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BIOREMEDIATION OF THE HELIOPOLIS-GUELMA GRAVEL QUARRY: A PROPOSAL FOR ENHANCING VEGETATION COVER AND ENVIRONMENTAL BENEFITS

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Abstract

Our research aims to assess the feasibility of restoring the Heliopolis quarry in Guelma, Algeria. The site has suffered degradation due to overexploitation and a lack of preventive measures. The project idea aims to enhance local environmental benefits and promote vegetation growth by introducing seeds of native plant species or seedlings. Modern techniques were employed to analyze the study area and assess soil characteristics. Technical maps and topographical representations generated through Geographic Information Systems (GIS) were created to depict the various elevation levels of the site and the degree of structural damage. Moreover, soil samples from the Heliopolis quarry and a rehabilitated quarry in Oued El Aneb, Annaba province, were analyzed using SEM-EDX. This fascinating device employs a highly focused scanning (primary) electron beam to produce high-resolution, depth-of-field images of surface topography. We applied this method to identify key elements that should be incorporated into the soil composition to improve soil fertility and facilitate effective site bioremediation. The SEM-EDX analysis results revealed varying compositions of the Heliopolis gravel quarry soil, including calcium oxide (CaO), silicon dioxide (SiO_2), magnesium (Mg), and other elements in different proportions. In contrast, the soil analysis from the Oued El Aneb gravel quarry, which underwent rehabilitation in Annaba, indicated that it was enriched with all essential elements for olive tree cultivation, such as Silicon, Iron, and Magnesium. Concerning the GIS cards, the results have indicated that the quarry floor has experienced huge topographical changes, posing a substantial challenge for bioremediation due to depths exceeding 12 meters at the bottom and reaching 15 meters in some areas. The bioremediation project of the Heliopolis gravel quarry will serve the environment, provide social and economic advantages, create jobs, and enhance the overall appearance of the quarry site and the Heliopolis town.

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1.0 INTRODUCTION

The extraction of raw materials for construction will persist due to significant demand in the global market, particularly since gravel extraction is indispensable. However, it is possible to mitigate the associated side effects and work towards enhancing the ecological environment, thereby contributing to the green economy and sustainable development [1].

In addition to gravel, several other extractive materials, such as phosphate, coal, and iron, are extracted using the open-pit method. In this case, the terminology differs, with the term "open-pit mine" being used instead of "quarry." However, all of these activities share significant negative impacts on both environmental health and human well-being [2].

The gravel extraction process encompasses several preparatory stages, beginning with prospection to ascertain the geological and natural characteristics of the site. Following this, the removal of the vegetation cover is undertaken. Subsequently, the mineralized zone is fragmented using explosive charges; at the Heliopolis quarry, engineers utilize MARMNIT III explosives, applying 45 kilograms [3].

Once the fragmentation is completed, the extraction phase is carried out using mechanical processes, with heavy machinery specifically designed for breaking stones. This is succeeded by the mechanical treatment of the extracted material, which involves crushing, grinding, and sifting to meet specified size requirements (e.g., 5 mm, 8 mm). Finally, the processed materials are transported for commercial purposes. [4].

Gravel is a crucial natural resource utilized in various fields, most notably in the production of concrete for infrastructure construction. Beyond its use in paving roads, gravel serves decorative purposes as well. For instance, it is often employed to create pathways in gardens and is also placed in plant vases for aesthetic enhancement with various particle sizes selected based on specific demands and requirements [5]. However, the negative impact of exploiting this material is markedly significant. Therefore, a critical phase in the rehabilitation and reclamation of mining sites involves restoring soil quality. This process includes enhancing soil structure and assessing nutrient concentrations to promote plant growth and development [6].

The Guelma region boasts rich plant diversity and dense vegetation cover, there are various types of trees and plants present in the area. The agricultural sector covers an estimated area of 264 618 hectares [7]. Additionally, According to reports from the Digital Platform for Tourist and Historical Sites of the Province of Guelma, the region showcases a diverse forest landscape, featuring cork oak and eucalyptus trees, as well as valonia oak and Aleppo pine. [8]. Concerning the precipitation, the official website of the Wilaya of Guelma indicated that the average annual precipitation ranges from 400 to 500 mm in the south, reaching nearly 1000 mm in the north. Approximately 66% of this precipitation is recorded during the rainy season, which spans from October to May [9].

The site that is being exploited is marked by the widespread presence of exposed rocks, as well as the scattered quarry residues from the tires of large trucks and empty plastic bottles. These materials are harmful to the remaining plants, leading to poor soil quality and erosion. Additionally, they hinder water retention. Furthermore, the extraction of gravel contributes to air pollution through the release of mineral dust [10].

This study proposes a concurrent approach to quarry restoration, integrating rehabilitation with ongoing exploitation to minimize environmental degradation and improve sustainability.

2.0 METHODOLOGY

2.1 Materials and Methods

2.2.1 Soil sampling

Eight (8) soil samples were collected from the Heliopolis and the Oued El Aneb quarries, at a depth of approximately 60 cm using a shovel and plastic bags, while wearing gloves to prevent contamination of the samples using the quarter sampling method for obtaining a representative sample of the soil in each high wall [11].

2.2.2 SEM +EDX analysis of soil

To determine the shape and composition of the quarry's soil, it was necessary to analyze the samples using SEM +EDX technology. This method is known for its precision in examining soil and dust samples. It provides insights into the mineral composition and the shape and surface characteristics of the sample, including features like surface roughness, fibers,and hollows [12].

2.2.3 Topographical analysis

Creating quarry floor-level maps with Geographic Information Systems (GIS) is a highly effective tool for accurately determining precise elevations and locations[13]. The significance of this technique is well recognized, particularly within the field of geography. One of the advantages of this system is its ability to generate detailed maps that incorporate various geographical features and diverse data layers, which assist researchers in visualizing the studied scenarios[14]. GIS facilitates regional spatial planning by providing tools to assess land conditions, infrastructure, and the extent to which these are affected by environmental changes in the study area. This capability enables us to simulate effective scenarios and make informed decisions [15].

2.2.4 Proposed rehabilitation project

Based on this format in Figure 1, which depicts the current condition of the quarry site we aim to rehabilitate, we can identify the essential steps required to initiate the project:

Figure 1: The Heliopolis-Guelma gravel quarry

The photography in Figure 1 illustrates the gravel quarry located in Heliopolis-Guelma, highlighting the steep rock walls resulting from excavations and blasting. Additionally, the image reveals exposed soil layers, which represent the geological strata of the Earth. . Pebbles and small stones indicate that rock extraction continues to date. Furthermore, the scattered vegetation inevitably exists and is affected by on-site activities, while the overall landscape reflects the adverse environmental impacts of mining. The rehabilitation of mining sites covers a range of restorative activities, in accordance with the Mining Law of 1992, which consists of the establishment of a healthy and stable environment through the treatment of cases of land and water pollution, and other actions that serve both the human and environmental needs [16].

Primarily, several documents must be gathered to outline the site's history of exploitation. This includes an assessment of risks present at the site, such as the potential for landslides or rock collapses. Additionally, a comprehensive management plan is required, which should begin with a technical description of the extraction process, including details on site access and the types of explosives utilized.
A crucial component of this initiative is the collection of topographic maps to identify the key features of the terrain, including elevations and depressions.

Efforts should also focus on restoring the site’s original vegetation layer, ensuring that any restoration efforts are conducted under appropriate conditions to support successful reestablishment operation [19].

Another critical step is to assess the climatic conditions of the area, particularly rainfall and temperature, to identify plant species that are well suited to the environmental conditions of the rehabilitation site. The study area is characterized by a relatively rainy climate during the winter months, precipitation levels of 420 to 450 mm were recorded in the year 2022, particularly approximately to the quarry. The levels in neighboring areas like El Feldjoudj and Guelma Cities are comparable.

3.0 RESULTS AND DISCUSSION

3.1 Soil Mineral Compositions

According to the Heliopolis quarry soil analysis with the SEM technique, the following results can be concluded:

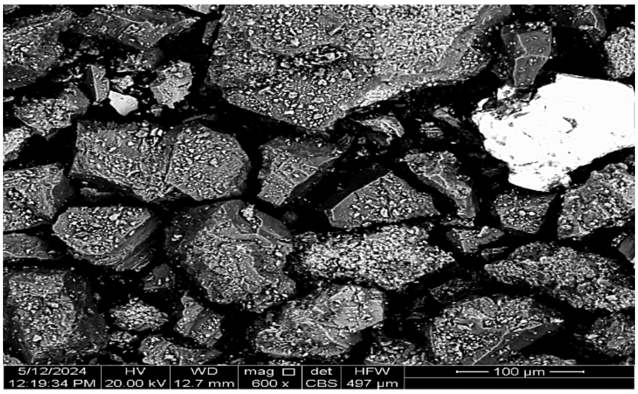

Figure 2: Image of the Heliopolis soil by SEM magnified to *600 times

Based on the Figures (2 and 3), it is evident that the quarry soil is characterized by cubic white shapes that are covered in white dust, exhibiting a variety of sizes (40µm, 50 µm, 55 µm, 100µm…).

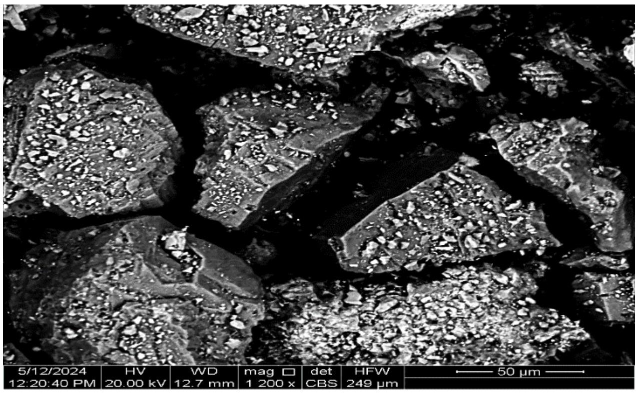

Figure 3: Imagerie of the Heliopolis quarry soil magnified to *1200 times by SEM

The graph illustrated in Figure 4 shows the mass percentages, atomic percentages, and total density of the most abundant elements in the Heliopolis soil sample BY SEM-EDX.

For instance, it can be noted that calcium (Ca) has a mass percentage and total density significantly higher

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than that of other elements, exceeding 300. It is followed by oxygen (O), with values approaching 200, while other elements such as carbon (C), magnesium (Mg), silicon (Si), and aluminum (Al) exhibit much lower percentages and densities.

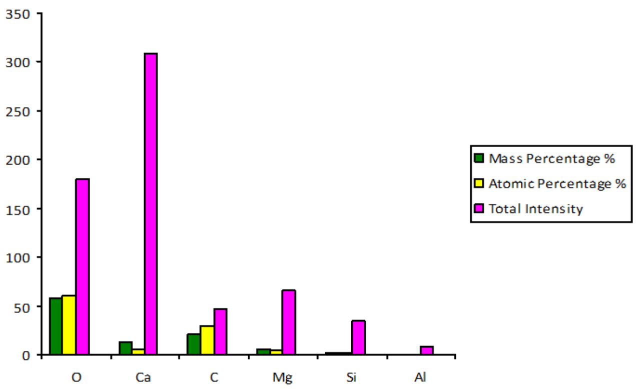

Figure 4: Mass percentages, atomic percentages, and total intensities of the elements present in the Heliopolis quarry soil

The graph in Figure 4 and the spectroscopy in Figure 5 highlight the dominance of calcium and oxygen in the sample's composition. This is probably due to the compositional nature of the rocks at the Heliopolis quarry site, in addition to the effects of mineral dust emitted from various exploitation activities.

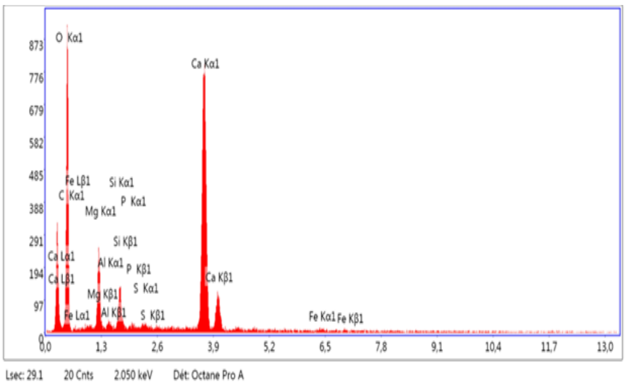

Figure 5: Results of SEM-EDX analysis on soil samples from Heliopolis Quarry

The physicochemical analysis of the Heliopolis soil samples indicates that the pH value has reached 9.5, by AFNOR X 31-103 standards according to the folowing Table 1 [3].

Table 1: Physicochemical analysis results of soil samples [3]

Parameters	Values	Method norms
pH at 25°C	9.51	AFNOR : X 31--103

According to the spectroscopy of the rehabilitated site at Oued El Aneb quarry, as illustrated in the Figure 6, it can be observed that the element with the highest intensity is oxygen (O), followed by silicon (Si) and iron (Fe), along with magnesium (Mg). Additionally, traces of titanium and potassium are present.

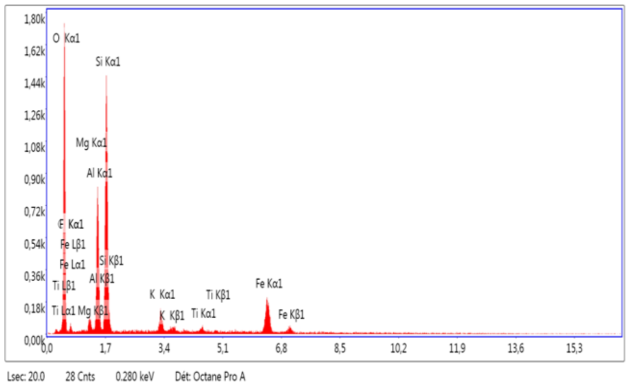

Figure 6: SEM-EDX analysis results of the rehabilitated quarry sample in Oued El Aneb, Annaba, Algeria

The spectrum analysis indicates a wide range of elements, suggesting a rich and diverse sample composition. Figure 7 depicts a scanning electron microscope (SEM) micrograph of a soil sample surface from the Oued El Aneb rehabilitated quarry.

The surface texture can be observed, which appears diverse, and includes a range of textures. The picture shows the presence of a mixture of materials. As for the shape, there are different shapes and sizes of various particles. the scale bar indicates a 50 µm size reference, which is very accurate as it provides context to the size of the observed features.

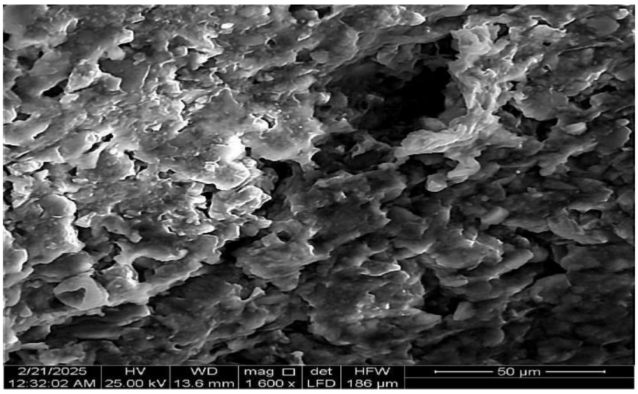

Figure 7: Image of the soil from the restored quarry in Oued El Aneb, captured at 1600x magnification using scanning electron microscopy (SEM)

3.2 Topographical Analysis of the Study Zone

The map in Figure 8 displays multiple colors, each representing a specific elevation. The blue color indicates low altitudes, reaching a maximum of 34 meters. The yellow color represents medium elevations, while the red signifies high elevations that exceed 1,396 meters. Such maps are very effective in visualizing the topography. Guelma State is diverse, as it includes mountains, flats, and low-lying regions, where the study area Heliopolis is located, as shown in Figure 9.

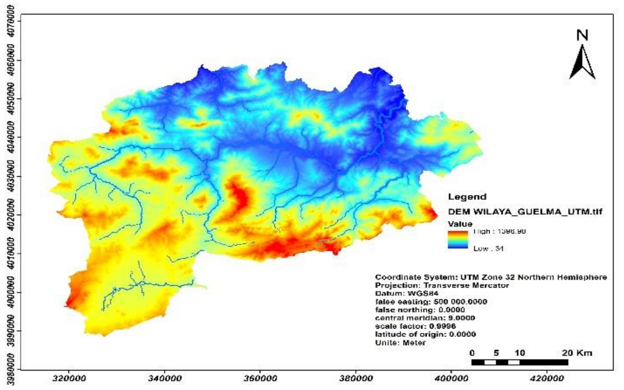

Figure 8: DEM - Digital Elevation Model of Guelma, Algeria

As for the blue lines in Figure 8, they refer to the water courses like valleys and the rivers as it is known that Guelma has many natural thermal spas like Hammam ouled Ali, Hammam El Baraka, Hammam Dbagh , and Hammam Maskhoutin [17].

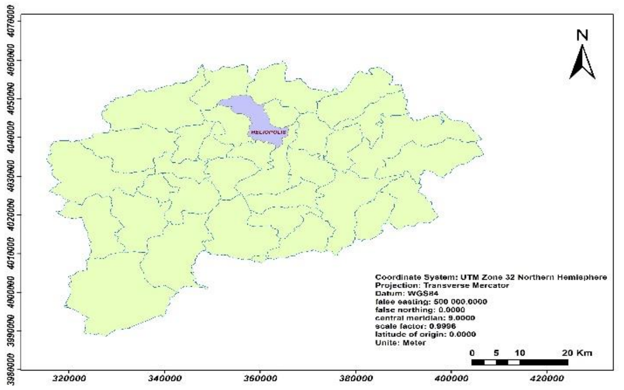

Figure 9: Geographical location of Heliopolis

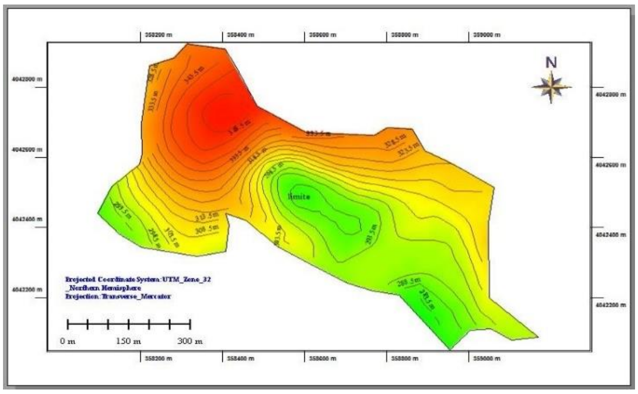

Figure 10: Ground elevation map of Heliopolis gravel quarry

Figure 10 represents the different ground elevations of the Heliopolis quarry by contour lines. This map uses different colors to represent elevations: green indicates lower elevations (288 meters, 293.5 meters, etc.), while red represents higher elevations, exceeding 300 meters (reaching 335.5 meters) at the quarry floor level. This clearly illustrates the significant changes that have occurred. Intensive drilling and the overexploitation of natural resources have degraded both the soil and subsoil, particularly in the northern section of the exploited area, where extraction processes are still ongoing today.

The analysis of the topographic data from the Heliopolis quarry heights indicates the challenges associated with site rehabilitation. The soil has deteriorated due to extensive excavation activities, resulting in a deficiency of essential nutrients necessary for plant growth, as evidenced by SEM analyses. Consequently, it is imperative to replenish the soil with the required elements to restore the vegetation cover. In addition to the physical stabilization of slopes to prevent landslides during rehabilitation, this represents one of the technical challenges we will encounter [18].

3.3 Metrological conditions of the study zone

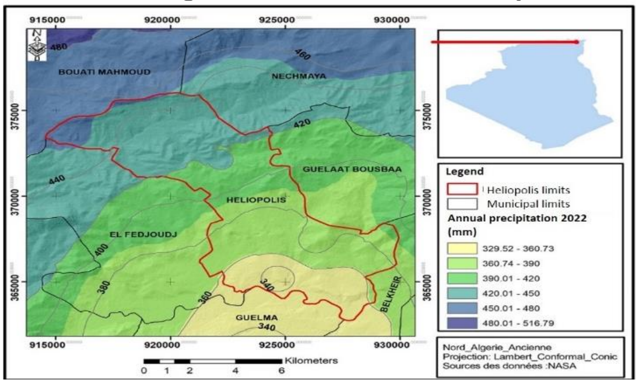

Figure 11: Annual precipitation of the Heliopolis region in 2022

The map presented in Figure 11 depicts the precipitation levels in the city of Heliopolis and its surrounding areas throughout the year 2022. Upon analysis, it is noted that the area encompassing the aggregate quarry is characterized by precipitation levels ranging from 420 to 450 mm, as indicated by the light green coloration on the map.

The graph shown in Figure 12 is official data on precipitation in Guelma from 1996 to 2024 [20], through the graph analysis (a) providing monthly collections of the study area in Guelma from 1996 to 2024. Blue columns represent total collections per year per millimeter while pink points indicate maximum collections per day.

We note that 2009 saw particularly high rainfall, reaching 140 mm. We also note a significant decrease in rainfall from 2010 to the current year 2024, which has not exceeded 70 mm as a maximum in 2017. Graph (b) represents rainfall that occurs in Guelma region during September each year during the period from 1996 to 2022. The blue dots represent days when rainfall is equal to or greater than 1 mm, while the green dots indicate days with rainfall of 5 mm or more, and the orange dots signify days with rainfall of 10 mm or more. Therefore, these data prove the conclusion that the rainfall rate in this region has witnessed a decline recently. Therefore, these data confirm our conclusion that the recent decrease in rainfall due to global climate change necessitates an inquiry into the proposed plant varieties for restoration.

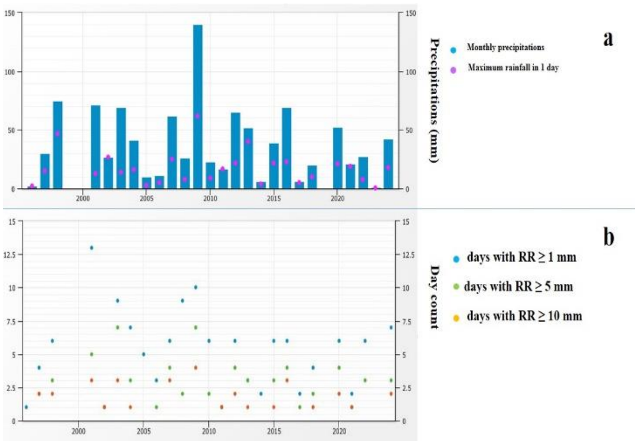

Figure 12: Precipitation in Guelma from 1996 to 2024, modified [20].

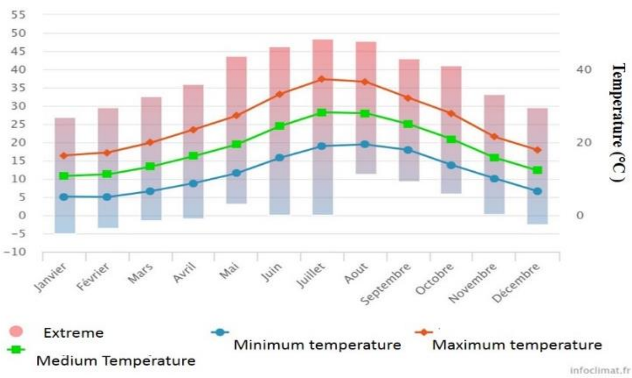

Figure 13: Temperature in Guelma Region 2010-2024, modified [20]

With regard to the temperatures of the study area, the curves shown in Figure 13 illustrate the changes in temperatures in the study area in Guelma for each month from 2010 to the current year 2024. temperatures are peaking in July and August, exceeding 40 degrees Celsius, while the winter period is seeing temperatures drop to around 5 degrees Celsius in January.

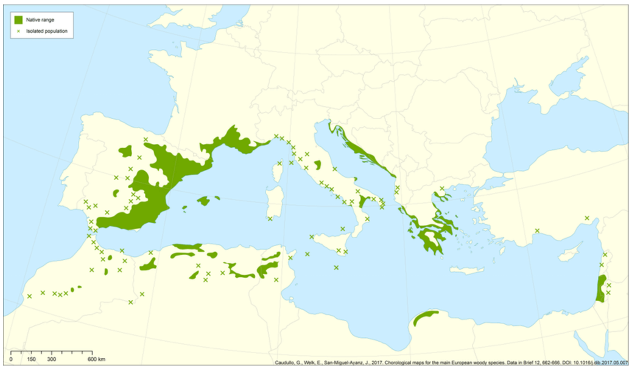

Figure 14: Natural Distribution Area of Aleppo Pines in North Africa and Some European Countries [22]

3.4 Selection of Plant Species for Ecological Restoration Initiatives at the Gravel Quarry Site in Heliopolis-Guelma

The environmental conditions that characterize the Guelma and Heliopolis region in particular enabled us to build the following considerations to identify the plant species that coexist according to these conditions:

A. Desiccation tolerance:

The region's low rainfall necessitates the selection of drought-resistant species that can thrive in arid conditions. The capacity of plants to withstand moderate drought is indicative of their ability to maintain protein integrity, while also safeguarding the health of roots, leaves, and membranes by inhibiting oxidation, thereby contributing to their overall vitality [21].

B. Temperature elasticity:

Given the climatic conditions and temperature ranges characteristic of the study area, we will identify species that can withstand high summer temperatures often exceeding 40°C, as well as those capable of surviving cold winter temperatures that may drop to 5°C or lower.

C. Soil conditions:

It is essential to consider the soil conditions of the site. As previously explained, analysis by scanning electron microscopy (SEM) confirms that the soil is primarily composed of calcium oxide, which indicates the presence of calcite. Notably, the pH of the soil exceeds 9.5, indicating alkaline conditions.

D. Native species:

The pine tree is among the best species adapted to endure harsh winter cold and summer heat.

Additionally, they exhibit resilience to water scarcity, particularly in our study region as noticed in Figure 14, which is home to approximately 5,715.50 hectares of Aleppo pine, and 1,638.00 hectares of other pine species [7].

Figure 15: Aleppo pine in Algeria [24]

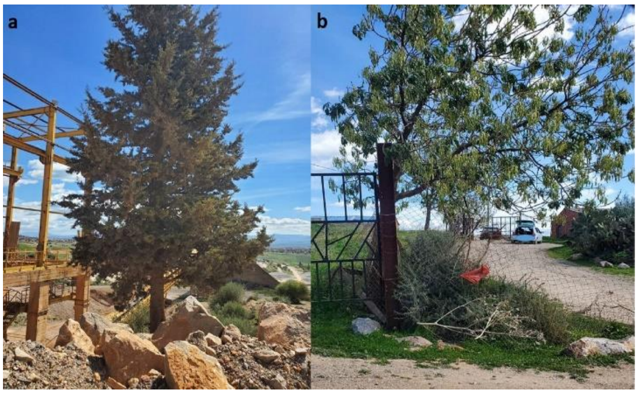

Figure 16: Pine and olive trees in Heliopolis quarry

Due to their many advantages, Aleppo pine trees are the most suitable choice for our project idea. First, they provide a large quantity of seeds because they are a local variety that is exceptionally adapted to the region's climatic conditions as seen in Figure 15. This explains their wide distribution in the northeast of Algeria, where they contribute to soil stability and cohesion [23]. Moreover, the pine tree has been recognized for its resilience to challenging environmental conditions, as evidenced by its presence in the center of the quarry and adjacent to the crushing station, as illustrated in Figure 16a. Additionally, it has been observed that the pine tree demonstrates greater resistance to pollution compared to the olive tree as shown in Figure 16b, which has been significantly affected by the repercussions of exploitation, such as metallic dust. This exposure has led to reduced growth, loss of leaves, and deterioration of root health in the olive tree.

4.0 CONCLUSION

The failure to implement rehabilitation or restoration methods for abandoned mining sites presents significant risks and tangible threats to security, public health, and the environment. For instance, in 2014, the abandoned coal mine in Morwell ignited and burned for over a month due to the site's neglect [25]. Conversely, in Ghana, the individuals overseeing the gold mining project have identified a designated location for the disposal of waste generated during gold extraction operations, as these materials are considered uneconomical. Nonetheless, they hold potential for repurposing in environmentally beneficial applications [19].

This original research paper aims to investigate the proposed bioremediation methods for the Heliopolis quarry site, which is characterized by significant spatial disturbances and substantial modifications to both surface and subsurface structures, as illustrated in the provided elevation maps. A primary benefit of our proposed project for these utilized sites is the reduction of soil contamination from heavy metals. By enriching the soil with essential nutrients and cultivating a diverse range of plant and tree species, including pine, we seek to achieve environmental revitalization, thereby mitigating pollution and supporting soil stability [26].

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