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Impact of Gravel Origin on Concrete Properties: Economic and Environmental Implications

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ABSTRACT

Aggregates represent approximately 80% of the weight of concrete and influence its strength. This study compares the mechanical, economic, and environmental performances of concrete made with crushed gravel and natural uncrushed aggregates sourced from Goma. The results show that concrete made with crushed gravel, with its angular shape and rough texture, provides higher compressive strengths than concrete made with natural uncrushed aggregates, although the difference is small (around 5%). From an economic standpoint, the use of natural gravel results in a 5 to 6% cost reduction per cubic meter of concrete due to the absence of costs related to crushing. In terms of environmental impact, the use of natural uncrushed gravel reduces the energy consumption required for crushing by 15 to 20%, thereby contributing to a reduction in greenhouse gas emissions and the preservation of ecosystems.

Keywords: *Concrete; Aggregates; Compressive strength; Crushed gravel; natural uncrushed aggregates; Production cost*

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I. INTRODUCTION

Concrete is a fundamental material in the construction sector, widely used to construct infrastructures ranging from roads and buildings to hydraulic structures. Its quality and performance are largely dependent on its composition, particularly the selection of aggregates, which represent a significant portion of its mass. Aggregates, whether natural or artificial, have a direct impact on the mechanical properties of concrete, such as its compressive strength, as well as its production cost. In this context, numerous studies have shown that the quality of aggregates significantly affects the durability and performance of concrete, especially for applications requiring high strengths and long service life [1], [2].

In Goma, a city that is both touristy and volcanic, the use of aggregates for concrete production is part of this dynamic. The main types of gravel available are crushed gravel, produced by crushing rocks extracted from quarries, and natural uncrushed aggregates, directly sourced from local lava flows, commonly referred to as "Makokoto." Previous studies, such as those by [3], have shown that crushed gravel generally provides better cohesion with cement, resulting in stronger concrete, particularly in terms of compressive strength. However, despite its quality in concrete production, concerns about the higher cost of crushed gravel make it a less attractive option in contexts with strong budget constraints.

In Goma, where economic resources may be limited, the choice of aggregates is thus not only a matter of technical performance but also cost optimization and environmental considerations. Given this situation, it is crucial to compare concrete made with these two types of gravel to determine their respective impacts on mechanical properties and production costs, and to provide practical recommendations for local engineers and contractors. While research has been conducted on the properties of concrete based on aggregate types in other regions[4] [5] [6], no study specific to Goma has been carried out so far. Therefore, this study aims to fill this gap by evaluating the performance of concrete made with crushed and natural uncrushed aggregates, focusing on three key aspects: compressive strength, production cost, and environmental impact. The expected results of this study will guide material selection for construction projects in Goma, taking into account local specifics and economic and environmental requirements.

Thus, the main objective of this study is to compare the mechanical and economic properties of concrete made with crushed gravel and natural uncrushed aggregates in Goma, using characterization methods adapted to local conditions. The specific objectives include: (1) the characterization of the materials used; (2) the formulation of concrete and the evaluation of its properties in both fresh and hardened states; and (3) the estimation of the production cost for 1m³ of concrete based on each type of gravel studied and the assessment of pollution levels. This analysis will contribute not only to improving the quality of local construction but also to optimizing resources and reducing costs in the construction sector in Goma.

II. MATERIALS AND METHODS

II.1. NATURE AND ORIGIN OF THE MATERIALS

The cement utilised in our studies is a CEM II/A-P 42.5N, characterised by its grey hue with the density of 2.969 g/cm³.

The mixing water utilised is potable water provided by the Water Distribution Authority (REGIDESO). It is sourced directly from the tap and is devoid of pollutants that could compromise the quality of the concrete, including organic or chemical substances. Potable water safeguards the concrete from impurities and ensures adequate hydration of the cement.

Granular material composed of finely divided rock and mineral particles. The sand utilised in this investigation is washed sand sourced from Idjwi land. This sand was chosen for its purity and suitable granulometry for concrete formation. It is essential for the compaction and strength of the concrete.

Sand is sourced from designated locations that ensure the absence of contaminants that may compromise the mechanical qualities of the concrete.

The natural gravel utilized originates from the most recent volcanic eruption in 2021 that impacted the city of Goma.

The crushed gravel utilised is manufactured by CARRIGO Sarl. Designated as 15/25, they undergo processing and crushing to achieve consistent granulometry and enhanced compaction, hence augmenting concrete strength. Figure 1 presents a visual summary of the various aggregates employed.

Figure1.Aggregates Used: (1) Crushed Gravel, (2) Idjwi Sand, and (3) natural uncrushed aggregates

II.2. Experimental Plan

The experimental plan for this study focused on the characterization of both natural uncrushed aggregates and crushed gravel. Based on the results of the characterization, six concrete mixes were formulated. Three of these mixes (B1, B3, and B5) were made with crushed gravel, with cement dosages of 350, 400, and 450 kg/m³, respectively. The remaining three mixes (B2, B4, and B6) were made with natural uncrushed aggregates, with cement dosages of 350, 400, and 450 kg/m³, respectively. These two categories of concrete were then compared in terms of mechanical strength, economic performance, and environmental impact to derive meaningful conclusions and recommendations.

II.3. Characterization of materials

This study involves conducting various laboratory tests to characterise the materials utilised, specifically aggregates and cement, and evaluate their qualities critical for concrete production. Before executing the tests, a meticulous sampling procedure is undertaken to guarantee that the samples accurately represent the components utilised in concrete manufacturing.

Grain Size Analysis: This analysis is conducted to ascertain the distribution of grain sizes within a sample of aggregates, facilitating the evaluation of their appropriateness for concrete composition. The sample is subjected to a series of sieves with progressively smaller mesh sizes, and the mass of each fraction is recorded to create a grain size curve, which offers insights into the compaction and workability of the concrete. The examination was performed following the stipulations of the [7] standard, which delineates the criteria for executing and interpreting the grain size analysis of aggregates.

The Sand Equivalent Test evaluates sand purity by quantifying the presence of tiny particles. The sand sample is stirred with a flocculating solution in a graduated cylinder, and the sand equivalent is determined by the ratio of the visible sand height to the total height in the cylinder.The examination was performed following the[8] standard, which delineates the methodologies for assessing sand equivalent and categorising sand purity.

Absolute Density: This test measures the mass of grains per unit volume, omitting the voids between the grains. The volume alteration following the immersion of the dry aggregate sample in a liquid is assessed to determine the absolute density, which affects the compaction of the aggregates and, subsequently, the concrete formulation. The examination was performed following the stipulations of the [9] standard, which delineates methodologies for ascertaining the absolute density of aggregates.

Absorption Rate: This assessment evaluates aggregates' capacity to hold water within their pores, which is especially significant for porous aggregates. The specimen is submerged in water for 24 hours, and the mass increment is recorded to determine the absorption rate. The examination was performed following the stipulations of the [9] standard, which delineates the procedure for assessing aggregates' absorption rate.

The Los Angeles Test assesses the durability of aggregates against wear and fragmentation by exposing them to impacts and friction within a spinning drum containing steel balls. The quantity of fines generated is assessed to ascertain the Los Angeles coefficient, a metric of the aggregates' durability in concrete. The examination was executed following the stipulations of the [10] standard, which delineates the procedure for assessing the wear resistance of aggregates using the Los Angeles test.

The Abrams Cone Slump Test evaluates the consistency of fresh concrete, which is a crucial determinant of its workability. The concrete is positioned in an Abrams cone, and the slump is assessed post-removal of the cone to evaluate the fluidity of the concrete and its appropriateness for placement. The test was performed following the [11] standard, which specifies the process for measuring the slump of fresh concrete with the Abrams cone.

Compressive Strength: The compressive strength of hardened concrete is assessed by applying axial pressure to cylindrical specimens until failure occurs. The strength is determined by the maximum force the specimen can withstand, and this test facilitates the verification of the concrete's adherence to strength specifications. The examination was performed following the [12] standard, which delineates the criteria and methodologies for assessing the compressive strength of hardened concrete.

The economic assessment of concrete, determined by the cost per cubic meter, entails calculating the price of the necessary materials (cement, aggregates and water) and subsequently estimating the quantity of each material required to produce one cubic meter of concrete according to the selected formulation.

The evaluation of environmental impacts was carried out using the SimaPro 9.5.0 software for a mix of one cubic meter of concrete, according to the mix proportions obtained from Dreux Gorisse's formulation.

III. PRESENTATION AND INTERPRETATION OF RESULTS

III.1. Aggregate Characteristics

Figure 2 presents the particle size distribution of the aggregates used, while Table 1 provides the grading parameters, including the uniformity coefficient (Cu), the curvature coefficient (Cz), and the Fineness Modulus.

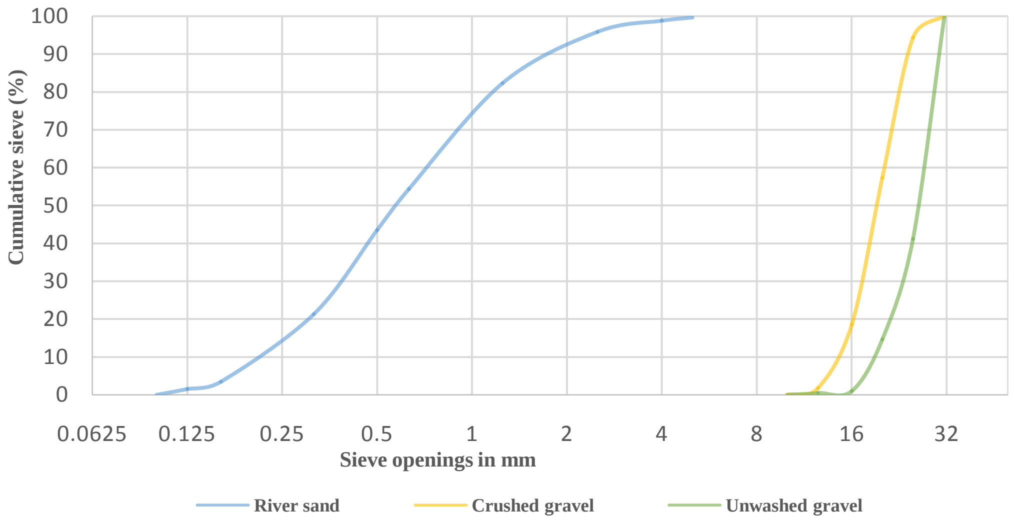

Figure 2. Particle Size Distribution of the Aggregates

Table 1. Granularity Parameters

Designation	Uniformity coefficient (Cu)	Curvature coefficient (Cz)	Fineness modulus	Form Coefficient
River sand	3,5	0,9	2,43	-
Crushedgravel	1,4	1,0	-	0,492
natural uncrushed aggregates	1,5	1,0	-	0,533

The analysis of the different granulometric curves reveals that both all-in gravel and crushed gravel fall within the 15/25 class, while the river sand is classified as 0/4. With form coefficients greater than 0.485 for Dmax> 20mm, it follows that the gravels are cubic in shape. Furthermore, the uniformity coefficient of the gravels is less than 2, indicating a tightly or uniformly graded particle size distribution. In contrast, the uniformity coefficient of the sand exceeds 2, signifying that the sand's granulometry is widely distributed or varied. With a Fineness Modulus of 2.43, the sand is suitable for concrete formulation.

Regarding the curvature coefficient, it is observed that the Cz value for the gravels ranges between 1 and 3, suggesting that the grading is well-graded. For the sand, however, the Cz value is less than 1, indicating that the sand's granulometry is poorly graded.

Table 2 presents the physical properties of the aggregates, including the absolute density, bulk density, absorption coefficient, porosity, and the Los Angeles abrasion coefficient.

Table 2. Physical properties of aggregates

	Absolute Density	Bulk density	Absorption coefficient	Porosity	CLA	ES
	(g/cm3)	(g/cm3)	(%)	(%)	(%)	%
River sand	2,52	1,32	-	-	-	91,2
Crushedgravel	2,69	1,19	2,3	2,74	15	
natural uncrushed aggregates	2,46	1,07	2,52	2,72	18	

Following the [9] standard, which defines the methods for measuring bulk density, porosity, absorption coefficient, and moisture content of aggregates such as gravel and sand, the aggregates used are exclusively standard. Furthermore, with a Los Angeles coefficient ranging from 15 to 25, these gravels are perfectly suited for the production of high-quality concrete. With a sand equivalent of 91.2%, the sand used is clean and suitable for concrete mix formulation.

III.2. Concrete Mix Design

The composition of the different concretes derived from the Dreux Gorisse formulation is presented in Table 3.

Table 3. Constituent dosing of the concretes

	B1	**B2**	**B3**	**B4**	**B5**	**B6**
Sand (Kg)	722,6	744,7	689,4	715,6	656,7	673,9
Gravel (Kg)	1110,9	994,5	1128,0	1006,1	1144,5	1030,0
Cement (Kg)	350,0	350,0	400,0	400,0	450,0	450,0
Water (l)	196,9	196,9	190,7	190,7	186,2	186,2

Concrete B1 and B2 are respectively made of crushed gravel and natural uncrushed aggregates, with a cement dosage of 350 kg. Concrete B3 and B4 are composed respectively of crushed gravel and natural uncrushed aggregates, with a cement dosage of 400 kg. Finally, concrete B5 and B6 are composed respectively of crushed gravel and natural uncrushed aggregates, with a cement dosage of 450 kg.

III.3. Properties of Fresh Concrete

Figure 3 shows the slump in the Abrams cone.

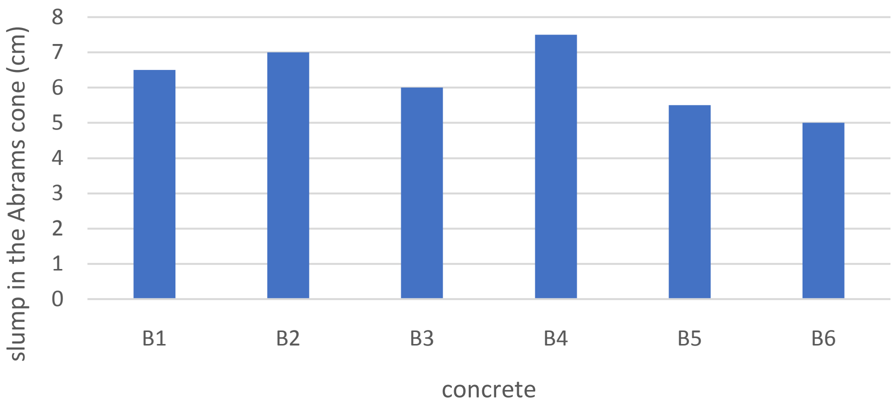

Figure 3. Slump in the Abrams cone (cm)

With regard to this figure, the slump values in the Abrams cone are 6±2 cm, which classifies the concretes as having a plastic consistency. Furthermore, to achieve this consistency, it was necessary to adjust the water content. Thus, an additional water content of 30%, 30%, 55%, 35%, 40%, and 40% of the calculated water content was added, respectively, for concretes B1, B2, B3, B4, B5, and B6.

III.4. Properties of Hardened Concrete

Figure 4 shows the density of hardened concrete obtained from specimens at 28 days of age.

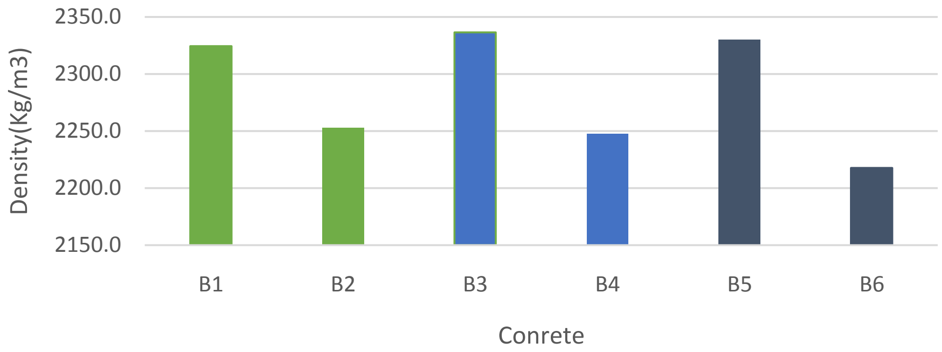

Figure 4. Density of concrete in kg/cm^3

Based on this figure, all the concretes are considered normal concretes with a density ranging from 2200 kg/m³ to 2500 kg/m³, following the NF EN 12390-7 standard.

Figure 5 shows the different compressive strengths obtained from cylindrical specimens at 28 days of age.

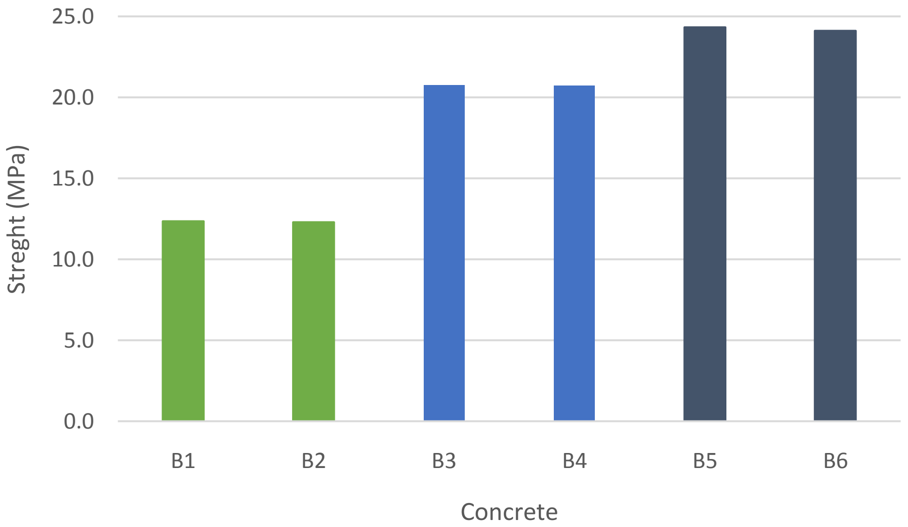

Figure 5. Compressive Strength of Concretes

Analysis of Figure 5 reveals that, although less significant (less than 5%), the compressive strengths of concretes made from natural uncrushed aggregates are lower than those made from crushed aggregates. This less significant difference is primarily attributed to the formulation method used (Dreux Gorisse), which provides different mix designs based on the physical properties of the aggregates. Indeed, with the same mix, the compressive strength depends on the gravel content, as it imparts strength to the concrete. Furthermore, concretes made with crushed aggregates often exhibit higher compressive strengths due to their angular shape and rough texture, which promote better adhesion to the cement. In contrast, natural uncrushed aggregates, which have more rounded shapes and smoother textures, tend to create less resistant mixes. However, the strength difference observed in this study appears to be relatively small.

The obtained compressive strengths are typical of normal concretes (greater than or equal to 20 MPa), except for concretes B1 and B2. Additionally, an increase in strength is observed with higher cement content. From these observed strengths, it is evident that the origin of the gravel influences the mechanical strength of the concrete. These results are consistent with those obtained by [13].

III.5. Economic Impact

Figures 6 and 7 compare the different prices of concrete, respectively, in US dollars. In the evaluation of the cost per cubic meter, the price of the constituents was assessed based on local prices (city of Goma/DRC).

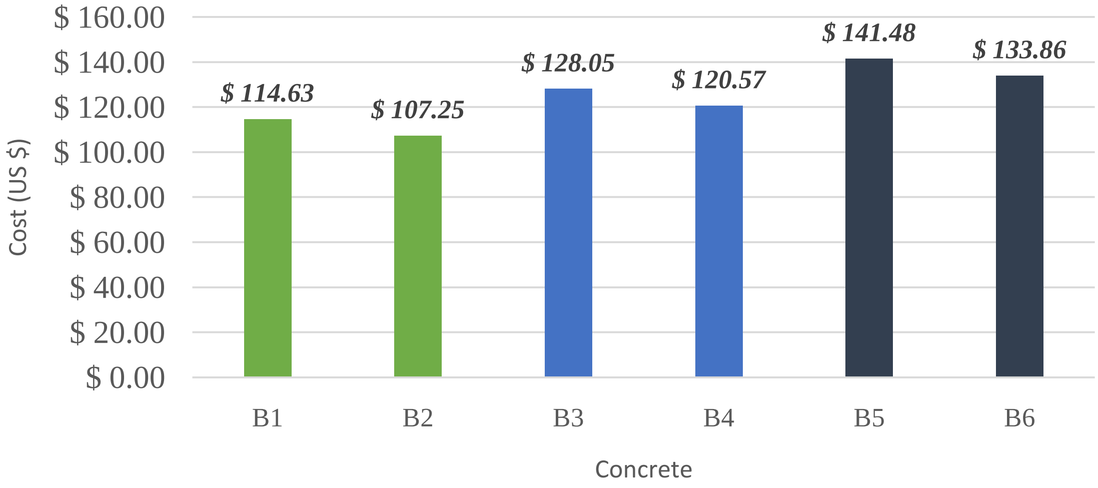

Figure 6. Comparison of the cost of one cubic meter of concrete

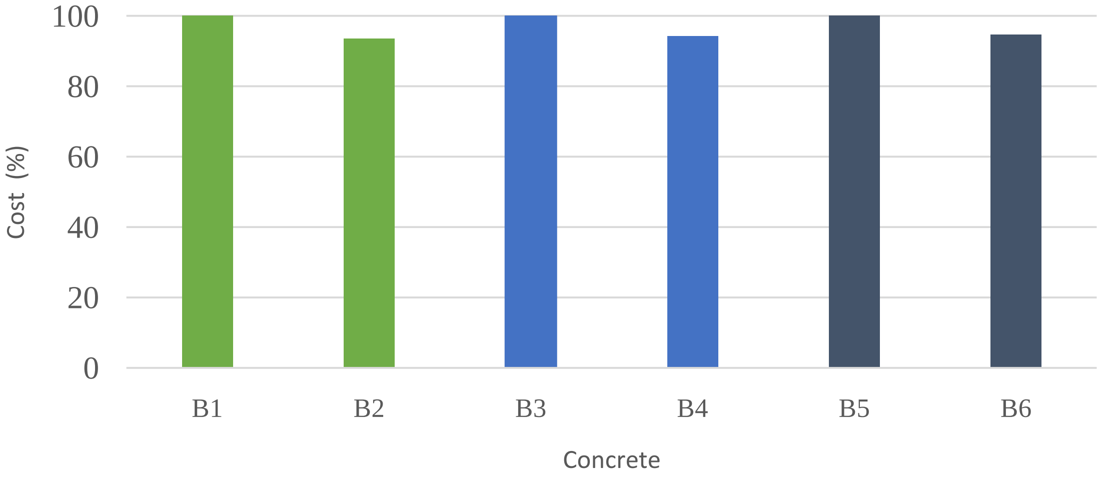

Figure 7. Comparison of the cost of one cubic meter of concrete as a percentage

Taking the concrete made from crushed gravel as a reference, the use of natural uncrushed aggregates presents an economic gain of 5 to 6%. This gain is primarily because natural uncrushed aggregates is used in its natural state, unlike crushed gravel, which requires additional crushing operations before use. Through the observed price differences, it is evident that the origin of the gravel influences the cost per cubic meter of concrete. However, these cost differences remain influenced by geographical factors, particularly the local availability of materials and transportation costs.

III.6. Environmental Impact

Figure 8 presents the results of the life cycle analysis of the concretes studied.

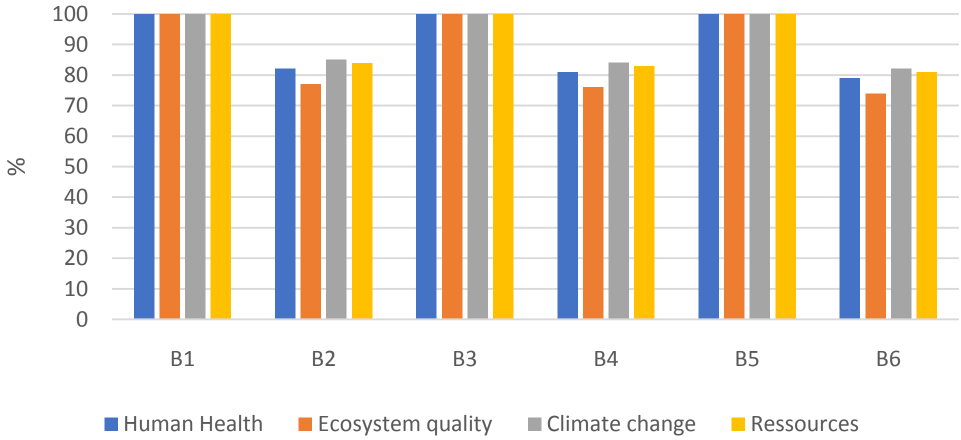

Figure 8. Environmental Impact of the Studied Concretes

The results highlighted in Figure 8 show that natural aggregates contribute to a reduction in the negative impact on ecosystem quality, human health, resources, and climate change. This can be explained by several factors, including their use in their natural state, which eliminates the need for additional crushing energy. Indeed, the use of natural uncrushed aggregates in concrete production helps to reduce energy consumption related to crushing, thereby contributing to a decrease in greenhouse gas emissions and less ecosystem degradation. Therefore, the use of natural uncrushed aggregates promotes the reduction of environmental impacts in concrete production by positively influencing ecosystem quality, human health, resources, and climate change.

The observed results, which show that the use of natural aggregates reduces these impacts, are consistent with those of studies by [14], who emphasized that the use of natural materials in construction promotes a more ecological and sustainable approach.

IV. CONCLUSION

In conclusion, this study has allowed for the comparison of the mechanical, economic, and environmental performances of concrete made from crushed gravel and natural gravel, both sourced from Goma. Aggregates, which represent about 80% of the total weight of concrete, play a crucial role in the material's mechanical strength. Our results showed that, although concrete made with crushed aggregates demonstrates superior compressive strength due to the angular shape and rough texture of the aggregates, this difference remains relatively small (around 5%) compared to concrete made with natural gravel, which has a more rounded shape. Economically, the use of natural gravel resulted in a 5 to 6% cost reduction per cubic meter of concrete, mainly due to the absence of costs associated with additional crushing operations. Furthermore, the environmental impact was also favorable, with a 15 to 20% reduction in energy consumption related to crushing, thus contributing to a decrease in greenhouse gas emissions and a greater preservation of ecosystems.

These results highlight the importance of considering the origin of aggregates when selecting materials for concrete production, especially in local contexts such as that of Goma. They demonstrate that, while concrete made with crushed gravel may offer advantages in terms of strength, natural gravel represents a more economical and environmentally friendly alternative. However, this choice will depend on local conditions, including the availability of materials and transportation costs.

Finally, this study paves the way for future research focused on optimizing concrete formulations using local aggregates and evaluating the use of recycled aggregates as an additional solution to reduce the environmental impact of concrete. A deeper analysis of the long-term effects of these materials, along with the exploration of other types of aggregates, could further enhance our understanding of their influence on the durability and performance of concrete in different climatic and geographical conditions.

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