ABSTRACT

This work studies the characteristics of pyroclastic (materials) and evaluates the environmental impacts due to the opening of a pyroclastic quarry in the Tombel graben area saturated lime test, specific surface determination, mechanical resistivity index within long and short terms have been used to characterize pozzolan materials in the study area and it’s important to the cement industry while environmental impact was determined through soil permeability test and nuisance noise. From the results obtained, samples had very large specific surfaces (>3500 Cm²/g) and highly reactive with lime. The samples studied are in conformity with standard mechanical resistivity index SAR. For cement manufacture. The environmental impacts define an "absolute average" impacts relating to the opening of the quarry. Hence a particular attention is needed in this area of study and mitigation measures have been proposed.

Keywords: Cameroon Volcanic Line, Environmental impact, Mechanical resistivity index, Mitigation measures, Pozzolan, Tombel Graben.

I. INTRODUCTION

The concept of Mineral development (MD) is nowadays emphasized in developing countries especially in African, Caribbean and Pacific (ACP) countries. Defined by [1] as minerals and materials extracted, processed, manufactured, and used locally by construction, manufacturing or agricultural industries, the concept of MD guides and defines a notorious importance for materials that have been considered as Ganges. These minerals represent in developing countries an effective response to local development, governed by small scale labor-intensive artisanal mining activities, as well as medium-scale mechanized quarries. Thus, contributing to the economies of these countries [2].

Cameroon, a developing country is in recent years defined by its strong mining potential [3]. The abundance of raw materials is driving a local development dynamic framed by the search for new materials (developing minerals) that would ensure an increase in the economy [4]. Most of these materials come from the Cameroon Volcanic Line (CVL) and are distinguished by their various applications. This justifies the intensification of the opening of quarries, both industrial and artisanal. Among them, the Pyroclastic Products (PP) or pozzolan, defined by their ability to react with lime is of even greater interest because of their ability to effectively reduce the environmental footprint during its implementation for cement design, and its abundance in certain regions is driving a development dynamic in which many contracts and exploitation titles have been awarded in recent years, particularly in the Tombel graben. Moreover, their exploitation is not without consequences on the biophysical and human environment. Hence the need to study and
measure the impact related to the opening of a quarry, in order to define not only the economic, societal but also environmental interest. This work studies some pyroclastic cones of the Cameroon Volcanic Line their impacts related to the opening of a quarry.

II. LITERATURE REVIEW AND LOCATION

The CVL is an alignment of volcanic, oceanic, and continental massifs [6]. It is fragmented by a network of faults that underline a succession of horsts and grabens [7]-[10] whose age varies from 51.7 Ma to the present [11], [12]. For [13], it is a volcano-tectonic megaregion with a general orientation of N30°E. This tectonic corridor has variable dimensions according to these authors; 2000 km long [13]; 1600 km long [14]; 1200 km long and 100 km wide [15] extends from the volcanic island of Annobon in the Atlantic Ocean to Lake Chad (Fig.1) where it includes the Tibesti [8], [10], [15]. The continental part consists of eruptive centers that form horsts such as Mount Bambouto, Mount Manengouba, and Mount Cameroon, the only active peak at 4095 m [16]. These horsts or volcanic massifs are separated by collapse plains or grabens dotted with monogenic volcanoes such as the Tombel plains: which is the base of this study. These plains are the result of monogenic strombolian volcanism, which is basaltic in nature and of recent age, resulting being dotted with large quantities of pyroclastic products, [17]. Better known as pozzolans, pyroclastic materials nowadays attract much attention [18], especially because of their genetic properties [19]. Their use in ancient Rome [20], whose remains are still present today, testifies to their effectiveness. In recent years, many researches have been particularly interested in this material, which not only shows durability properties [21], but also develops a positive interaction with the environment [22]. The GT represents an important receptor of pyroclastic materials whose importance remains to be proven. [23] Defines for these materials an important pozzolanic activity, supported by the work of [24], which highlight the potential of these lavas for the cement industry. These last works coupled with the edifying works on their use as soil amendment [25] support the importance of the study of these materials.

For the construction industry, the challenges have always been to meet the demands of society while keeping the cost low and limiting the destruction of the natural ecosystem. Many studies have recommended the replacement of clinker and mixed concrete with pozzolan [27]-[31]. Pozzolan contributes to the improvement of the ecological properties of cement by substituting the clinker responsible for CO₂ emissions [32]-[35], while maintaining or improving the mechanical properties of cement [36]. Chemically, it improves sulfate resistance and workability [29], reduces shrinkage, creep and decreases permeability [37]. However, not all pyroclastic materials have the characteristics necessary for this interest from the cement industry, pozzolanic activity is thought to be related to magma chemism [18]. Therefore, it is important to evaluate the degree of pozzolanicity of each pyroclastic deposit for their exploitation for construction purposes. Cameroon, endowed with the famous CVL, hosts several volcanoes that produce lava and pyroclastic materials [26], [38]-[42]. The exploitation of which remains slow due to the lack of knowledge of their physical, chemical, and mechanical properties. With Goals 7 of the Millennium Development (UN), this exploitation will have to involve the notion of sustainable development which, according to [43], must integrate profit, people, and the planet. In other words, an operation that respects social equity while thinking about the environment and the legacy to be left for the future generations.

III. SAMPLING AND ANALYSIS TECHNIQUES

A. Sampling Techniques

6 representative samples (one of which was taken from a cone currently being mined NTD04) of volcanic ash and lapilli from six volcanic cones were carefully collected for this study (Table I). The selection of cones was guided by their volumetric importance. The sampling was done in bulk according to [44]. Two to four samples were taken from each cone, depending on the accessibility of the material. The samples were then subjected to a quartering exercise to ensure a representative sample of material from each cone. They were oven dried for 24 hours at 90 °C and brought to a fine particle size of 100 µ and then characterized.

Pure cement used in this work is produced by Cimencam, a subsidiary of the Lafarge group based in Cameroon. It is an ordinary Portland cement (CEM I 52.5R) conforming to the
European standard [45]. It is characterized by a Blaine fineness of 4400 cm²/g and an absolute density of 3.14 g/cm³.

For the manufacture of the specimens, standard Leucate silica sand (0-2 mm) was used, in accordance with [45]and [46]. This sand is non-reactive to the alkali-reaction phenomenon according to standard NF-P 18-590.

B. Analytical Techniques

To achieve these objectives is by characterizing the physico-chemical properties of the pyroclastic materials and evaluating the environmental possibility of opening a quarry within the Tombel graben and the impact related to it. These include physical parameters (specific surface area; measurement of the pozzolanic activity index SAI); a chemical parameter (lime reactivity test and pozzolanicity); identification of potential impacts and determination of soil permeability.

TABLE I: LOCATION OF THE SAMPLES STUDIED

| Cone 1 | Cone 2 | Cone 3 | Cone 4 | Cone 5 | Cone 6 |
|--------|--------|--------|--------|--------|--------|
| Location | Location | Location | Location | Location | Location |
| Name | Name | Name | Name | Name | Name |
| NTD04 | NTD05 | NTD06 | NTD07 | NTD08 | NTD09 |

1) Physical parameters

a-) Determination of the specific surface area (SSA)

This analysis was carried out in accordance with the requirements of European standard [48]. It consists of measuring, the Blaine permeability meter, and the time of passage of a given volume of air through a sample. By calculating the time of passage of a gas under pressure through a given volume of aggregate, we deduce the specific surface of the aggregate. Once the specific weight has been measured, the samples are alternately introduced into the compacting piston and the fine oil contained in the graduated manometer tube rises to the first gauge line with the help of the suction bulb. The time taken by the fine oil to go down to the second line is recorded. This analysis was performed at LaboGenie in Yaoundé (Cameroon).

2) Pozzolanic activity resistance test

This test takes into consideration the compressive strength of 50 mm thick specimens made with 80% portland cement + 20% of the studied materials with the compressive strength of specimens made with artificial Portland cement only (considered as a control). For this purpose, normal mortars were shaped, and the strength ratio after 28 days were measured. The formulas developed in our work were compared to the control solution made under the same conditions as for the different samples.

\[
\text{Ca}^2+ + 2\text{OH}^- + 2\text{H}_3\text{O}^+ + \text{Cl}^- \rightarrow (\text{Ca}^2+ + 2\text{Cl}^-) + 4\text{H}_2\text{O}
\]

The method combines the requirements of the “Chapelle test” and [49]. 20.00 g of pozzolan is introduced into 100±1 ml of saturated lime solution. The whole is kept at 90±1 °C statically for 16 hours in hermetically sealed plastic boxes. A control solution, containing only the saturated lime solution (100 ml), is subjected to the same conditions. At the end of this period, the filtrate is stored in a hermetically sealed box and the concentration of hydroxyl ions is determined using a 0.1 mol/l hydrochloric acid solution (H⁺, Cl⁻). The hydroxyl ion reduction of the solution is deduced by comparison with the result given by the control solution. The final result is the average of three determinations.

C. Environmental Impacts

1) Identification of potential impacts related to the opening of a quarry

The identification of impacts and their sources was done through observations and consultations with the population. It is based on the Leopold matrix method for which seven parameters were used to define these impacts (Table II).

TABLE II: QUALIFICATION AND SYMBOLOGY OF ENVIRONMENTAL IMPACT CHARACTERIZATION PARAMETERS.

| Parameters | Qualification and symbolism |
|------------|-----------------------------|
| 1 | Nature of the impact Intensity | Positive (+) Negative (-) |
| 2 | Extent or scope | Strong (F) Regional (Cameroon) |
| 3 | Interaction | Direct (D) Indirect (I) |
| 4 | Occurrence | Certain (Cameroon) Probable (P) |
| 5 | Duration | Long Term (Lt) Medium term (Mt) Irreversible (Ir) Short term (ST) |
| 6 | Reversibility | Reversible (Re) Low (f) |

2) Treatment of environmental data

The purpose of the impact assessment is to assign a relative or absolute importance to the impacts in order to determine the order of priority according to which they must be avoided, mitigated or compensated.
The absolute importance is determined using Martin Fecteau's grid, which takes into account only three characterization criteria. These are: Intensity, Duration and Extent. Depending on the combination key of these three criteria, the absolute importance can be major, medium, or minor (Table III).

The significance of the impact is determined by the overlay of the above indicators and allows each project impact to be assessed using a grid.

The following three levels have been defined:

a. Major significance (Ma);

b. Medium significance (Mo);

c. Minor importance (Mi).

| Intensity | Scope | Duration | Absolute importance |
|-----------|-------|----------|---------------------|
| High      | Regional | Long     | Major               |
|           |         | Medium   | Major               |
|           |         | Short    | Major               |
| Local     | Long    | Medium   | Medium              |
|           |         | Short    | Average             |
|           |         | Long     | Major               |
|           |         | Medium   | Average             |
|           |         | Short    | Minor               |
| Medium    | Punctual | Long     | Major               |
|           |         | Medium   | Average             |
|           |         | Short    | Average             |
| Regional  | Long    | Medium   | Average             |
|           |         | Short    | Average             |
|           |         | Long     | Average             |
|           |         | Medium   | Average             |
|           |         | Short    | Minor               |
| Low       | Long    | Medium   | Major               |
|           |         | Short    | Average             |
| Punctual  | Long    | Medium   | Medium              |
|           |         | Short    | Minor               |
|           |         | Long     | Minor               |
|           |         | Medium   | Minor               |
|           |         | Short    | Minor               |

Of all the impacts identified, only those specific impacts for which there is public concern will be developed. The general measures will also be clarified so that they are better adapted to the specificities of the PP quarry project.

**D. Determination of Soil Permeability**

Permeability of the ground was determined at a depth ranging between 50 and 60 cm by the Porchet method. This method consists of following the infiltration of a quantity of water poured into a hole dug with a manual auger. The hole is filled with water and the speed of infiltration in the hole is measured by reading the water level over time. The method is simple and fast. It is imperative to start monitoring water levels after a certain period of time (usually about 20 mm) so that the area around the hole can be considered saturated. This requires several fills of the hole with water.

The permeability \( K \) is obtained by plotting the log \((H+ R/2)\) versus time curve on a semi-logarithmic scale. Once the regime is stabilized, we obtain a straight line with slope:

\[
P = 2 \frac{K}{(2.3R)}
\]

The hydraulic conductivity is given by the relationship:

\[
K = P \left(\frac{2}{2.3R}\right)
\]

\( K \): permeability (m/s)
\( R \): radius of the hole (m)
\( P \): slope of the line representing the infiltration test.

**IV. RESULTS**

A. **Pozzolanic Activity**

The results presented here allow to define the importance of the studied materials in the cement industry.

1) **Specific surface area (SSA)**

The values of the specific surfaces of the 06 samples studied in this work vary from 4084 cm\(^2\)/g to 6155 cm\(^2\)/g (Table IV), with an average value of 5119.5 cm\(^2\)/g. These results show that the tested materials have SSA higher than those imposed by the standard (3500 cm\(^2\)/g for the Cameroonian standard), however, compared to the control sample, they have lower SSA.

| Samples   | SSA  |
|-----------|------|
| NTD04     | 4210 |
| NTD05     | 6155 |
| NTD06     | 4084 |
| NTD07     | 4088 |
| NTD08     | 4105 |
| NTD09     | 4122 |

2) **SAI strength test**

The values of the mechanical measurements carried out on materials containing 20% pozzolan partially substituting the artificial cement are presented in Table V. These measurements were carried out at 7 and 28 days. With values ranging from 62.8% to 84.9%. These indices, compared to the SAI of the control sample, show for each site their importance in relation to a possible exploitation. making it possible to classify these materials as usable or not in cement manufacturing. With the exception of NTD09 samples whose SAI value is lower than the one imposed by the standard (67% at 28 days [51]), all the tested samples are suitable for use in the cement industry. However, we note a retrograde evolution with time for samples NTD05, NTD06 and NTD09.

| Samples   | UCS (MPa) | Activity index (%) |
|-----------|-----------|--------------------|
|           | 7 days    | 28 days            | 7 days | 28 days |
| Cement    | 21.4      | 41.1               | 100    | 100 |
| NTD04     | 19.2      | 37.2               | 89.71  | 90.51 |
| NTD05     | 9.47      | 32.75              | 44.25  | 79.68 |
| NTD06     | 12.1      | 34.3               | 56.54  | 83.45 |
| NTD07     | 13.53     | 33.96              | 77.8   | 84.9 |
| NTD08     | 13.02     | 32.60              | 74.82  | 81.5 |
| NTD09     | 8.95      | 25.81              | 41.82  | 62.8 |

3) **Pozzolanicity test**.

Table VI shows the results of the pozzolanicity test according to [49]. It shows the reactivity of the samples to lime. Its variability ranges from one sample to another (73.91% to 98.3%). Compared to the control samples, during operation, the materials show reactivity’s that may be attractive to the cement industry.

**TABLE VI: VALUES OF POZZOLANIC STRENGTH WITH AGE**

| Samples   | UCS (MPa) | Activity index (%) |
|-----------|-----------|--------------------|
|           | 7 days    | 28 days            | 7 days | 28 days |
| Cement    | 21.4      | 41.1               | 100    | 100 |
| NTD04     | 19.2      | 37.2               | 89.71  | 90.51 |
| NTD05     | 9.47      | 32.75              | 44.25  | 79.68 |
| NTD06     | 12.1      | 34.3               | 56.54  | 83.45 |
| NTD07     | 13.53     | 33.96              | 77.8   | 84.9 |
| NTD08     | 13.02     | 32.60              | 74.82  | 81.5 |
| NTD09     | 8.95      | 25.81              | 41.82  | 62.8 |

DOI: http://dx.doi.org/10.24018/ejgeo.2021.2.4.160
TABLE VI: POZZOLANICITY TEST RESULTS

| Samples | Concentration of (OH\(^-\)) (mol/l) | Concentration of Ca(OH\(_2\)) (g/l) | Concentration of CaO absorbed (g/l) | Concentration absorbed (%) |
|---------|-------------------------------------|----------------------------------|----------------------------------|---------------------------|
| Control | 0.0115                              | 0.85215                          | -                                | -                         |
| NTD04   | 0.003                               | 0.2223                           | 0.62985                          | 73.91                     |
| NTD05   | 0.0006                              | 0.0445                           | 0.80765                          | 94.77                     |
| NTD06   | 0.0022                              | 0.1638                           | 0.68835                          | 80.77                     |
| NTD07   | 0.0003                              | 0.02223                          | 0.8299                           | 97.39                     |
| NTD08   | 0.0002                              | 0.01482                          | 0.8373                           | 98.26                     |
| NTD09   | 0.0013                              | 0.0983                           | 0.8376                           | 98.3                      |

B. Environmental Results

1) Identification of impacts

Impacts are identified at each stage of the quarry’s life, from the preparation phase to site closure. Tables VII, VIII and IX present the interaction matrices for each stage of the quarry’s life. The existence of an interaction is indicated by X. The negative potentials and positive impacts can then be defined.

TABLE VII: MATRIX OF POTENTIAL INTERRELATIONSHIPS BETWEEN PROJECT ACTIVITIES AND ENVIRONMENTAL COMPONENTS IN THE PRE-CONSTRUCTION PHASE

| Components of the environment | Biophysical environment | Human environment |
|-------------------------------|-------------------------|-------------------|
| Preliminary studies and obtaining sectoral authorizations | x | x |
| Construction of access roads | x | x |
| Delimitation of the site (layering and demarcation) | x | x |
| Construction of the various workshops and infrastructures (office, hydrocarbon storage areas...) | x | x |
| Development of the garage | x | x |

TABLE VIII: MATRIX OF POTENTIAL INTERRELATIONSHIPS BETWEEN PROJECT ACTIVITIES AND ENVIRONMENTAL COMPONENTS IN THE OPERATIONAL PHASE

| Components of the environment | Biophysical environment | Human environment |
|-------------------------------|-------------------------|-------------------|
| Cutting of the PP | x | x |
| Handling and loading of the PP at the face of size | x | x |
| Cutting or felling of PP | x | x |
| Transport and circulation of vehicles | x | x |
| Waste management | x | x |
| Equipment maintenance | x | x |

TABLE IX: MATRIX OF POTENTIAL INTERRELATIONSHIPS BETWEEN PROJECT ACTIVITIES AND ENVIRONMENTAL COMPONENTS DURING SITE CLOSURE

| Components of the environment | Biophysical environment | Human environment |
|-------------------------------|-------------------------|-------------------|
| Purging of the fronts and safety work | x | x |
| Management of waste from the dismantling of the various workshops | x | x |
| Restoration of the site | x | x |
| End of staff contract | x | x |
| Dismantling and removal of materials and equipment | x | x |
| Reforestation of the site and follow-up of the works | x | x |
2) Assessment of Negative Impacts and Significance

On the basis of the work carried out, 06 major impacts were identified throughout the life cycle of the quarry. The criteria of duration, extent and intensity were used to assess the absolute significance of the impacts.

➢ Impact No. 01: Loss of biodiversity

Causes and Manifestation: The development of the quarry site remains one of the main causes of destruction of the biodiversity like; felling of trees, destruction of fauna habitats, flora, and easy access to poaching

Absolute importance: this impact will extend over the entire length of the project and defines according to the Fecteau grid a medium absolute importance. Although it is certain to occur, it is of medium intensity and local extent,

➢ Impact No. 02: Erosion and soil degradation

Causes and manifestation: This impact is linked to the implementation of quarrying works. It is therefore unavoidable. The exposed soil is exposed to all forms of weathering: soil compaction and sealing are direct consequences.

Absolute significance: The absolute importance of the impact is medium with the effective implementation of adequate mitigation methods the interaction with the project is direct which makes its duration long although it is reversible.

➢ Impact No. 03: Air pollution or degradation

Causes and manifestation: it is linked to the operation of the quarry (circulation of motorized machines, the expansion and loading) and is materialized by the emission of dust and gases notably CO₂, CO and volatile compounds.

Absolute importance: The intensity of this impact depends on many factors (the state of the machines, the speed of their rotation among others), but if they are optimized it is weak, of punctual range and of long duration. It is therefore a reversible impact of medium absolute importance.

➢ Impact No. 04: Noise and vibration

Causes and manifestations: These are the most perceptible nuisances for humans. They result from the operation of the various machines on the site, the falling of blocks, the generator, the rotation of trucks and other vehicles. Directly linked to the quarry activities, they are of a certain occurrence because of a life span proportional to that of the quarry.

Absolute significance: This is a reversible impact whose extent depends on the intensity and the presence or absence of obstacles. The intensity of this impact will depend on the distance at which the target is located, the types of machinery present on the site, the height of fall of boulders, the presence or absence of screen between the source and the target. Thus, measurements were taken on the two control quarries and the results are presented (Table X).

These results show higher noise levels around the Njombé quarry, which is justified by the presence of several machines (more than 10) on the site, associated with other activities in the vicinity (dense road traffic). The impact being cumulative, this causes an increase in the noise level. On the other hand, on the Dangoté site, the measured levels are relatively low because not only is the site isolated, but also the number of machines used is low (4) thus reducing the noise sources. It should be noted that the noise levels measured outside the quarries are all below 70dB recommended during the day by most health organizations and also the Cameroonian law on noise emission. Therefore, the intensity of this impact is low outside the quarry. The different results obtained on this impact allow us to give it a medium absolute importance according to the Fecteau grid.

TABLE X. MEASUREMENTS OF NOISE LEVELS AROUND PP QUARRIES

| Measuring point | Distance to the source (m) | Type of protection | Noise level (dB(A)) |
|-----------------|---------------------------|--------------------|--------------------|
| 1A              | Less than 30 m            | None               | 76                 |
| 2A              | 100 m                     | Vegetation screen of at least 30 m | 63 |
| 3A              | 200 m                     | Plant screen of at least 30 m | 59 |
| 4A              | 350 m                     | Vegetation screen of at least 30 m | 57 |
| 1B              | 200 m                     | Vegetation screen of at least 30 m | 51 |
| 2B              | 350 m                     | Vegetation screen of at least 30 m | 49 |

A= quarry of SEPT enterprise (Njombe) B= quarry of Dangoté (Loum).

➢ Impact No. 05: Risk of soil, groundwater and/or surface water pollution

Causes and manifestations: This impact is related to the discharge of hydrocarbons used by heavy machinery, the discharge of various types of waste produced (dust deposits, wastewater, used oils, hydrocarbon spills or leaks).

Absolute importance: This impact has a probable and not certain occurrence. Its interaction is direct with the quarry activities and can occur throughout its life. However, the extent and intensity depend on many factors, including the quantity and quality of hydrocarbons spilled, soil permeability, soil type, and groundwater vulnerability. In the framework of this work, the permeability’s of the soils of the sites potentially hosting the facilities were determined by the Porchet method. The results obtained are as follows:

Using the formula \( K = \frac{P}{2.3R/2} \), we obtain \( K_1=2.691\times10^4 \text{ m/s} \) for the Loum cone and \( K_2=2.553\times10^4 \text{ m/s} \) for the Yeptché cone. These permeabilities being of the order of \( 10^4 \text{ m/s} \), these soils are both classified as permeable formations with a degree of permeability judged as "good". In fact, these soils will absorb hydrocarbons quickly in the event of a spill, resulting in their pollution and that of the water table. In view of these results and the precautions generally taken around the installations housing the oil depots, this impact is judged to be medium. Consequently its absolute importance will be average with the taking of...
preventive measures.

V. DISCUSSION

A. Use of PP in Cement Works

The hardening of cement is the result of a series of chemical reactions that take place on the surface of the different cement grains, so the larger the surface area, the more reactive the material [52]. According to them, the specific surface would be a key parameter in the definition of pozzolanic activity. However, the observation of the results of the pozzolanic test seems to highlight another parameter. For [53] the presence of amorphous silica is the key element of the reactivity, supported by [23] who’s, work which is used as a control in this study, emphasizes on a better activity for specific surfaces at 4000-4800, which is very close to the prediction made by [52]. It would seem that there is a specific surface for which we obtain the best reactivity to lime. Note also that large amounts of lime can be fixed by the pozzolanic material, but the binding properties of the reaction products are low [54]. Mechanical performance would not be a consequence of lime fixation. For the American standard on cements [51], the absorption capacities of a material do not make it a material with pozzolanic properties. According to it, this material must first contain an amount of SiO₂ + Al₂O₃ + MgO > 70% and must be able to develop in the short and long term (7 and 28 days, respectively) an activity index greater than 67%. This indication confirms the hypothesis of [54]. However, although the tested samples do not present a significant amount of alumina silicate, in comparison with the control samples, it is possible to define the importance of the latter in the cement industry. In fact, these samples have strengths which when, compared to Cameroonian standards, ASTM and control samples, makes them resources to be valued for the manufacture of ecological cements.

B. Environmental Impacts and Mitigation Measures

As the environmental impacts are linked to the different activities of the quarry, mitigating will consist of optimizing the activities that cause or generate nuisances. This approach is chosen because the causes can be easily controlled, unlike the consequences. Thus, mitigation measures for each component are proposed.

Loss of biodiversity: this measures takes into account the vulnerable species of the site in order to proceed to a targeted felling and later on reforestation for the restoration phase - Erosion and soil degradation.

In order to minimize this impact, it is necessary to:
- dig gutters and pipes to drain the water;
- avoid stripping the ground where it is not necessary;
- designing fixed routes for machinery to reduce compacted areas;
- remobilize soil during reclamation and plant trees.

C. Degradation of Air Quality

The consequences of these impact are multiple and directly affect the biophysical environment. Among them we have: respiratory disturbances, depigmentation of plant cells, acidification of the soil, retention of metals in the surface horizon, penetration and reflection of light, reduced visibility and transport of diseases. These consequences are all equally

Impact N° 06: Decay of the landscape of the project site

Cause and effect: During the different phases, the panoramic view of the project site with regard to the different installations and developments has a degraded aspect compared to its immediate environment. The vegetation is affected and presents a discontinuous silhouette.

Absolute Significance: This is the most visible negative impact even though its consequences are often considered minor. Its interaction with quarry activities is direct, of medium intensity for PP quarries if the operation is completed and there is no abandonment of work, its scope is on the scale of the quarry and long term. It is reversible and not cumulative. In terms of the Fecteau grid, the absolute significance is medium.

![Fig. 3. Graph showing the behavior of soil permeability near the Yeptché cone.](image)

### TABLE XI: SUMMARY TABLE OF IMPACT ASSESSMENT AND ABSOLUTE SIGNIFICANCE

| Negative impacts                                | Occurrence | Reversibility | Interaction | Duration | Extent | Intensity | Absolute importance |
|-------------------------------------------------|------------|---------------|-------------|----------|--------|-----------|---------------------|
| Loss of biodiversity                            | C          | Re            | D           | Lt       | Lo     | Mo        | Mo                  |
| Erosion and soil degradation                    | C          | Re            | D           | Lt       | P      | Mo        | Mo                  |
| Air quality degradation                         | C          | Re            | D           | Lt       | P      | Fa        | Mo                  |
| Noise and vibration                             | C          | Re            | D           | Lt       | P      | Mo        | Mo                  |
| Risk of soil, groundwater or surface water pollution | I          | Re            | D           | Lt       | Lo     | Mo        | Mo                  |
| Decay of the landscape of the site              | C          | Re            | D           | Lt       | P      | Mo        | Mo                  |

DOI: http://dx.doi.org/10.24018/ejgeo.2021.2.4.160
serious, hence the need to take adequate measures. Thus, we propose:

- to maintain and renew the machines in a regular way. The works of [55], show that the emissions of pollutant is closely related to the state of the machines thus the more a machine is old and dilapidated the more it rejects pollutants;
- extract the PP in stages, this would reduce dust emissions due to their fall;
- regularly water the tracks and cover the tracks transporting the PP;
- reduce activities when the wind is too strong.

D. Noise Pollution

Measurements taken in the PP quarries show low noise levels. However, in order to avoid possible noise pollution, it is necessary to:

- erect barriers between the source of impact and the receptor, which would absorb part of the sound waves, because according to [55]'s work the vegetation cover and the merlons absorb the sound waves (10dB for 100m of vegetation cover and the same for a 4m merlon). The construction of these screens should be based on the desired level of sound reduction;
- avoid night work because the sound seems to be amplified at night.

E. Risk of Soil, Groundwater or Surface Water Pollution

The risk linked to the possible spillage of hydrocarbons, will have to be accentuated in the sense of avoiding possible accidents:

- secure the hydrocarbon storage facilities, concrete the areas where hydrocarbons are handled (consumption station, garage);
- recycle used oils and other hydrocarbon waste, or entrust them to companies specialized in the treatment of this type of waste;
- avoid any handling of these products outside the areas indicated and equipped for this purpose.

In case of spillage:

- assess the situation
- stop or contain the spill
- communicate the situation
- recover the spilled material
- dispose of contaminated material

F. Decay of the Project Site Landscape

The implementation of corrective methods makes this impact minor. In fact, after dismantling it would be wise to:

- restoration and rehabilitate the site:
- reclaim stored vegetal soil
- plant trees in deforested areas
- remove large blocks and dead ground.

When all these measures are implemented, the residual impact of all quarry activities will be minor; thus making these quarries sustainable.

VI. CONCLUSION

Pozzolans are of particular interest today due to their positive interactions with the environment. However, their exploitation has a direct impact on the biophysical environment in which it takes place. Thus, this work defines the materials of the GT, their importance in cement factory, and to evaluate the impact of their exploitation (the opening of career) on the environment. The materials were characterized by their properties and the results evaluates the large specific surfaces, which has a considerable impact on the mechanical activity of materials studied, (especially with surfaces close to 4000 cm²/g), resulting in agreement with the pozzolanic reaction. For large specific surfaces the materials define great pozzolanic reactivity. Reactivity which, however depends on the proportions of amorphous phases. These results suggest a direct relationship between the chemistry of the materials (amorphous phases), the specific surface and the long-term strength developed conforming the opinion of [53] that a pozzolanic material must be acidic, have a high proportion of glassy phase and react to the lime test. Compared to the Cameroonian [56] and American [51] standards and control samples, the materials studied are of great interest to the cement industry in its efforts to develop an environmentally friendly cement. Furthermore, the environmental impacts studied reveal that the main sources of impact occur at each stage of the quarry's life; from preparation work to dismantling and operation, machinery working on the site as well as their consumption and maintenance. The evaluation of all the impacts on the biophysical and human environment, gives them a medium absolute importance. This has necessitated the proposal of mitigation measures, and the effective implementation of which will considerably reduce the overall residual impact on the quarry activities. Thus the exploitation of these PP, for use in the cement industry would be part of a sustainable development approach.

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European Journal of Environment and Earth Sciences

DOI: dx.doi.org/10.24018/ejgeo.2021.2.1.460
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