LOCALLY SOURCED COARSE AGGREGATES IN CONCRETE PRODUCTION IN SOUTHERN BORNO: A REVIEW

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ABSTRACT

Infrastructure development in North-Eastern Nigeria has significantly increased demand for high-quality, locally available construction aggregates. Among these are the naturally occurring alluvial deposits found in Gwoza Local Government Area of Borno State, particularly at Warabe and along the Mayo Ibbi river system. Although widely used by local builders and large-scale construction firms, these gravels have not been subjected to formal scientific characterisation. This paper presents a systematic review of published literature on locally sourced and alternative coarse aggregates with two objectives: to synthesise global evidence on the performance characteristics of natural and recycled aggregates, and to identify critical knowledge gaps justifying an empirical investigation of Warabe gravel. A structured Google Scholar search yielded 260 studies, from which 30 thematically relevant empirical and review articles were selected and analysed across six dimensions: author and year, study focus, objective, methodology, key findings, and limitations. The review indicates that analogous washed, well-graded local gravels in Nigeria and similar regions can achieve compressive strengths of 24–30 N/mm^2, suitable for residential and low-to-medium rise structures. The Warabe and Mayo Ibbi deposits are described as sub-rounded, well-graded gravels with stable brownish-tan mineralogy; however, their rounded morphology may require mix optimisation to enhance mechanical interlock. Crucially, no published study specifically characterises Warabe gravel, creating an empirical gap. This review therefore establishes the scientific basis and urgency for a first-of-its-kind characterisation study.

Keywords: Coarse Aggregates; Warabe Gravel; Bama Gravels; Gwoza LGA; Mayo Ibbi; Concrete Production; Locally Sourced Materials; North-Eastern Nigeria

1 INTRODUCTION

The performance and long-term durability of concrete structures are inextricably linked to the properties of the aggregate they contain. Aggregates typically constitute 60–80% of concrete by volume and, in doing so, govern its workability, density, mechanical strength, and resistance to environmental degradation [1]. In regions where access to standardized, commercially processed aggregates is limited by cost or logistics, locally sourced materials become the primary and often sole practical option for construction. Borno State in North-Eastern Nigeria presents a compelling case in point. The state is in the midst of significant post-insurgency reconstruction and infrastructure expansion [2, 3]. Yet the construction sector continues to rely on imported stone chippings and formally processed aggregates that are prohibitively expensive for many projects. Against this backdrop, naturally occurring gravel deposits known collectively as 'Bama gravels' have become the de facto

aggregate source for concrete production across the region. Of particular significance are the coarse aggregate deposits found in Warabe, a locality approximately 15 km from Gwoza town in the Gwoza Local Government Area, situated at an altitude of 347 m above mean sea level (coordinates: 11.339° N, 13.612° E). These deposits extend into the Ajiyari region and are replenished by the Mayo Ibbi river system. Their abundance and accessibility have made them the primary aggregate source for both large-scale mechanized construction firms and local builders engaged in residential development. The extraction of these materials follows a dual modality. Heavy machinery, including excavators and front-end loaders, is deployed for high-volume commercial operations, while manual excavation and loading are used for smaller-scale projects a method that also facilitates informal at-source sorting for particle size [4]. Physically, the deposits are characterized by sub-rounded, well-graded alluvial gravels exhibiting a predominant brownish-tan colouration, indicative of stable mineralogical composition and significant prior fluvial transport. Despite their widespread practical application, no formal scientific investigation has ever been conducted to evaluate the mechanical properties, grading characteristics, chemical composition, or concrete performance potential of Warabe gravel. This constitutes a significant knowledge gap that has material implications for structural safety, construction quality, and the responsible management of a natural resource that underpins regional development. This paper addresses that gap through a systematic literature review. The review synthesises evidence from 30 published studies on locally sourced natural aggregates, recycled aggregates, and alternative construction materials drawn from Nigeria, Sub-Saharan Africa, and analogous developing-region contexts globally. The objectives are to establish the state of knowledge regarding the performance characteristics of natural local gravels in concrete; contextualise the Warabe deposits within that broader body of evidence; and articulate the scientific rationale and priority testing agenda for an original empirical investigation.

2 CONTEXTUAL BACKGROUND AND PROBLEM STATEMENT

2.1 Infrastructure Demand and Material Availability in Borno State

Borno State is experiencing reconstruction pressure following years of insurgency that devastated civilian infrastructure. Onundi et al. [5] documented the effect of the conflict on construction material quality in Maiduguri, finding that sandcrete blocks tested at 7-day compressive strengths as low as 0.253–0.634 N/mm^2 — values far below the 1.5 N/mm^2 minimum stipulated for load-bearing walls under Nigerian standards. Their study directly linked the forced use of inferior aggregate substitutes to widespread structural failures and building collapses in the conflict zone. This finding underscores the critical importance of validated, locally available aggregate sources in the region. Stone chippings (artificially crushed stone), the most widely used coarse aggregate in Nigerian concrete specifications, are extremely scarce in Borno State and prohibitively expensive when transported from quarrying centres. This reality has made Bama gravels the default aggregate for practically all concrete production in the region. Gideon et al. [6] documented an analogous situation in Akwa Ibom State, where locally sourced gravel costs approximately half the price of equivalent crushed granite, a disparity driven entirely by the elimination of rock-blasting and crushing processing requirements. In the context of post-conflict reconstruction and affordable housing, this cost advantage is transformative.

2.2 The Paradox of Unvalidated Local Aggregates

The paradox that characterises construction practice in Gwoza LGA — and, indeed, across much of informal construction in developing regions — is a profound one. A material relied upon for structural load-bearing applications is deployed in the absence of any published data on its fundamental engineering properties. This is not merely an academic concern. Gideon et al. [6] noted that any proposed use of locally sourced or blended materials must be preceded by rigorous structural and mechanical testing to evaluate both short- and long-term performance, and that past studies have repeatedly linked substandard materials, particularly poor-quality concrete, to building collapses. Fookes [7] established the foundational principle, still current today, that aggregate properties physical, mechanical, and chemical, directly determine concrete performance in both fresh and hardened states. The seminal review emphasised that geologically weathered rock used as aggregate is particularly problematic, leading to reduced strength, higher porosity, and accelerated deterioration. Without basic petrographic and mechanical characterisation, it is impossible to predict whether naturally occurring gravels such as those at Warabe will perform adequately or constitute a latent structural risk. This

review is therefore framed not as an academic exercise in aggregate science, but as a prerequisite for evidence-based construction practice in a region where structural failure carries direct human consequences.

3 REVIEW METHODOLOGY

This review follows a structured, systematic approach to literature selection and synthesis. The primary search term 'locally sourced aggregates concrete' was queried in Google Scholar, returning 260 results. The search was supplemented by targeted queries including 'natural gravel concrete Nigeria,' 'Bama gravel concrete,' 'aggregate properties concrete performance,' and 'recycled concrete aggregates developing regions.' From the combined results, 52 articles were identified as potentially relevant (approximately 20% of total results). Following full-text screening for thematic alignment, empirical rigour, and applicability to the study context, 23 studies were retained. Seven other studies were obtained through snowballing technique for detailed review. Inclusion criteria required that studies: (i) reported original empirical testing or comprehensive synthesis of aggregate properties or concrete performance; (ii) were published in peer-reviewed journals, conference proceedings, or verified technical reports; and (iii) addressed natural gravels, recycled aggregates, or locally sourced non-standard construction materials. Studies focused exclusively on admixtures, cement chemistry, or highly specialised industrial concretes were excluded as peripheral to the study's objectives. The 30 selected studies were systematically classified across six analytical dimensions: (1) author(s) and year of publication; (2) study title and focus; (3) research objective; (4) methodology; (5) key findings; and (6) identified limitations. This matrix-based approach, presented in Table 1 (Section 4), facilitates comparative synthesis and enables the identification of convergent evidence, contested findings, and research gaps. The flowchart of the methodological procedure is shown in Figure 1.

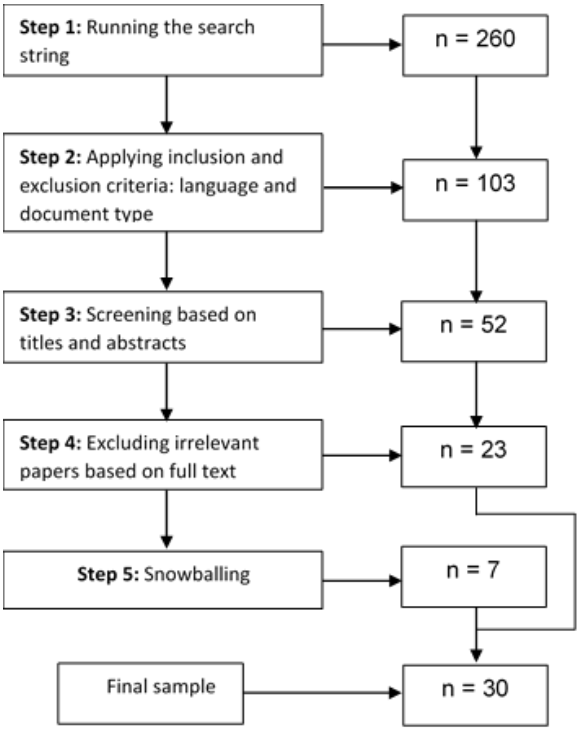

Figure 1. Flowchart of the data collection

4 SYNTHESIS OF REVIEWED LITERATURE

4.1 Natural and Locally Sourced Aggregates in Nigerian and West African Contexts

The closest analogues to Warabe gravel in the published literature are the 'Bama gravel' studies originating in Borno and Yobe States. Onundi et al. [8] conducted the foundational mix-proportioning investigation for Bama gravel (Category B), establishing the empirical relationship between water-cement ratio, fine aggregate content, and concrete compressive strength. Their study confirmed that strength is inversely proportional to both fine aggregate content and water-cement ratio — the canonical Abrams' rule relationship — and identified an optimal mix of 1½:4 with w/c = 0.55, which produced a 28-day strength of 28.00 N/mm^2 with a density of 2495 kg/m^3. This remains the only published

scientific benchmark for aggregate from this geological zone. Bamigboye et al. [9] demonstrated in Akwa Ibom State that properly washed local gravel is fully capable of meeting structural concrete targets. Their study showed that washed 10 mm gravel produced 29.7 N/mm^2 compressive strength at 28 days, exceeding the 25 N/mm^2 target, while unwashed gravel achieved only 24.5 N/mm^2 due to impurities that compromised cement–aggregate bonding. The lesson for Warabe gravel is unambiguous: particle cleanliness is a critical processing variable, and the established manual sorting practice at Mayo Ibbi may be functionally significant in ways that have never been quantified. Sulymon et al. [10] expanded the regional evidence base by testing gravel from 15 mining pits across five Southwestern Nigerian states. Compressive strengths ranged widely from 9.63 N/mm^2 to 24.81 N/mm^2 using a standard 1:2:4 mix; a variation attributable to differences in parent rock mineralogy, particle shape, and the degree of silty or clayey contamination. The study confirmed that while gravel-based concrete performance is location-dependent, many sources are adequate for low-rise and rural infrastructure. Crucially, the performance spread across those 15 sites would represent the baseline uncertainty facing any engineer specifying Warabe gravel without specific test data. Ajamu and Ige [11] compared gravel and crushed granite in Ogbomoso and found that machine-mixed granite concrete achieved 29.60 N/mm^2 versus only 15.11 N/mm^2 for equivalent machine-mixed gravel; a near-100% performance differential attributed to the superior mechanical interlock of angular crushed particles compared to smooth, rounded natural gravels. While this finding might initially appear discouraging for Warabe gravel, it must be contextualised: all aggregates in that study were classified as "poorly graded" according to USCS standards, suggesting that a well-graded, clean gravel deposit could substantially close the gap with granite. The well-graded, sub-rounded character described for Warabe gravel is a materially different starting point. Quayson and Mustapha [1] added nuance from a Ghanaian perspective, demonstrating that quartzite, a rock with lower individual particle strength than granite, nevertheless produced higher 28-day compressive strength (24.48 MPa versus 22.01 MPa for granite) in a 1:2:3 nominal mix. The mechanism was a denser interfacial transition zone (ITZ) facilitated by rougher surface texture of the quartzite and higher angularity, which reduced workability (slump of 15.23 mm versus 26.70 mm) but enhanced aggregate–paste bonding.

4.2 Role of Aggregate Morphology and Classification

The importance of systematic aggregate characterisation is reinforced by Fookes [7], whose foundational paper remains essential reading for any aggregate investigation. The paper argued persuasively that grading, particle shape, absorption, and chemical soundness collectively determine concrete performance, and that inadequate attention to geological weathering particularly in tropical and semi-arid environments is a common source of premature concrete failure. Vishalakshi et al. [12] demonstrated that the relative importance of aggregate type shifts with concrete strength grade. In normal-strength concrete (M30), aggregate mineralogy has negligible impact because the interfacial transition zone is the controlling weak link. In high-strength concrete (M80), however, aggregate type becomes the dominant strength-limiting factor, with Grey Granite outperforming Gneiss by a significant margin. Gudimettla et al. [13] demonstrated the utility of the Aggregate Imaging System (AIMS) for rapid, automated characterisation of angularity, surface texture, and sphericity. The system was shown to provide highly consistent, repeatable measurements that correlate strongly with performance parameters in both concrete and asphalt applications. While bespoke AIMS testing may not be immediately feasible in the Borno State context, the methodological framework it represents should inform the approach to Warabe gravel assessment.

4.3 Recycled and Alternative Aggregates: Transferable Insights

A significant body of the reviewed literature addresses recycled concrete aggregates (RCA) and non-conventional aggregate sources, the lessons from which are instructive for evaluating any non-standard material. Tabsh and Abdelfatah [14] demonstrated in the UAE that RCA from high-strength parent concrete (50 MPa) achieved strength properties comparable to natural aggregates, but RCA from weaker or unknown sources caused 10–40% strength reductions. The parallel for Warabe gravel is clear: aggregate source quality and geological consistency are fundamental determinants of performance, and characterisation cannot be assumed on the basis of visual similarity alone. Ahmed et al. [15] provided particularly valuable evidence from a full-scale field application in Canada, where concrete containing up to 100% RCA met 25–32 MPa target strengths and demonstrated no cracking or durability degradation over five years of monitoring in severe freeze-thaw conditions. This study bridged the

persistent gap between laboratory promise and field performance, demonstrating that locally non-standard materials can perform reliably when properly characterised and mix designed. The methodology, including the development of RAC-specific rebound hammer calibration curves, provides a transferable protocol for monitoring Warabe gravel concrete in the field. Islam et al. [16] employed a SWOT framework alongside conventional mechanical testing to assess volcanic scoria as a lightweight aggregate in Saudi Arabia, finding that despite logistical barriers (a consistent challenge for non-standard local materials in developing contexts), scoria-based concrete offered 15% weight reduction and 2.2% cost savings versus conventional concrete. Sims et al. [17] demonstrated in Qatar that processed Wadi gravel, after removal of gypsum-rich deleterious deposits, satisfied all alkali-aggregate reactivity criteria for structural concrete, including ASTM C1260 expansion below 0.20%. This is especially relevant for Warabe gravel: the arid Sahelian environment of Borno State is associated with sulphate and chloride mineral formation in superficial deposits, and chemical screening for deleterious substances must be a priority component of any characterisation programme.

4.4 Sustainable Aggregate Management and Policy Dimensions

Veraart [18] provided a historically grounded policy analysis of aggregate resource management in the Netherlands, tracing how domestic gravel extraction evolved across four distinct policy phases from technocratic national supply strategies in the 1950s to a spatially integrated, sustainability-conscious framework by the 2000s. A key finding that local environmental and spatial concerns drove the 'offshoring' of aggregate extraction to Germany, rather than genuine domestic resource scarcity is a cautionary tale directly applicable to Nigerian policy contexts. It illustrates how the absence of a coherent local aggregate development strategy generates unnecessary import dependency while wasting available domestic resources. For the Gwoza context, this policy dimension is urgent. The Mayo Ibbi river system is a finite alluvial resource, and its extraction is currently unregulated and unmonitored. Umar et al. [4], in their survey of alternative aggregates in Northern Nigeria, found that while 70% of contractors in Gombe State were aware of alternative locally sourced materials, none had adopted them, primarily due to the absence of a formal validation framework and client specification resistance. This gap between awareness and adoption reinforces that scientific characterisation alone is insufficient: institutional knowledge infrastructure, including a regional aggregate quality database and a riverbed management framework, is essential to translate research findings into lasting practice change. Table 1 presents a structured synthesis of the 30 reviewed studies, organised by author, study focus, objective, methodology, key findings, and limitations. Studies are grouped thematically rather than chronologically to facilitate cross-comparison.

Table 1. Structured Summary of Empirical Literature Reviewed

SN	Study Focus / Title	Objective	Methodology	Key Findings	Limitations	Author & Year
1	Natural aggregates in concrete: performance and durability	Review how natural aggregate properties affect concrete durability	Literature synthesis; classification of physical and chemical properties	Weathered rock reduces strength and accelerates deterioration; rigorous climate-specific testing essential	Review paper; qualitative; UK/temperate focus; no original data	[7]
2	Mix proportion effects on compressive strength of Bama gravel concrete	Establish optimal w/c and FA content for medium-grade concrete using Bama gravel	Concrete cubes from Bama gravel (Category B); varied mix proportions; tested at 7, 14, 28 days	Peak 28-day strength of 28.00 N/mm^2 at mix 1½:4, w/c = 0.55; strength inversely proportional to FA content and w/c ratio	High-quality medium-grade concrete; proportions and w/c must be carefully controlled when using Bama gravel	[8]
3	Strength of concrete from locally sourced gravel in South-South Nigeria	Assess washed versus unwashed local gravel as substitute for	Sieve analysis, specific gravity, ACV, slump, compressive strength (3–28 days); 1:2:4 mix, w/c = 0.62	Washed 10 mm gravel: 29.7 N/mm^2; washed 20 mm: 26.2 N/mm^2; unwashed	Fixed w/c ratio; small sample (45 cubes); no tensile/flexural or long-term testing	[9]

		granite in structural concrete		20 mm: 24.5 N/mm² (below target)		
4	Engineering properties of concrete from gravels in Southwestern Nigeria	Evaluate suitability of locally sourced gravels across five states as granite substitutes	15 mining pits; 1:2:4 mix, w/c = 0.6; tested slump, density, compressive/flexural/split tensile strength at 28 days	Compressive strength: 9.63–24.81 N/mm^2; flexural: 2.17–3.50 N/mm^2; split tensile: 1.71–2.80 N/mm^2. Many gravels suitable for low-rise and rural structures	Fixed mix ratio; no long-term durability tests; gravel properties vary significantly by source	[10]
5	Influence of coarse aggregate type and mixing method on concrete properties in Ogbomoso	Compare gravel and crushed granite; evaluate impact of mixing method on workability and strength	Sieve analysis, compaction factor, compressive strength (7–28 days); 1:3:6 mix, w/c = 0.65; three mixing methods	Granite (machine-mixed): 29.60 N/mm^2; gravel (machine-mixed): 15.11 N/mm^2. All aggregates poorly graded (USCS); machine mixing recommended	Machine mixing and granite aggregate recommended; gravel required for higher strength applications	[11]
6	Influence of locally available coarse aggregates on compressive strength of normal-weight concrete in Ghana	Compare crushed granite and quartzite in a standard mix for fresh and hardened concrete performance	1:2:3 nominal mix; workability (slump), density, and compressive strength at 7 and 28 days compared for two aggregate types	Quartzite: 24.48 MPa at 28 days (denser ITZ, lower slump = 15.23 mm); granite: 22.01 MPa (slump = 26.70 mm). Neither met 30 MPa target	Non-linear strength gain pattern (peak at 7 days); neither aggregate met design target with nominal mix	[1]
7	Effect of coarse aggregate type on mechanical properties and fracture energy of normal to high-strength concrete	Determine how aggregate mineralogy affects strength and fracture behaviour at M30, M50, and M80 grades	Five igneous/metamorphic aggregates (Granite, Anorthosite, Charnockite, Limestone, Gneiss); standard cube and beam tests	Aggregate type negligible in NSC but dominant in HSC; Grey Granite yielded highest compressive strength and fracture energy in M80 concrete	Limited to laboratory conditions; no field validation; results specific to tested rock types	[12]
8	Compressive strength of concrete made from natural fine aggregate sources in Minna, Nigeria	Investigate how fine aggregate source affects concrete strength and develop predictive regression models	Five FA samples (A–E) from Minna; three mix proportions (1:2:4, 1:2:3, 1:1:2); w/c = 0.4–0.6; 28-day compressive strength; regression modeling	Compressive strength: 18.97–34.98 N/mm^2; all FAs met BS 882:1992 grading; regression models achieved R^2 = 0.891–0.991	Only 28-day strength tested; limited to one coarse aggregate type (gravel); models not generalizable beyond Minna	[20]
9	Impact of Boko Haram insurgency on construction material quality in Maiduguri	Assess how conflict-driven supply disruptions compromise construction material quality	Field sampling and laboratory testing of blocks, cement, steel, and aggregates; comparison with standards	Sandcrete blocks failed at 0.253–0.634 N/mm^2 (vs 1.5 N/mm^2 standard); inferior aggregates used; steel reinforcement undersized	Context-specific to conflict environment; limited generalisation to normal construction conditions	[5]
10	ANN modelling of slump for Bida Natural Gravel concrete	Develop an accurate predictive model for workability of BNG concrete as a sustainable granite substitute	36 BNG concrete mixes; ANN architectures (5–20 neurons, Levenberg–Marquardt training) compared with MLR	Best ANN (5:20:1): MSE ≈ 0, R = 98%, NSE = 0.96; significantly outperformed MLR (MSE = 0.83, R = 88.68%)	Slump prediction only; limited to specific BNG materials and proportions; no external validation	[21]
11	AAR potential of processed Wadi gravel in Qatar as	Assess alkali–aggregate reactivity of Wadi gravel through	Petrography (BS 812-104); accelerated mortar-bar (ASTM C1260); concrete	Gravel classified non-expansive (BS 812-123); ASTM C1260 expansion <	Al-kharaji expansion varies with particle size; alkali-release	[17]

	replacement for imported gabbro	multi-phase testing to justify structural application	prism expansion (RILEM AAR-4.1, BS 812-123)	0.20%; safe with GGBS or FA mitigation	method not finalised; limited long-term data for one deposit	
12	Influence of recycled concrete aggregates on strength properties of concrete (UAE)	Test viability of RCA from high-strength parent concrete in new structural concrete mixes	RCA from 30 MPa and 50 MPa parent concrete; ASTM toughness and soundness tests; 80 cylinders; 25–50 MPa target strength	RCA from 50 MPa parent = comparable strength to natural aggregate; lower-quality RCA → 10–40% strength loss; +10% water demand	Only two target strengths tested; no durability data; fine RCA not studied	[14]
13	Field application and long-term performance of recycled aggregate concrete (Canada)	Validate large-scale, commercially produced RAC in real structural applications under freeze-thaw conditions	Full-scale sidewalk (32 MPa) and foundation (25 MPa) with 0–100% RCA; 5-year monitoring; rebound hammer calibrated for RAC	RAC met target strengths; long-term performance comparable to conventional concrete; no cracking after 5 years in −24.8°C environment	Limited to ≤ 30% RCA for highest strengths; no microstructural or corrosion data; only 5-year monitoring period	[15]
14	Use of local volcanic waste scoria as LWA for structural lightweight concrete in Saudi Arabia	Evaluate scoria-based LWC as a sustainable alternative to limestone NWC; include commercial SWOT analysis	Three mixes (NWC, LWC, SLWC with 7% silica fume); mechanical and NDT tests; SWOT analysis and cost estimation	LWC = 78%, SLWC = 86% of NWC strength; 15% lighter; SLWC 2.2% cheaper; high R^2 > 0.9 UPV-strength correlation	Lab-scale only; high water absorption; regional applicability limited; logistics costs remain a barrier	[16]
15	Shear strength of plain concrete using recycled low-strength concrete aggregates (Kuwait)	Investigate how RCA from low-strength demolition waste affects push-off shear and compressive strength	90 push-off specimens; varied aggregate type (RCA, limestone, gabbro); w/cm = 0.31–0.72; linear-elastic FEA validation	$v_{po} = 0.7\sqrt{f_{cu}}$ valid for both RCA and NA; smoother fracture surfaces in RCA concrete indicate weaker ITZ	RCA sourced from low-strength demolition concrete; no long-term durability or environmental impact assessment	[22]
16	Review of alternative aggregates for sustainable concrete production in Northern Nigeria	Identify and evaluate 14 locally available or waste-derived materials to replace sand and gravel	Literature survey + survey of 25 registered contractors in Gombe State	PKS, WGC, CR, plastics, burnt bricks and ceramics are viable; 28-day strengths: 14–55 N/mm^2; 70% contractor awareness but 0% adoption	No empirical testing; adoption barriers (project complexity, client specifications) identified but not quantified	[4]
17	Metallurgical sludge as sand substitute in CSA cement mortar	Assess feasibility of hazardous sludge as a fine aggregate substitute and mitigate its adverse effects on mortar	10–30% sludge replacement; CEM I and CSA cement; superplasticizer; ANOVA analysis; SEM/MIP characterisation	10% CSA effective for setting retardation; up to 20% sludge viable with superplasticizer; >20% CSA reduces 28-day strength	Mortar-scale only; sludge variability unaddressed; no concrete-scale or durability testing	[23]
18	Influence of fine aggregate source on concrete strength in Anambra and Imo states, Nigeria	Provide localised guidance on fine aggregate selection and develop a predictive strength model using RSM	Three river sands; 1:1.5:3 mix, w/c = 0.6; slump and compressive strength; Response Surface Methodology	Uli sand: 33.02 N/mm² (lowest workability, 20 mm slump); Njaba: 28.65 N/mm^2; model: $f = 23.44 - 1.19A + 6.90B$	Location-specific results; limited to one coarse aggregate type; no long-term or durability tests	[24]

Source: Author's compilation from reviewed literature.

5 DISCUSSION

5.1 Convergent Evidence on Local Gravel Performance

Across the reviewed studies, it is noted that locally sourced natural gravels, when clean, well-graded, and mix-designed appropriately, are capable of producing concrete that meets the structural requirements for low-to-medium rise construction. Studies from Nigeria [8, 9, 10], Ghana [1], and the broader developing world context converge on compressive strength ranges of 20–30 N/mm^2 achievable with gravel-based mixes, with performance sensitive to cleanliness, grading, and water-cement ratio. These findings collectively establish the technical plausibility of Warabe gravel but do not constitute evidence of its actual suitability. The sub-rounded, well-graded character of Warabe gravel deposits is, on the basis of the reviewed literature, a more favourable starting profile than the poorly graded or contaminated gravels reported in several cited studies. Dense particle packing, enhanced concrete flow, and reduced void content are associated benefits of rounded, well-graded particles [7, 19]. The trade-off of reduced mechanical interlock compared to angular crushed stone is real but manageable through mix design, particularly the water-cement ratio optimisation demonstrated by Onundi et al. [8] for analogous Bama gravel deposits. The most fundamental gap revealed by this review is the complete absence of published data on Warabe gravel's engineering properties. No study has reported its particle size distribution, specific gravity, aggregate crushing value (ACV), aggregate impact value (AIV), water absorption, flakiness index, elongation index, or chemical composition. Without this baseline characterisation, the deposits cannot be specified in engineering contracts, tested for standard compliance, or responsibly incorporated into structural designs. The distinction between informal use which has occurred for decades and validated engineering application is precisely this body of empirical evidence.

5.2 Implications for Construction Practice and Policy

The practical implications of this review are threefold. First, there is an immediate need for a comprehensive empirical characterisation programme for Warabe gravel, covering physical, mechanical, and chemical properties against standard classification frameworks [25, 26]. This must include concrete trial mixes at multiple strength grades to establish performance envelopes and water-cement ratio relationships analogous to those published for Bama gravel by Onundi et al. [8]. Second, the institutional framework for aggregate quality assurance in Gwoza LGA requires development. The current dual-extraction model mechanical for large-scale and manual for residential has no formal quality monitoring component. Drawing on the policy lessons from Veraart [18] and the contractor awareness findings of Umar et al. [4], a regional aggregate quality database linked to site-specific characterisation studies would provide the knowledge infrastructure necessary to transition from informal reliance on unvalidated materials to evidence-based engineering practice. Third, the Mayo Ibbi River system requires a sustainable riverbed management framework. Unregulated alluvial extraction poses ecological risks such as channel destabilisation, riparian habitat loss, altered sediment transport dynamics that threaten the long-term viability of this resource. The Dutch experience documented by Veraart [18] is instructive: deferred environmental regulation eventually forces costlier interventions. Early integration of extraction limits, monitoring protocols, and seasonal restrictions would protect both the resource and the river system's ecological functions.

6 CONCLUSIONS

The primary conclusion of this review is unambiguous: while the theoretical and contextual case for Warabe gravel as a viable construction aggregate is strong, no published scientific evidence exists to validate that case. This knowledge gap constitutes a fundamental barrier to responsible engineering practice. The deposits are currently used for structural concrete on the basis of tradition and economic necessity rather than empirical evidence. This review establishes both the scientific context and the urgent justification for first-of-its-kind empirical characterisation of Warabe gravel. A secondary conclusion is that the global evidence base on locally sourced aggregates particularly from Nigerian, West African, and developing-region contexts provides a robust methodological framework for that characterisation programme. The specific testing protocols, mix design approaches, and performance benchmarks established in the reviewed literature constitute a ready-made technical roadmap for Warabe gravel investigation. Based on the synthesis of reviewed literature, the following recommendations are made for future research and practice: A systematic physical and mechanical

characterisation of Warabe gravel should be conducted as an immediate priority, including particle size distribution (ASTM C136), specific gravity and water absorption (ASTM C127), ACV, AIV, flakiness and elongation indices, and Los Angeles abrasion loss (ASTM C131). Chemical analysis including sulphate and chloride content, alkali-silica reactivity screening (ASTM C1260), and organic impurity testing should be conducted to screen for deleterious substances consistent with Sahelian geological environments. Concrete trial mixes at multiple strength grades (M20, M25, M30) and water-cement ratios should be produced to establish strength-w/c relationships and workability envelopes.

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