Initial River Sand Characterization from Five Quarry Sources in North Luwu Regency as a Construction Material Database

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ABSTRACT

River sand is a primary fine aggregate extensively used in cement concrete, asphalt pavements, and precast concrete products. Its performance is governed by physical and chemical characteristics, which in practice often vary significantly between material sources. North Luwu Regency, South Sulawesi Province, Indonesia, possesses abundant river sand resources derived from several major river systems. However, a systematically documented database of sand characteristics is still lacking. This study aims to characterize the physical and chemical properties of river sand obtained from five quarry sources in North Luwu Regency, namely the Masamba, Rongkong, Radda, Baliase, and Baebunta Rivers. The testing program included particle size gradation, sand equivalent, mud content, specific gravity, silica (SiO_2) content, and sulfate (SO_4^{2-}) content. The results demonstrate pronounced inter-quarry variability in sand characteristics, although all samples comply with construction material standards. Sand from the Rongkong and Masamba Rivers exhibits superior quality in terms of cleanliness, density, and chemical stability, whereas sand from the Baebunta and Radda Rivers shows marginal conditions for several cleanliness-related parameters. This study establishes an initial regional database of river sand characteristics that can support material selection and quality control for construction applications in North Luwu Regency.

Keywords-river sand; fine aggregate characteristics; sand equivalent; gradation; material database

I. INTRODUCTION

River sand is a significant constituent of various construction materials. In addition to functioning as a filler between coarse aggregates, fine aggregate plays a critical role in governing the density, strength, and durability of concrete, asphalt mixtures, and precast concrete products. Fine aggregate characteristics, such as gradation, cleanliness, and mineral composition, significantly influence the strength and durability of construction materials. River sand characteristics, including grain size distribution and mineral composition, are strongly influenced by the geological origin of source materials and are further modified by sediment transport processes within fluvial systems, resulting in important spatial and temporal variability [1-4]. Important variations in particle size distribution, sediment cleanliness, and mineralogical composition can occur even within the same geographic region due to differences in local depositional conditions and sediment sources [1, 3, 5]. Variations in aggregate characteristics significantly impact the mechanical performance and durability of cement-based and asphalt materials by affecting strength, stiffness, resistance to deformation, and susceptibility to moisture-related damage [6, 7].

In many regions, local sand resources are utilized primarily based on availability and conventional practice, rather than on a systematic evaluation of material properties. The absence of reliable characteristic data may result in inconsistent construction quality and inefficiencies in mixture design, particularly when materials from different sources are used interchangeably without technical justification. North Luwu Regency is a region in South Sulawesi Province with considerable river sand potential. Sand deposits are distributed across several major rivers, including the Masamba, Rongkong, Radda, Baliase, and Baebunta Rivers. Despite extensive utilization, scientific information regarding the physical and chemical characteristics of sand from these rivers remains limited. Differences in geological settings, sediment transport, and depositional processes among river systems are likely to produce significant variability in sand properties, underscoring the need for systematic comparative characterization.

Most existing studies on local sand materials focus on single-source characterization or directly assess construction product performance without establishing a comprehensive aggregate database. Such approaches limit the generalizability of findings and complicate quality control when materials are sourced from multiple locations. Consequently, developing a multi-source sand characteristic database within a single region represents an important step toward rational material selection and controlled utilization of local resources. However, comprehensive multi-source databases of river sand characteristics remain limited, particularly for regional construction materials [8]. The development of material and aggregate databases is an important approach to support rational material selection and improve quality control in construction practices [9, 10]. Multi-source characterization approaches allow engineers to evaluate aggregate suitability based on both physical and chemical indicators rather than availability alone [11, 12].

Previous studies have extensively investigated the influence of fine aggregate characteristics on the performance of concrete and asphalt mixtures. Several researchers have focused on the relationship between gradation and mechanical strength, while others have examined the effects of cleanliness, clay contamination, and mineral composition on durability performance. However, most of these studies evaluate aggregates within a single source or directly relate aggregate properties to mixture performance without first establishing a systematic multi-source material database. In addition, the regional variability of river sand within a defined administrative boundary remains underexplored in the literature. Therefore, a comprehensive comparative characterization of multiple quarry sources within a single region is still needed to provide a reliable reference for material selection and quality control.

Accordingly, this study aims to comprehensively characterize the physical and chemical properties of river sand from five quarry sources in North Luwu Regency. The scope of this research is restricted to sand characterization as a base material and does not address its performance in concrete, asphalt, or paving block applications. The outcomes are expected to provide a reliable reference database for fine aggregate selection and quality control in construction practice.

II. RESEARCH METHODOLOGY

A. *Location and Materials Sources*

This study utilized river sand collected from five different quarry sources in North Luwu Regency, South Sulawesi Province, Indonesia (Figure 1). The sand sources included the Masamba, Rongkong, Radda, Baliase, and Baebunta Rivers. The five rivers exhibit different geomorphological and hydrological characteristics that potentially influence sediment composition. The Rongkong and Masamba Rivers are relatively wide channels with moderate to high flow velocities, promoting better sediment sorting and deposition of coarser particles. In contrast, the Baebunta and Radda Rivers are characterized by relatively lower flow velocities and localized sediment accumulation zones, which may contribute to finer particle distribution and higher mud content. The Baliase River exhibits intermediate flow conditions. Variations in river morphology, channel width, sediment transport intensity, and depositional environments influence grain size distribution and mineral composition of river sand. These geomorphological differences are therefore considered relevant factors in explaining the variability of sand characteristics observed in this study.

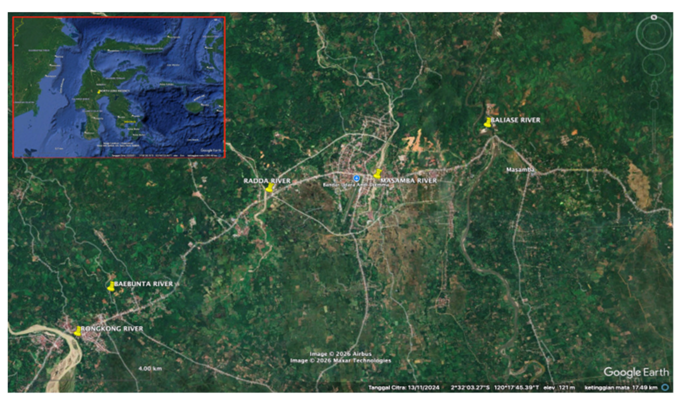

Fig. 1. Map of the study location and sampling points.

All laboratory tests were conducted at the Asphalt and Road Materials Laboratory of the Department of Civil Engineering, Politeknik Negeri Ujung Pandang.

B. *Sampling Procedure*

Sampling was conducted using a systematic spatial distribution approach within each quarry area. Three sampling points were selected at each river location, representing the upstream, midstream, and downstream zones within the active extraction area to capture potential spatial variability. At each sampling point, approximately equal volumes of sand (±25 kg per sample) were collected manually from the surface layer at a depth of approximately 20–30 cm to avoid surface contamination. Two replicate samples were obtained from each point to ensure representativeness and consistency. The sampling volume was kept uniform across all locations to maintain comparability among quarry sources. The sand was used in its natural condition without washing or additional sieving processes, ensuring that the test results represented the actual field material conditions. Prior to testing, the materials were air-dried and homogenized under laboratory conditions. All subsequent laboratory tests were carried out in accordance with the relevant ASTM and SNI standards, and the measured values were comparatively analyzed among quarry sources to evaluate variability and compliance.

C. Testing Program

The testing program focused on the physical and chemical characteristics of the river sand. The evaluated parameters included:

1) Particle Size Gradation Analysis

Particle size gradation analysis was performed to determine the particle size distribution and the tendency toward finer or coarser sand, and to determine the distribution of particle sizes in the sand samples from different sources. This test is essential for evaluating the grading characteristics of fine aggregates and their suitability for use as construction materials. The procedure was carried out in accordance with the applicable standard methods for sieve analysis of fine aggregates. The test involved oven-drying the samples to a constant mass, followed by sieving through a series of standard sieves arranged in descending order of size. The mass retained on each sieve was measured, and the percentage passing and cumulative distribution were calculated. The results were then used to assess the gradation pattern and classify the sand based on standard grading requirements.

Fig. 2. Particle size gradation analysis test.

2) Sand Equivalent

Sand equivalent was used as an indicator of sand cleanliness with respect to clay and fine particle content. The test was conducted to evaluate the cleanliness of the fine aggregate by determining the relative proportion of sand-sized particles to clay-like fines. This test is significant for assessing the quality of fine aggregates and their suitability for use as construction materials. The procedure was performed in accordance with the applicable standard methods for sand equivalent testing.

The test involves placing a prepared sand sample into a graduated cylinder, followed by the addition of a standard flocculating solution. The cylinder was then agitated using a mechanical shaker to separate the fine particles from the coarser sand fraction. After a specified settling period, the heights of the sand layer and clay suspension were measured to calculate the sand equivalent value.

The sand equivalent value represents the ratio of clean sand to detrimental fines and is used as an indicator of aggregate cleanliness. This parameter is important for evaluating the potential effects of fine impurities on the performance of construction materials.

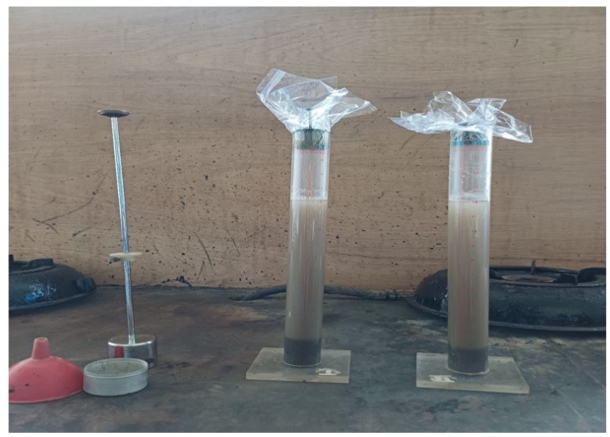

Fig. 3. Sand equivalent test.

3) Mud Content

Munt content was estimated to evaluate the proportion of fine materials that may interfere with bonding in construction materials.

4) Specific Gravity

Specific gravity was used as an indicator of aggregate density and mineral quality. The specific gravity of the sand samples was determined to characterize the density and physical properties of the fine aggregates from different sources. The tests were conducted in accordance with the applicable standard procedures for fine aggregate testing. The measurements included the determination of the bulk specific gravity, apparent specific gravity, and water absorption.

The procedure involves oven-drying the sand sample to a constant mass, followed by immersion in water to achieve a Saturated Surface-Dry (SSD) condition. The mass of the sample was recorded under dry, SSD, and submerged conditions to calculate the specific gravity values. These parameters are important for evaluating the physical characteristics of aggregates and their suitability for use in construction materials.

Fig. 4. Specific gravity test.

5) Silica Content

Silica content was used to assess the chemical stability and mineral purity.

6) Sulfate Content

Sulfate content was utilized to evaluate the potential risks related to construction material durability.

Each test was performed in accordance with the respective ASTM and SNI standards. Particle size distribution was determined using mechanical sieving and cumulative percentage passing calculations. Sand equivalent and mud content were measured using standardized washing and sedimentation procedures. Specific gravity and absorption were determined using the pycnometer method under oven-dried and SSD conditions. Silica and sulfate contents were analyzed through laboratory chemical testing.

For each parameter, replicate measurements were conducted and averaged to obtain representative values. All test results were analyzed comparatively among quarry sources to identify characteristic differences and their compliance with construction material standards. All laboratory tests were conducted in accordance with the relevant ASTM and SNI standards applicable to fine aggregate characterization. The measured results were evaluated against both ASTM and corresponding Indonesian National Standard (SNI) specification limits, where available, to ensure local regulatory relevance for fine aggregate characterization [13-15]. Selected testing parameters, including particle size distribution and morphological characteristics, are widely used as indicators for the characterization of fine aggregates [16, 17]. Gradation analysis, cleanliness-related parameters, and specific gravity tests are employed as indicators to evaluate particle packing behavior and bonding characteristics in cementitious materials [18, 19].

III. RESULTS

Table I presents the physical and chemical properties of river sand obtained from different sources, compared with the relevant standard specifications. The results indicate variations in key parameters, such as fineness modulus, clay content, specific gravity, and sand equivalent values, which reflect differences in material quality and characteristics among the sampled locations.

TABLE I. PHYSICAL AND CHEMICAL PROPERTIES OF RIVER SAND COMPARED WITH STANDARD REQUIREMENTS

Property	Method	Standard	Measured values				
			Masamba	Rongkong	Radda	Baebunta	Baliase
Fineness modulus	ASTM C 136	1.5-3.8	2.90	2.39	2.82	2.62	2.47
Clay lumps and friable materials	ASTM C 142	Max 5%	1%	4%	9%	2%	9%
Organic impurity	ASTM C 40	≤ No. 3	Non organic	Non organic	Non organic	Non organic	Non organic
Angularity with cavity content test	SNI 03-6877-2002	Min 45	44.48%	47%	45%	47%	47%
Material passing #200 sieve	ASTM C 117 : 2012	< 5 %	1.82%	3%	1%	1%	1%
Spesific gravity	ASTM C 128	> 2.5	2.49	2.43	2.5	2.49	2.53
Absorbtion		3-5%	1%	2%	1%	1%	1%
Soundness test (Na_2SO_4)	ASTM C 88	≤ 12% (5 cycles)	11%	13%	17%	12%	19%
Sand equilavent value	SNI 03-4428-1997	Min. 50%	97%	94%	96%	95%	95%
Unit weight (Kg/L)	ASTM C 29-71		1.49	1.38	1.48	1.42	1.46
Silica content mass %		60-90	69.73%	65.11%	67.36%	67.19%	67.28%
sulfate content mg/kg		≤ 5000 mg/kg	1820.68	3170.57	2793.53	1857.62	2994.48

TABLE II. PARTICLE SIZE DISTRIBUTION OF RIVER SAND SAMPLES

Sieve size	Standard (%) ASTM C -33	Masamba	Rongkong	Radda	Baebunta	Baliase
Passing 1"		100	100	100	100	100
Passing 3/4"		100	100	100	100	100
Passing 1/2"		99.81	99.95	99.80	99.96	99.65
Passing 3/8"	100%	99.55	99.84	99.46	99.92	99.51
Passing no. 4	95-100	98.62	99.30	97.94	99.61	99.08
Passing no. 8	80-100	95.47	97.91	94.85	98.42	98.22
Passing no. 16	50-85	76.57	91.77	81.51	88.47	94.32
Passing no. 30	25-60	34.94	61.03	38.37	44.40	53.19
Passing no. 50	10-30	8.41	15.77	8.32	9.52	13.21
Passing no. 100	2-10	2.08	3.73	1.38	1.70	3.25

Table II shows the particle size distribution of the river sand samples based on sieve analysis, along with the standard grading limits. The results demonstrate differences in gradation patterns among the samples, which are important for evaluating their compliance with standard requirements and suitability for use as construction materials.

A. Sand Gradation Characteristics

Figure 5 depicts the particle size distribution curve for the sand from the Masamba River. The curve lies predominantly within Zone 3, indicating a moderately fine gradation. The percentage passing decreases gradually from coarse to fine sieves, with a significant portion of particles retained between the No. 4 and No. 30 sieves, confirming a relatively coarser distribution compared to finer zones.

Figure 6 presents the gradation curve of sand from the Baliase River. The curve is positioned closer to Zone 4, indicating finer gradation. This is reflected by a higher percentage of material passing through the smaller sieves, particularly sieves No. 50 and No. 100, suggesting a greater proportion of fine particles.

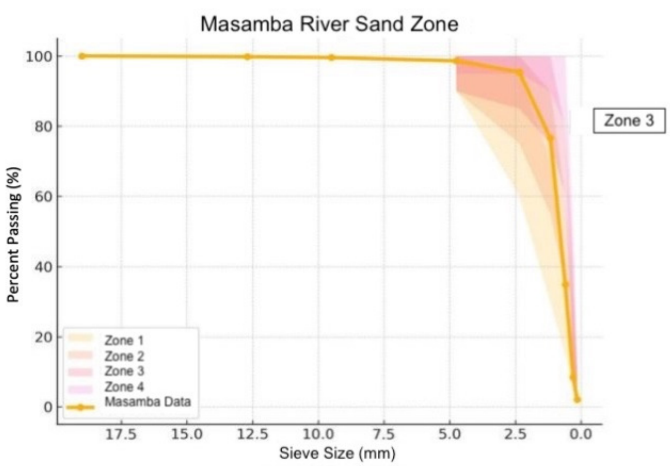

Fig. 5. Particle size distribution of river sand from the Masamba River.

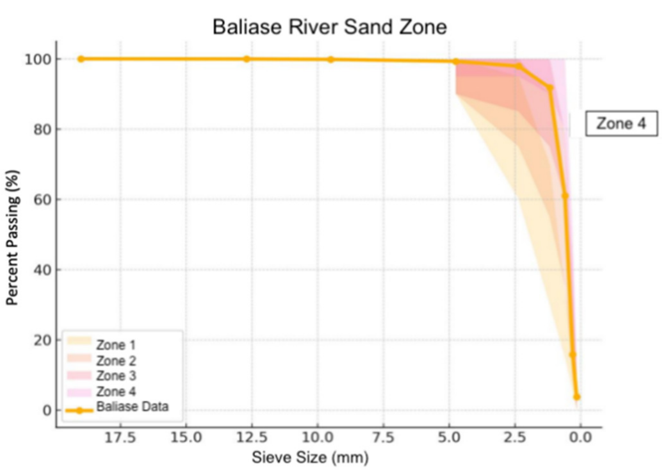

Fig. 6. Particle size distribution of river sand from the Baliase River.

Overall, both curves remain within standard gradation limits; however, the Baliase sand exhibits a finer distribution than the Masamba sand. This difference in particle size distribution may influence the workability and water demand in practical applications.

B. Sand Equivalent

The sand equivalent values demonstrated varying levels of sand cleanliness among the quarry sources. The Rongkong and Masamba Rivers exhibited the highest sand equivalent values, indicating relatively clean sand with low clay and fine particle content. Sand from the Baliase River showed moderate cleanliness, whereas sand from the Baebunta and Radda Rivers presented lower sand equivalent values approaching the minimum allowable limits.

Despite these differences, all sand equivalent values still satisfy the minimum requirements for construction materials. However, sand equivalent values close to the threshold for Baebunta and Radda sands demonstrate the need for increased attention to sand cleanliness when used in applications requiring higher material quality.

C. Mud Content

The results show that all sand samples complied with the maximum allowable limit of 5% specified in construction material standards. However, noticeable variations were observed among the quarry sources.

Sand from the Baebunta and Radda Rivers exhibited relatively higher mud content compared to other sources, although still within permissible limits. In contrast, sand from the Rongkong River showed the lowest mud content, indicating superior material cleanliness. These variations may be attributed to the local geomorphological conditions and sediment transport processes along the river channels.

D. Specific Gravity

All samples fell within the acceptable range for mineral aggregates, indicating adequate density and mineral quality.

Sand from the Masamba and Rongkong Rivers exhibited relatively higher specific gravity values compared to other sources, suggesting denser material composition. Conversely, sand from the Baebunta River showed the lowest specific gravity value, which may indicate slightly higher porosity. Although all samples satisfy standard requirements, these differences reflect variability in aggregate characteristics among quarry sources.

E. Silica Content

Silica content analysis indicated that all sand samples possessed SiO_2 levels consistent with quartz sand characteristics, ranging from approximately 60% to 90%. Sand from the Baliase and Rongkong Rivers exhibited the highest silica content, indicating relatively high quartz mineral purity.

A high silica content suggests that the river sand is chemically stable and does not exhibit indications of reactive materials that could potentially cause problems in construction applications.

F. Sulfate Content

The sulfate content in all sand samples was well below the maximum allowable limit. Sand from the Baebunta River demonstrated the highest sulfate content, whereas sand from the Rongkong and Masamba Rivers showed the lowest values.

The consistently low sulfate content across all quarry sources indicates that the sand is safe for construction applications, including environments with potential moisture exposure or soil contact.

IV. DISCUSSION

A. Variation of Characteristics Among Quarry Sources

The test results demonstrated that although all sand samples met the construction material standards, significant variations in characteristics existed among the quarry sources. These variations reflect the differences in geological conditions, sedimentation processes, and river flow dynamics at each location.

Sand from the Rongkong and Masamba Rivers consistently exhibited superior characteristics, as indicated by the high sand equivalent values, low mud content, relatively high specific gravity, high silica content, and low sulfate content. This combination of parameters suggests higher cleanliness and better mineral quality.

In contrast, sand from the Baebunta and Radda Rivers demonstrated characteristics closer to the lower limits for several cleanliness-related parameters, particularly for sand equivalent and mud content. Although this does not indicate unsuitability, it highlights the need for stricter quality control during utilization.

Similar variability in river sand properties has been reported in comparative studies, where differences in river morphology and sediment transport processes play a significant role in controlling aggregate characteristics [4, 20, 21]. These findings stress the importance of systematic evaluation in understanding material characteristics within a regional context [22].

Variability in particle distribution and sediment quality is closely associated with river flow dynamics and depositional conditions, which significantly influence the characteristics of fine aggregates used in construction applications [20, 23, 24]. The influence of aggregate size and sediment characteristics on material behavior has also been highlighted, reinforcing the importance of establishing a regional database of aggregate properties, such as that presented in [8].

B. Implications of Physical Characteristics on Material Quality

Differences in sand gradation, particularly the tendency toward finer or coarser materials, have important technical implications. The observed differences in the particle size distribution among the quarry sources provide important baseline information for material classification and selection. Variations in fine–coarse tendencies may influence material behavior in practical applications. However, in the present study, these differences were documented as part of a regional material database rather than being evaluated in specific mixture designs. Conversely, the coarser sand from the Masamba and Rongkong Rivers tended to produce more stable and denser particle arrangements.

The sand equivalent and mud content serve as primary indicators of sand cleanliness. Sand with high sand equivalent values and low mud content provide more favorable conditions for bonding in various construction applications. Therefore, quarry sources with superior cleanliness characteristics offer technical advantages for material utilization.

Cleanliness and particle size distribution significantly affect the bonding performance, shrinkage behavior, and overall structural performance of cement-based materials [25-27]. Excessive fine particles and clay contamination have weaken the aggregate–paste interface and reduce bonding efficiency, leading to decreased mechanical performance and long-term durability of cement-based materials [28, 29].

Sand gradation and cleanliness play critical role in particle packing and bonding efficiency, which in turn significantly influence the mechanical performance and long-term durability of cement-based materials [30, 31].

C. Implications of Chemical Characteristics on Material Stability

The measured sulfate (SO_4^{2-}) content ranged from 1820.68 mg/kg (Masamba) to 3170.57 mg/kg (Rongkong), which is significantly below the maximum allowable limit of 5000 mg/kg. Although Rongkong sand showed the highest sulfate concentration among the five sources, the value remained well within acceptable thresholds and did not pose a durability concern under normal construction conditions.

Elevated sulfate content in aggregates may contribute to internal sulfate attack, leading to expansion and cracking in cementitious systems. However, the values observed in this study were substantially lower than the levels reported in the literature. The relatively moderate sulfate content of Baebunta and Radda sands also indicates no immediate risk of chemical degradation. Consequently, from a chemical stability perspective, sulfate content does not represent a limiting factor for the utilization of any of the five river sand sources tested.

A high silica content in aggregates is commonly associated with quartz-rich compositions, which are generally chemically stable and exhibit low reactivity in cementitious systems compared to more reactive forms of silica [32, 33]. Quartz-rich fine aggregates are generally associated with improved durability and reduced susceptibility to deleterious reactions in cementitious materials due to their chemical stability and low reactivity [34, 35].

Variations in silica content among quarry sources primarily reflect differences in mineral purity rather than potential chemical problems.

The predominance of silica and relatively low impurity content observed in river sand are consistent with typical chemical characteristics reported in the literature, indicating their chemical stability and suitability for construction applications [36-38].

D. Evaluation of Compliance with Material Standards

Based on the evaluation of all testing parameters, river sand from the five quarry sources in North Luwu Regency generally complied with the construction material standards. However, relative quality levels differ among the sources.

Compliance with established standards ensures consistent quality and reliable performance in construction materials and structures [39]. Systematic evaluation based on specification limits contributes to controlling variability-related risks and enhancing the reliability of material selection and performance in engineering applications [40, 41].

Sand from the Rongkong and Masamba Rivers can be categorized as having the best overall quality based on the combined physical and chemical parameters. Sand from the Baliase River falls into the moderate category with stable characteristics, whereas sand from the Baebunta and Radda Rivers meets the minimum requirements but requires greater attention with respect to cleanliness control.

V. CONCLUSIONS

Based on the experimental results and analysis of the river sand characteristics from five quarry sources in North Luwu Regency, the following conclusions can be drawn:

River sand from the Masamba, Rongkong, Radda, Baliase, and Baebunta Rivers exhibits significant variability in physical and chemical characteristics, although all samples comply with construction material standard requirements.

Gradation characteristics indicate clear differences in fine–coarse tendencies among the quarry sources. Sand from the Baebunta and Radda Rivers tends to be finer, whereas sand from the Masamba, Rongkong, and Baliase Rivers shows relatively coarser and more stable particle distributions.

Cleanliness indicators, represented by sand equivalent and mud content, demonstrate that sand from the Rongkong and Masamba Rivers possesses the highest cleanliness levels. In contrast, sand from the Baebunta and Radda Rivers approaches minimum cleanliness thresholds and therefore requires stricter quality control during utilization.

Specific gravity values for all sand sources fall within acceptable ranges for mineral aggregates, with higher values observed for sand from the Masamba and Rongkong Rivers, indicating better density and mineral quality.

Chemically, all sand samples exhibit silica contents consistent with quartz sand characteristics and sulfate contents well below allowable limits, confirming their chemical stability and suitability for construction use.

Overall, sand from the Rongkong and Masamba Rivers can be classified as the most favorable source based on the combined physical and chemical characteristics. Sand from the Baliase River demonstrated moderate quality, while sand from the Baebunta and Radda Rivers met the minimum requirements but required greater attention to cleanliness control.

Based on the comparative evaluation of physical and chemical characteristics, specific practical applications can be proposed. Sand from the Rongkong and Masamba Rivers is proposed for structural cement concrete, high-quality asphalt pavements, and precast concrete products due to its superior cleanliness, density, and chemical stability. Sand from the Baliase River is suitable for general concrete works and asphalt layers with moderate performance requirements. Although the sand from the Baebunta and Radda Rivers meets standard specifications, it is more suitable for non-structural concrete, masonry mortar, paving blocks, and applications where additional quality control measures are implemented.

This study establishes an initial regional database of river sand characteristics for North Luwu Regency, which can serve as a technical reference for fine aggregate selection, construction material quality control, and future research on sand performance in various construction applications.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing interests regarding the publication of this paper.

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DATA AVAILABILITY

All data generated or analyzed in this study are included in this published article. Additional data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI USE AND DECLARATION OF GENERATIVE AI USE

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist with language editing and improving the clarity of the manuscript. The experimental data and research results presented in this study were obtained entirely through laboratory testing and direct analysis conducted by the authors, and were not generated using any AI tools. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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