aluminum removal ranging from 0 to 73% [27].

## III. CONTRIBUTION

For many years, various innovative acid water treatment techniques have been studied and developed to apply them in abandoned mines, specifically in mining liabilities such as tailings deposits, in order to not frequently use traditional treatment systems such as active treatments. , which are characterized by their infrastructure, high operating cost and the use of chemical inputs.

### *A. General Contribution*

The contribution of this research focuses on providing treatment alternatives for acid mine drainage in operational processes in artisanal or abandoned mines. For this reason, in this investigation it has been proposed to consider a passive treatment to treat acidic waters, using the technique of surface flow artificial wetlands. These passive treatments are appropriate to implement in abandoned mines, since they have access to the facilities and the area. In addition, its application is low cost, does not use chemical inputs for the treatment of acid water and favors the creation of new ecosystems.

This technique is a type of artificial wetland that is characterized by the fact that acidic water comes into direct contact with the atmosphere, circulates through the plants and substrates. Constructed wetlands adapt to and resist high acidity environments, and have the ability to absorb heavy metals and increase the pH of the water.

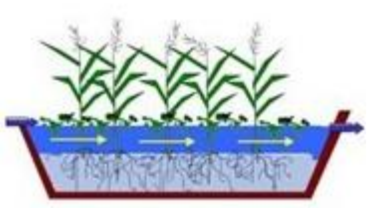

Fig. 1 Image of the technique proposed for the treatment of acid mine drainage. Retrieved from https://flowen.com.pe/humedales-artificiales-para-la-remocion-de-nutrientes-en-las-aguas-residuales/

### *B. Proposed methodology*

The development of the methodology encompasses four main processes to estimate and conclude the effectiveness of the proposal. Next, the four contribution processes that will be carried out for the investigation are exposed (Fig. 2).

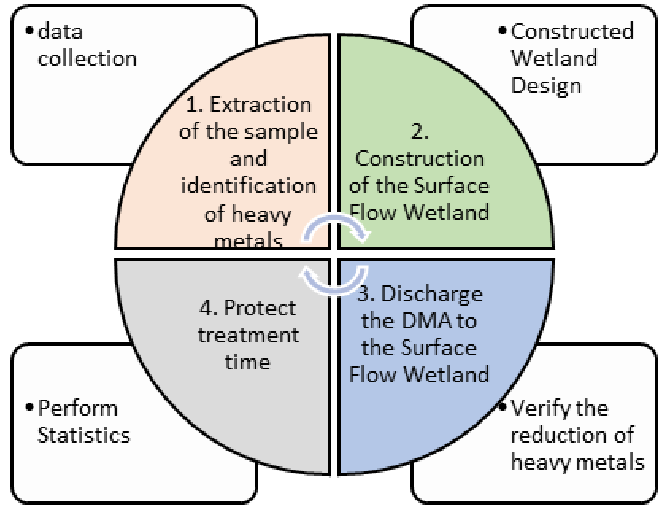


Fig. 2 Proposed methodology

The approach exposed for this research is of the quantitative type, in which the identification and operation of identified variables is addressed. That is, the research work being quantitative allows us to use mathematical or statistical analysis tools in order to describe and explain the results obtained in the course of applying the proposed technique. In this way, to conclude if the passive treatment of surface flow wetlands could be considered for the treatment of acid drainage in a waste rock deposit.

### *C. Variables to consider*

The variables for the development of the research were identified, among which the following stood out:

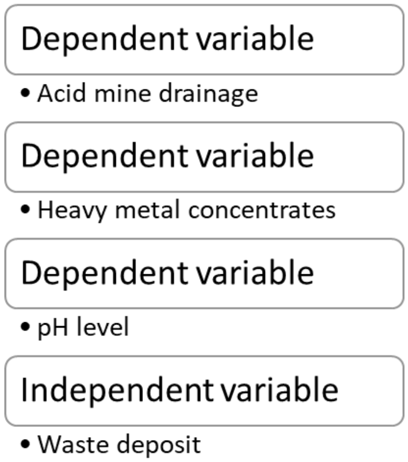


Fig. 3 Identified variables

### D. *Process input*

Next, the process diagram of the contribution of this research is presented, which shows a set of methodological processes that were carried out to meet the stated objective.

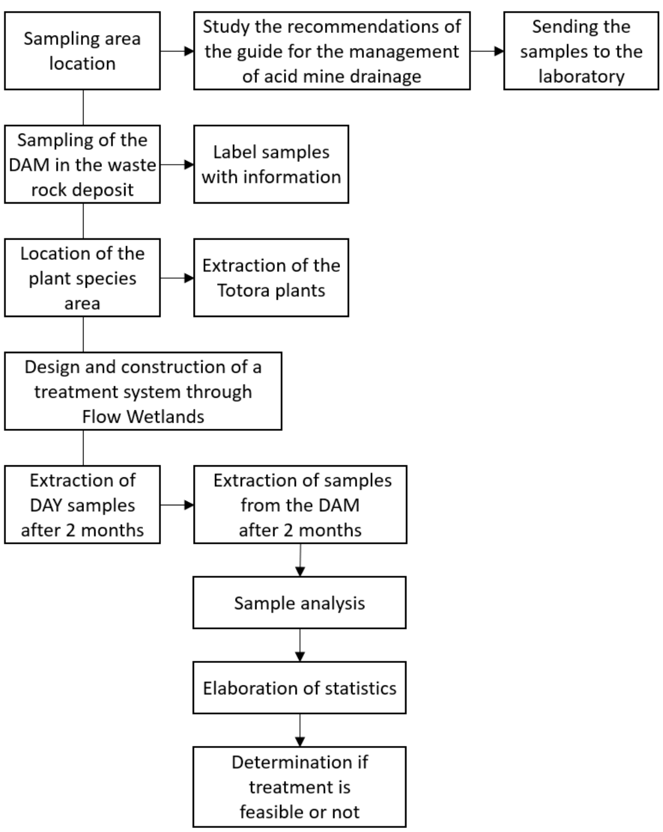


Fig. 4 Process flowchart

In this way, all the processes involved in the development of the research are identified, whether in the sample extraction part, preparation of the treatment system in the laboratory, analysis of the samples after a given period of time. and even determine whether or not this treatment of acid mine drainage in the waste rock deposit could be considered.

## IV. Validation

### A. *Validation scenario*

The scenario where this investigation was developed is the former Huampar mining unit, which is a polymetallic deposit. This mine is located 80km northeast of the city of Lima, specifically in the province of Huarochirí in the district of Huanza. This zone is part of the central polymetallic belt of Peru. Likewise, the location of the tailings deposit is at UTM coordinates 342 631 east and 8 720 046 north.

The entrance to the mine is through an affirmed trail that joins the district of Huanza. In addition, there is a network of trails that connect with the different mines that exist in the area and the towns of this district.

### B. *Sampling Validation*

The DAM sampling point is identified, so the samples were extracted at the base of the tailings deposit, where a polypropylene bottle was placed and the container was closed with the cap and screw cap. Subsequently, the labeling with the corresponding information of the sample was carried out. Finally, the sample was transferred to the private laboratory, where an induced plasma spectrometry (ICP) analysis was performed to identify the metallic elements and the amount of concentrates contained in the acid drainage.

TABLE I
Sample Analysis

| GEO Method 044 | Element | Unit mg/L | U1 |
|---|---|---|---|
| GEO 044 | Ag | mg/L | 0.154 |
| GEO 044 | Al | mg/L | 0.424 |
| GEO 044 | As | mg/L | 1.058 |
| GEO 044 | Ba | mg/L | 0.03 |
| GEO 044 | Be | mg/L | 0.002 |
| GEO 044 | Bi | mg/L | 0 |
| GEO 044 | Ca | mg/L | 5.627 |
| GEO 044 | Cd | mg/L | 0.108 |
| GEO 044 | Co | mg/L | 0.263 |
| GEO 044 | Cr | mg/L | 0 |
| GEO 044 | Cu | mg/L | 0.161 |
| GEO 044 | Fe | mg/L | 0.141 |
| GEO 044 | Ga | mg/L | 0 |
| GEO 044 | Hg | mg/L | 0.034 |
| GEO 044 | K | mg/L | 4.185 |
| GEO 044 | La | mg/L | 0.415 |
| GEO 044 | Mg | mg/L | 10.154 |
| GEO 044 | Mn | mg/L | 19.413 |
| GEO 044 | Mo | mg/L | 0 |
| GEO 044 | Na | mg/L | 15.541 |
| GEO 044 | Nb | mg/L | 0.01 |
| GEO 044 | Ni | mg/L | 0.05 |
| GEO 044 | P | mg/L | 0.08 |
| GEO 044 | Pb | mg/L | 0.23 |
| GEO 044 | S | mg/L | 20.517 |
| GEO 044 | Sb | mg/L | 0.015 |
| GEO 044 | Sc | mg/L | 0 |
| GEO 044 | Se | mg/L | 0 |

| | | | |
|---|---|---|---|
| GEO 044 | Sn | mg/L | 0 |
| GEO 044 | Sr | mg/L | 0.335 |
| GEO 044 | Te | mg/L | 0 |
| GEO 044 | Ti | mg/L | 0.002 |
| GEO 044 | Tl | mg/L | 0 |
| GEO 044 | V | mg/L | 0.004 |
| GEO 044 | W | mg/L | 0.198 |
| GEO 044 | Y | mg/L | 0.015 |
| GEO 044 | Zn | mg/L | 8.35 |
| GEO 044 | Zr | mg/L | 0 |

Fig. 5 Acid drainage sample

Finally, having the results of this analysis, a comparison will be made with the environmental quality standards for water Supreme Decree No. 004-2017-MINAM, in order to identify which metals have exceeded the maximum permitted limits and with these metals. make observations.

## C. *Validation of the design of the Surface Flow Wetland*

Various studies were consulted that developed prototypes of surface flow wetland treatment systems. For this reason, an adaptation of these studies was carried out to create one of our own. The dimensions of the prototype were established and the organic materials used to conform the Wetland were indicated, for example: gravel, sawdust, prepared compost and soil. In addition, the location of the reed plant was made to be collected and later planted in the prototype. Finally, once this wetland is built, the acid drainage that was extracted in the tailings deposit will be poured and two and a half months will be left for this system to act.

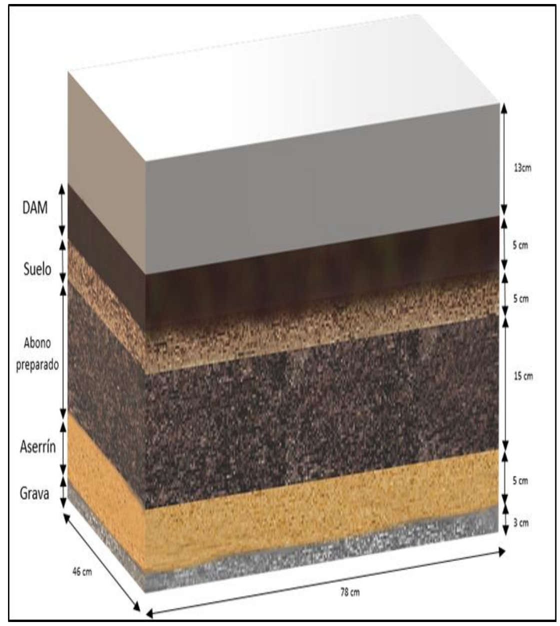


Fig. 6 Elaboration of the constructed wetland

## D. *Validation of Overland Flow Wetland Efficiency*

With the Wetland built and after two and a half months, a sample of acid drainage from the Wetland will be extracted, in order to identify which metals have decreased their concentrations during the treatment time. To do this, the sample will be transferred to a private laboratory for analysis with the induced plasma spectrometry (ICP) method.

Fig. 7 Induced plasma spectrometer (ICP). Retrieved from the Polytechnic University of Cartagena

TABLE II
COMPARATIVE GRAPH

| Analysis results | | | |
|---|---|---|---|
| Element | Unit | U1 | U2 |
| As | mg/L | 1.058 | 1.001 |
| Cd | mg/L | 0.108 | 0.091 |
| Pb | mg/L | 1.23 | 1.01 |
| Zn | mg/L | 8.35 | 8.05 |

### *E. Validation of the comparison of PH levels of acid mine drainage samples before and after treatment*

The pH level of the acid drainage sample extracted from the tailings deposit is measured. Then, after two and a half months of treatment, the pH level of the acid drainage discharged into the artificial wetland is measured again.

With the data from these two samples we will make a table, in which we will compare whether the pH levels rose or not.

TABLE III
PH LEVELS BEFORE AND AFTER TREATMENT

| | DAM (tailings) | DAM (wetland) |
|---|---|---|
| Ph | 3.68 | 3.81 |

## V. DISCUSSION

### *A. Identified Metals*

The acid drainage samples extracted in situ from the waste deposit of the former Huampar mining unit, it was observed that the minerals with the highest concentration are arsenic, cadmium, lead and zinc. These samples exceed the maximum permissible limits established by the State, which resulted in As (1.058 mg/L), Cd (0.108 mg/L), Pb (1.23 mg/L) and Zn (8.35).

Making the comparison with the samples extracted from a coal mine in the Philippines, the results were that the metals manganese, cadmium, lead and arsenic exceeded the maximum limits allowed for wastewater in categories A and B, the laboratory results were Mn (2.56 -3.75 mg/L), Cd (0.33-0.63 mg/L), Pb (0.37-0.65 mg/L) and As (0.22-0.30 mg/L) [19, 28].

However, the results obtained in these two mining scenarios are different, be it in their geography, type of deposit, metal content, among others. However, the identification of heavy metals that exceed the maximum allowable limits are almost similar.

### *F. Elaboration of the surface flow wetland at laboratory scale*

Accordingly, to the development of the investigation, a treatment system was elaborated at the laboratory level, with the purpose of analyzing the efficiency of the constructed Wetlands. For this, in this investigation, an artificial wetland with simple characteristics was built, in which various materials were used according to various study articles. Firstly, the dimensions of the reservoir where the wetland would be placed were established: Height (45 cm), width (46 cm) and lake (78). Once this deposit is finished, a layer of gravel will be placed with a height of 3 cm, a layer of sawdust at a height of 5 cm, another layer of cow dung at a height of 10 cm and another layer of soil at a height of 5 cm. . Afterwards, 5 reed plants 60 cm high will be planted from them. Finally, water and acid mine drainage samples will be poured at a height of 5 cm.

Compared to other scientific studies, the constructions of the Wetland adhered to the following design parameters: total length 4200 mm, total width 900 mm and height 700 mm. Once the wetland was deposited, layers of dolomite gravel, layers of compost and soil were placed. Then 5 plant species Zantedeschia aethiopica, Cyperus papyrus nana, Typha capensis, Juncus effusus and Chondropetalum tectorum were planted [29].

In another article, an experimentation of a Wetlands treatment system was carried out, in which four tanks were built and the following dimensions were considered: 80 cm long, 30 cm wide and 50 cm high. After that, a layer of gravel is placed at a height of 4 cm, a layer of ballast (river sand) at a height of 46 cm and a free edge of a height of 10 cm. For this experiment, six Phragmiles australis plants of approximately 60 cm height were used [30].

### *G. Results of the decrease of the metallic content during the application of treatment*

Regarding the results of the surface flow wetland treatment during the application period, it was observed that the heavy metal concentrates that have exceeded the maximum permitted limits decreased their concentrations. Arsenic decreased 5% (0.057 mg/L), Cadmium decreased 16% (0.017 mg/L), Lead decreased 18% (0.022 mg/L), and Zinc decreased 4% (0.3 mg/L). .

Regarding the results obtained by Silva. J, et al. (2019), it was verified that the wetland treatment applied in this investigation resulted in the average removal of total iron being 54% and 67%, the removal of sulfides was 16% and 35%, nickel reduced to 5 and 50% and aluminum was 73%. In addition, this research used limestone as a pretreatment in order to improve the efficiency of heavy metal removal. Likewise, no drawbacks were observed with the treatment.

Likewise, the removal of metals was comparable with the results obtained by Shweta.S and Saswati. C (2021), in his research we can see that the average removal of Zinc was 97% and 92% during the first phase of treatment. In this investigation, several divisions of the deposit were used in order to find which zone was more efficient to remove zinc [31].

In addition, making a comparison of a passive treatment carried out with four neutralizers for the treatment of acid mine drainage. In the tests it was observed that the concrete aggregate showed efficiency in the treatment, which resulted in the removal of 99% iron, 99% nickel, 96% aluminum and 57% sulfates. In addition, the concrete aggregate was evaluated, which resulted in the removal of 94% iron, 78% nickel, 92% aluminum and 28% sulfate [32].

### *H. Comparison of pH levels before and after treatment*

It was observed that the pH level rose significantly 0.13. That is, the drainage sample before the treatment had a pH level of 3.68 and after two and a half months the pH levels rose to 3.81.

According to Oberholzer, M., et al (2022) [22], the result of the pH levels in their wetland treatment system were the following: the pH was raised from 2.62 to 7.04 by implanting cow dung; Also, fly ash was used as a substrate, obtaining as a result a pH of 2.62 to 6.52.

## VI. CONCLUSIONS

The results show that DAM is one of the most common problems in mining activities and must be treated efficiently to avoid generating any impact. Furthermore, these articles reveal several cases of different abandoned mining activities that illustrate the problem.

The articles featured above focus on solving this problem with innovative and cost-effective passive treatments such as surface flow constructed wetlands.

In conclusion, the proposed technique to treat acid drainage in the closure of a waste deposit is feasible, since it could be used in mines that have been abandoned and which need to be closed at all, in order to establish a physical equilibrium. and chemical of the mining passive.

Another conclusion about the investigation is the efficacy of the technique for the treatment of acid drainage, since they identified only four metals that exceeded the maximum permitted limits and a decrease in the amount of these heavy metals was observed. These metals are arsenic, cadmium, lead and zinc. Comparing with other investigations, the presence of these metals is frequent in acid drainage and applying the treatment, the results were positive, removing the metals by 89% and 99%.

On the other hand, when estimating the treatment time, it can be concluded that it depends on the objective that is being carried out within the investigation. Likewise, it is known that all acid drainages vary with respect to the amount of metal concentrate they contain and the pH level they have. These variables will define the treatment time needed. But with the help of programs like Excel in this case, a treatment period of approximately 10 months was established. However, this date is a linear projection that was made and is considered an ideal date. However, this date could change in reality in the course of the process.

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