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River Sand Characterization for Its Use in Concrete: A Revue

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Abstract

Despite the gradual professionalization of the construction sector as well as the abundance of sand mining sites offered by the North Kivu, Democratic Republic of Congo Region, ignorance of materials by local builders persists. This is the case of quarries extracting river sand used to make concrete and mortar. However, the dosages of the various constituents are most often chosen on the basis of experience without any prior characterization of this material. This paper presents a comprehensive review of the characterization of river sand for its use in concrete in DRC. The origin and global use of river sand in construction are presented in percentage terms to highlight the importance of river sand as a construction material. The physical properties of river sand, including particle size distribution, bulk density, absolute density, and cleanliness are discussed in detail. The paper examines the effect of variations in river sand properties on concrete behavior, including density and compressive strength. Overall, this paper emphasizes the need to properly characterize river sand before using it in construction to ensure durable, high-quality structures. This will avoid the problems that are observed in particular a bad behavior of the coating on the walls; cracks and crumbling of the beams, lintels, posts and even the ruin of the structures.

Keywords

Characterization, River Sand, Concrete, Construction Material, Structure

1. Introduction

Concrete is one of the most widely used construction materials in the world, and it is essential for the development of modern infrastructure [1] [2] [3]. It is a composite material that is made up of several components, including cement, aggregates, water, and sometimes admixtures. Aggregates, which constitute the bulk of concrete, play a crucial role in determining the properties of the material. Among the aggregates, sand is one of the most important components of concrete, as it provides bulk and stability to the mixture [4].

River sand, in particular, is a common source of sand for concrete production, and it is widely used as a construction material. According to industry estimates, river sand accounts for more than 60% of the total sand used in concrete production worldwide [5]. However, river sand varies in quality and characteristics depending on its origin, and these variations can significantly affect the properties of concrete made from it [4] [6].

Several studies have investigated the effect of using river sand, sea sand, and crushed rock sand on the properties of concrete [7] [8] [9]. For example, some studies have examined the mechanical properties of concrete from partial substitution of river sand. It follows that the properties of concrete change when the origin or quality of the sand is modified [10] [11] [12]. Another study analyzed the demand for natural river sand in the construction industry and explored alternative sources of sand [13]. It is worth noting that the failure of concrete structures leading to building collapse has initiated various researches on the quality of construction materials. Building collapses resulting in injuries, loss of life and investment have been widely attributed to the use of poor-quality concrete ingredients.

This paper emphasizes the need to properly characterize river sand before using it in the design of concrete mixtures, since the compressive strength of concrete depends on the quality of its constituent elements. This will guarantee durable and good quality structures but also avoid the problems observed, notably a bad behavior of the plaster on the walls, cracks and crumbling of the beams, lintels, posts and even the ruin of the structures.

2. Literature Review

River sand is one of the most commonly used aggregates in concrete production, and it is widely available in most parts of the world. According to industry estimates, river sand accounts for more than 60% of the total sand used in concrete production worldwide [13].

In Africa, river sand is the most common source of sand for concrete production. In countries like Cameroon and the Democratic Republic of Congo (DRC), river sand is readily available and widely used as a construction material [14]. In Cameroon, for example, river sand is estimated to account for over 80% of the total sand used in concrete production [13].

Globally, the use of river sand in concrete production varies widely depending on the availability of resources and local construction practices. In some regions, such as Southeast Asia and parts of the Middle East, river sand accounts for over

90% of the total sand used in concrete production. In contrast, in some developed countries, such as the United States and Australia, the use of river sand in concrete production is relatively low, and alternative sources of sand, such as crushed rock and manufactured sand, are more commonly used [7].

It is worth noting that the use of river sand in concrete production is a contentious issue in some regions, particularly in Southeast Asia, where rapid urbanization has led to a significant increase in demand for sand [15]. The high demand for sand has led to unsustainable mining practices, causing environmental degradation, and social conflicts in some areas. As a result, there has been a growing interest in using alternative sources of sand, such as recycled construction waste and manufactured sand, to reduce the reliance on river sand in concrete production.

River sand is a naturally occurring material that is widely used in the construction industry for its physical properties. Some of the key physical properties of river sand include:

1) Particle size distribution: River sand is composed of a mixture of different sized particles, ranging from fine sand to coarse gravel. The particle size distribution of river sand is important because it affects the workability, strength, and durability of concrete. Generally, river sand with a well-graded particle size distribution is preferred for use in concrete production [16] [17]. The presence of fine elements in the sand generates a significant shrinkage modifying the properties of the concrete, if the sand is fine, there is a risk of shrinkage resulting in cracks [18] [19]. The correction of the modulus of fineness of the sands makes it possible to improve the granularity and increase the compressive strength of the concretes by more than 70% [20].

2) Bulk density: The bulk density of river sand is an important property that affects the weight and volume of concrete. The bulk density of river sand typically ranges from 1.4 to 1.6 g/cm^3 [16].

3) Absolute density: The absolute density of river sand is a measure of its compactness and is defined as the mass of a unit volume of sand. The absolute density of river sand typically ranges from 2.4 to 2.7 g/cm^3 [16] [21].

4) Cleanliness: River sand should be free from impurities such as clay, silt, and organic matter, which can affect the workability and durability of concrete. Clean river sand is essential for producing high-quality concrete [16].

Additionally, river sand is an important material for the production of concrete, and its properties affect the physical and mechanical properties of concrete. Some of the key physical and mechanical properties of concrete obtained by using river sand include:

1) Compressive strength: The compressive strength of concrete is one of the most important mechanical properties that affects its performance. Studies have shown that concrete made with river sand has higher compressive strength compared to concrete made with other types of sand [22] [23].

2) Durability: The durability of concrete is a measure of its ability to resist

damage caused by weathering, chemical attacks, and other environmental factors [24]. Concrete made with river sand has good durability due to its physical properties [25].

3) Workability: Workability refers to the ease with which concrete can be placed, compacted, and finished. Concrete made with river sand has good workability, which makes it easier to work with during construction [26].

4) Water absorption: The water absorption capacity of concrete made with river sand is lower compared to concrete made with other types of sand, which makes it less susceptible to damage caused by water [5].

Other Applications of River Sand:

Apart from its use in concrete production, river sand is also used in a variety of other applications, including:

1) Landscaping: River sand is used in landscaping projects to create artificial beaches, riverbeds, and water features [27] [28].

2) Glass manufacturing: River sand is an important raw material for glass manufacturing [29] [30].

3) Agriculture: River sand is used in agriculture as a soil amendment to improve drainage and aeration [31] [32].

4) Road construction: River sand is used in the construction of roads and highways as a base material and for drainage [32] [33].

5) Building and construction: River sand is used in the construction of buildings, bridges, and other structures as a construction material [32] [33].

In summary, river sand is a versatile material that has numerous applications in construction and other industries. Its physical and mechanical properties make it a preferred choice for the production of high-quality concrete, and its other applications make it a valuable resource for a variety of industries.

3. Presentation of Results

3.1. Origin

The origin of river sand can be traced back to the natural erosion of rocks and minerals, which then get carried downstream by rivers and deposited in riverbeds [34]. River sand is extensively used in construction, particularly in concrete production, due to its abundance and desirable properties. Globally, river sand accounts for around 30% of the total sand used in construction. **Figure 1** and **Figure 2** indicate maps from a systematic literature review related to sand characterization and use in concrete. These results were obtained from Dimensions data base. **Figure 1** presents data related to a few key words criteria such as: river sand characterization or concrete use in general (2502 results). **Figure 2** presents data related to a few key words criteria such as: river sand characterization or concrete use in Africa (2502 results). Those results have been exported on Apr 13, 2023. The map has been generated under the VOS viewer software.

In Africa, river sand is the most commonly used construction material, with an estimated 50% - 60% of all sand used in construction being sourced from

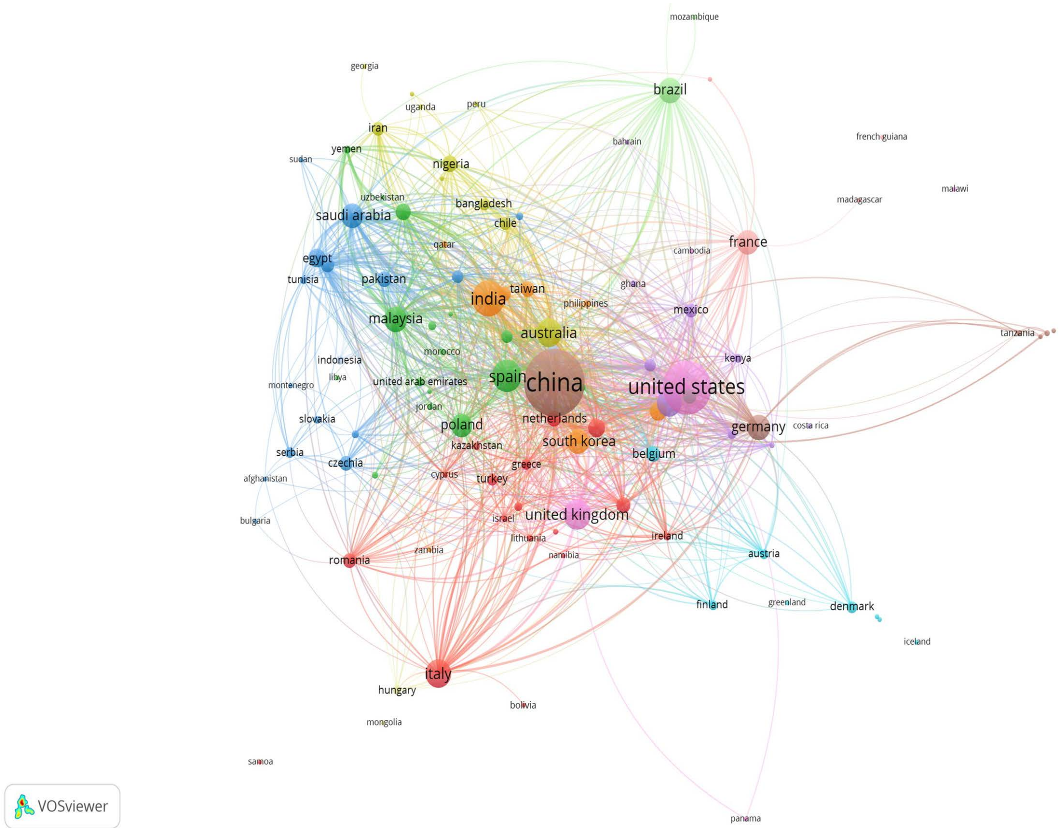

Figure 1. Map from a systematic literature review related to sand characterization and use in concrete.

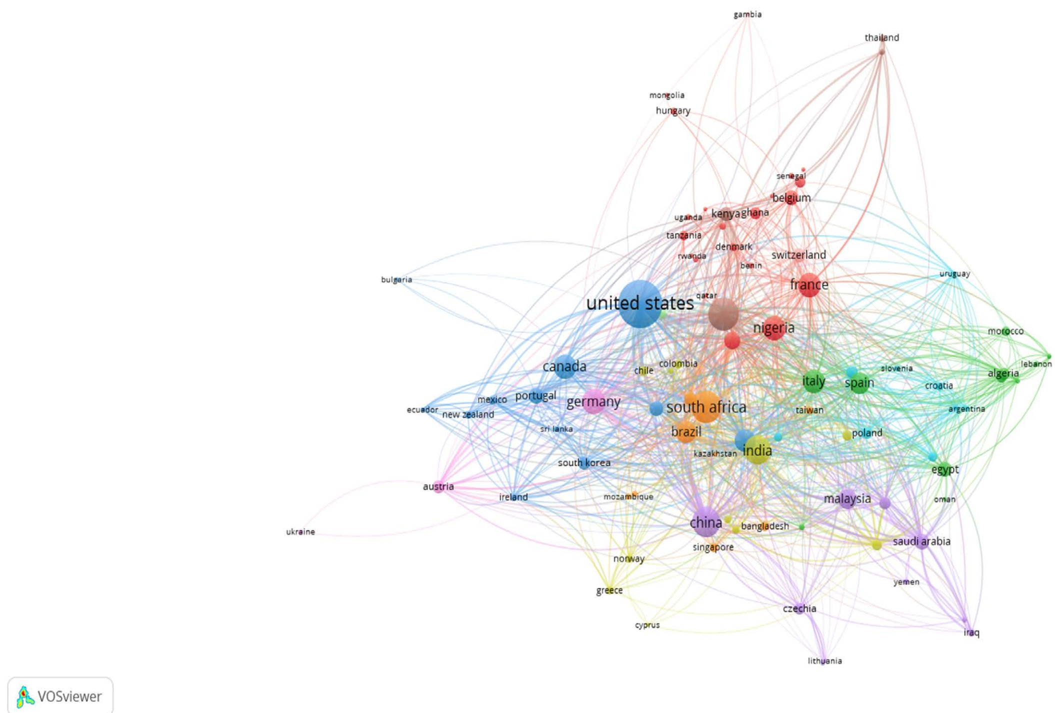

Figure 2. Map from a systematic literature review related to sand characterization and use in concrete in Africa.

rivers [14]. In Cameroon and the DRC, river sand is also the primary source of sand used in construction, with an estimated usage rate of over 80%.

In terms of other countries, India is the largest consumer of river sand in the world, accounting for approximately 60% of the total river sand used in construction globally. China is another major consumer, using around 20% of the total river sand used in construction worldwide [6].

River sand is not only used in concrete production but also in other construction applications, such as road and building foundations, landscaping, and as a bedding material for pipes and underground cables.

Overall, river sand plays a crucial role in the construction industry, particularly in developing countries where it is the most commonly available and affordable construction material. **Table 1** presents the percentage of total sand used in construction sourced from rivers by some region.

Table 1 shows that river sand is much more used in concrete in DRC and Cameroon. This is up to 80%.

3.2. Physical Characteristics of River Sands

River sand is a common construction material, but not all river sands are suitable for use in concrete. The characteristics of river sand can vary greatly depending on its origin, and certain properties need to be considered before using it in concrete. Some important physical properties of river sand that need to be considered include particle size distribution, bulk density, absolute density, water absorption, and cleanliness.

3.2.1. Particle Size Analysis

Particle size distribution is an important property to consider because it affects the workability of the concrete mix. The fineness modulus (FM) is often used to describe the particle size distribution of the sand. Sands with lower FM tend to be finer, while those with higher FM tend to be coarser. If the FM of the sand is too low, the concrete mix may be too fluid and very easy to work with. If the FM is too high, the concrete may be too stiff and prone to segregation. These two cases presented lower the strength of the concrete.

Thus, to know with certainty whether the sand is mostly fine-grained, we calculate the fineness modulus which is equal to 1/100 of the sum of the accumulated refusals, expressed in percentages on the sieves of the following series: 0, 16-0, 315-0, 63-1, 25-2, 5-5 mm.

If modulus of fineness (Mf): Between 2.2 to 2.8: Suitable for obtaining satisfactory workability and good resistance with limited risk of segregation.

Thus, the granulometric curves obtained and their average slopes make it possible to characterize the degree of uniformity of the size of the elements of the ground. These are the Hazen uniformity coefficient (Cu) and the curvature or grading coefficient (Cc) defined by the formulas:

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{and} \quad C_c = \frac{(D_{30})^2}{D_{10} * D_{60}}$$

Table 1. River sand used in construction [14] [35].

Region/Country	Percentage of total sand used in construction sourced from rivers
Global	Around 30%
Africa	50% - 60%
Cameroon	Over 80%
DRC	Over 80%
India	Around 60%
China	Around 20%

D_{60} is the effective diameter of the particles which corresponds to 60 percent of the passers-by.

D_{30} is the effective diameter of the particles which corresponds to 30 percent of the passers-by.

D_{10} is the effective diameter of the particles which corresponds to 10 percent of the passers-by.

If uniformity coefficient Cu > 3 the particle size is uniform or even tight.

If uniformity coefficient Cu < 3the particle size is varied or even spread out.

If curvature coefficient (Cc): Between 1 to 3: well graded soil.

3.2.2. Bulk Density

The bulk density of river sands typically ranges from 1600 to 1800 kg/m^3. The bulk density depends on the mineral composition, sorting, and void ratio of the sand grains. Well-sorted sands with quartz and feldspar minerals tend to have higher bulk densities, around 1700 - 1800 kg/m^3. Poorly sorted sands with more porous minerals will have lower bulk densities. As sand particles get finer, the bulk density increases due to better particle packing. Very fine sands (0.125 mm) can have bulk densities over 1800 kg/m^3 [4] [7] [21]. Coarse sands (2 mm) may be around 1600 kg/m^3. Compaction through pressure increases the bulk density of sands. The bulk density of river sands typically increases with depth due to overburden pressure. It can increase to over 2000 kg/m^3 at depths of 50 - 100 m. Factors like saturation, consolidation, and cementation can also increase the bulk density over time due to particle rearrangement and bonding. Old, lithified sandstones can have bulk densities of 2400 kg/m^3 [21]. For practical purposes, a bulk density of 1700 kg/m^3 is often assumed for compacted river sands used for construction materials like concrete aggregates, road bases, and foundations. This value can be adjusted based on the specific sand properties and compaction conditions. Measuring the bulk density of river sands typically uses sampling techniques and requires determining the mass and volume of the sand samples. Non-invasive geophysical techniques are still being researched to assess bulk density without sampling [21]. **Table 2** presents the results of the bulk density of some research.

Table 2. Bulk density of river sands [21] [35].

Study	Bulk density (g/cm³)	Sand type	Location
A [36]	1.64	Medium sand	Amazon river
B [15]	1.65	Fine to medium sand	Mississippi river Nile
C [37]	1.68	Fine sand	River
D [38]	1.72	Fine to medium sand	Danube river

From **Table 2**, it can be seen that the bulk density of river sands ranges from 1.6 to 1.8 g/cm³. This makes it possible to formulate current concretes whose density is close to 2.4 g/cm³.

3.2.3. Absolute Densit

In general, studies have shown that the absolute density of river sands ranges from 2.51 to 2.65 g/cm³, with an average around 2.55 - 2.65 g/cm³. There is some variability likely due to differences in composition, but most researchers have concluded an absolute density in this range for well-sorted river sands [39]. **Table 3** presents a summary of studies on the absolute density of river sands.

It appears from **Table 2** that river sands are common aggregates because the absolute density is between 2.5 and 2.7 g/cm³.

3.2.4. Cleanliness

The cleanliness of river sands can vary depending on several factors, including the location of the river, the surrounding land use, and the level of human activity in the area. In general, river sands that are located in areas with less human activity and industrial development tend to be cleaner than those located in heavily urbanized or industrialized areas.

Clean river sands are important for several reasons, particularly for construction and infrastructure projects that use sand as a key component [43]. Clean sand is required to prevent the formation of voids or weak spots in concrete, which can compromise the integrity and strength of the structure. Clean sand is also important for environmental reasons, as contaminated sand can contribute to pollution and harm aquatic ecosystems.

There is no specific percentage or standard for the cleanliness of river sands, as the acceptable levels of contaminants can vary depending on the intended use of the sand. For example, sand used in construction may have different cleanliness standards compared to sand used for recreational purposes or environmental restoration.

In general, it is important to ensure that river sands used in construction or other applications are clean and free from contaminants that could affect the quality or safety of the project. This is why many countries have regulations and guidelines in place to ensure that river sands meet certain standards for cleanliness and quality.

Table 3. Summary of result on the absolute density of river sands.

Study	Absolute Density (g/cm^3)
Krumbein and Sloss [40]	2.65
Folk [41] [42]	2.65
Bluck [13]	2.65
Selley [14]	2.65
Konhauser *et al.* [15]	2.55
Platl and Legros [16]	2.51

3.3. Physical and Mechanical Properties of Concrete

Studies have shown that the physical and mechanical properties of concrete can be significantly affected by the characteristics of the river sand used in its production. The bulk density and absolute density of the sand have been found to directly affect the density of the resulting concrete. Similarly, the particle size distribution, which is expressed as the fineness modulus, has been found to influence the workability, compressive strength, and durability of the concrete.

Research has also shown that the water absorption capacity of the river sand can affect the water-cement ratio of the concrete, which in turn affects the strength and durability of the resulting concrete. Furthermore, the cleanliness of the sand, including the presence of organic and inorganic impurities, can affect the setting time, workability, and strength of the concrete [44].

Several studies have reported that the mechanical strength of concrete made with river sand is influenced by the particle shape, texture, and surface characteristics of the sand. In general, sands with a rounder particle shape and smoother surface texture have been found to produce stronger and more durable concrete. The compressive strength of the concrete has been found to increase with increasing bulk density and absolute density of the sand [44].

3.3.1. Density of Concrete

The density of concrete is influenced by a variety of factors, including the types and quantities of materials used in its composition. The type of sand used in concrete, for example, can significantly affect the density of the final product.

Several studies have been conducted to investigate the impact of different sands on the density of concrete. One study, published in the journal Construction and Building Materials in 2021, examined the effect of using river sand instead of crushed sand on the density of concrete [45].

The researchers found that using river sand instead of crushed sand led to a slightly lower density of concrete. Specifically, the density of concrete made with river sand was found to be 2.467 kg/m^3, while the density of concrete made with crushed sand was 2.514 kg/m^3. This difference in density can be attributed to the fact that river sand is typically less dense than crushed sand.

Another study, published in the Journal of Cleaner Production in 2017, investigated the effect of using different types of sand on the density of concrete. The researchers tested concrete made with three types of sand: river sand, crushed sand, and desert sand. They found that the density of concrete made with river sand was 2.520 kg/m^3, while the density of concrete made with crushed sand was 2.612 kg/m^3. The density of concrete made with desert sand was 2.406 kg/m^3, which was significantly lower than the densities of concrete made with either river sand or crushed sand [46].

Overall, these studies suggest that the type of sand used in concrete can have a significant impact on the density of the final product. River sand and crushed sand, in particular, can lead to slightly different densities due to their differing densities.

3.3.2. Compressive Strength of Concrete Based on River Sands

The compressive strength of concrete is influenced by various factors, including the type and quality of materials used in its composition. The type of sand used in concrete, such as river sand, can also have an impact on its compressive strength.

Several studies have investigated the compressive strength of concrete made with river sand. One study, published in the journal Construction and Building Materials in 2019, examined the compressive strength of concrete made with river sand compared to concrete made with crushed sand [47]. The study found that the compressive strength of concrete made with river sand was slightly lower than that of concrete made with crushed sand. Specifically, the compressive strength of concrete made with river sand was found to be 28.25 MPa, while the compressive strength of concrete made with crushed sand was 28.85 MPa.

Another study, published in the Journal of Civil Engineering and Management in 2016, investigated the compressive strength of concrete made with river sand compared to concrete made with manufactured sand [48]. The study found that the compressive strength of concrete made with river sand was lower than that of concrete made with manufactured sand. Specifically, the compressive strength of concrete made with river sand was 32.1 MPa, while the compressive strength of concrete made with manufactured sand was 34.2 MPa.

Overall, these studies suggest that the type of sand used in concrete, including river sand, can have a small but significant impact on its compressive strength. Other factors, such as the quality of the cement and the water-cement ratio, also play important roles in determining the compressive strength of concrete.

4. Conclusions

This paper explored the important role of river sand in construction, particularly in concrete production. The origin and overall use of river sand in construction was presented, highlighting its importance as a construction material.

The physical properties of river sand, including particle size distribution, bulk density, absolute density, and cleanliness, were examined along with their influences on the physical and mechanical properties of concrete.

The results showed that variations in river sand characteristics significantly affect concrete properties, indicating the need for proper sand characterization and selection for concrete production.

This paper ends by presenting the problem of river sand from the city of Butembo being used without any prior characterization. This has harmful consequences on the structural plan of the works, in particular a bad behaviour of the coating on the walls; cracks and crumbling of the beams, lintels, posts and even the ruin of the works.

Overall, this article highlights the importance of proper selection and characterization of river sand in construction to ensure the production of durable, good quality concrete structures.

5. Future Prospects

Located in the northeast of the Democratic Republic of Congo (DRC), and 17 km north of the equator, the city of Butembo has typical equatorial climate conditions [49] [50]. During the rainy season, water from various sources flows into the rivers, carrying with it quantities of sand that it washes along its path. These naturally washed sands end up accumulating on the riverbeds of Thalihya, Mutinga, Musienene, Kimemi, Kihuli, Kaliva and Kalengera. All along these rivers, the populations have set up quarries to extract sand in huge quantities in order to make concrete and mortar. However, the dosages of the various constituents are chosen most often on the basis of experience, without any prior characterization. This is not sufficient for a better use of this patrimony that nature offers. The future work will have as objective to characterize the different products of the above-mentioned rivers in view of their better use in the concrete.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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