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Suitability of River Sand for Production of Concrete: Focus on Engineering Properties and Cost-Benefit

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Abstract

The utilization of river sand in construction is a widespread practice globally, resulting in a surge in demand for it. This research aims to assess the applicability of river sand in engineering applications and to determine its cost-effectiveness. The American Society of Testing Materials carried out evaluations on sand samples to ascertain their engineering qualities, including silt content, fineness modulus, moisture content, and specific gravity. Concrete cubes with a 1:2:3 mix ratio underwent compressive strength tests at 7, 14, and 28 days. The study analyzed the economic viability of river sand based on the relationship between the cost of producing a single cube and its compressive strength at 28 days. Sugele's sand had the least silt content, measuring 5%, while Didiga's sand had the highest at 17%. The compressive strengths of Didiga and Sugele river sands were 13.01 and 26.489 MPa, respectively, with the former and latter having the lowest and highest compressive strengths.

Keywords: cost/benefit, concrete, compressive strength, engineering properties, sand

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1. Introduction

The utilization of concrete is a ubiquitous practice in construction projects across the globe. The quality of this material is contingent upon several factors, with the purity of the aggregate being a crucial one[1]. The two primary constituents of concrete are paste and aggregate, comprising cement, water, and occasionally other cementitious and chemical additives, along with sand, gravel, or crushed stone. As aggregates comprise a substantial proportion of concrete (roughly 70-80%), their quality plays a pivotal role in determining the overall quality of the final product[2][3][4]. While river sand is a common selection for construction projects, its overuse has resulted in negative impacts, such as reduced water tables, saline intrusion, and increased riverbed depths. Riverbeds and natural deposits remain the fundamental and most economical sources of sand for construction purposes[5][6][7]. Regrettably, Bule Hora town does not subject the use of high-quality sand to specific criteria.

The characteristics of fine aggregate are significantly impacted by its gradation and the quantity of silt, clay, and organic pollutants present within it. It is important to note that silt materials are smaller than the No. 200 sieve size and cannot interact cohesively with cement, fine aggregate, or water due to their non-cohesive nature[8][9]. However, when exposed to water, they can react with concrete and cause hairlines or significant fissures. Therefore, it is imperative to understand the influence of silt on fine aggregate quality to ensure that the final product meets the required standards[10]. Ensuring the appropriate silt content of sand is of utmost importance to sustain the compressive strength of concrete[11]. Additionally, the grading of fine aggregate plays a crucial role in determining the physical and chemical properties of concrete. Fine aggregate that contains excess coarseness can lead to a mix that is harsh and prone to bleeding and segregation. Conversely, if the fine aggregate is too fine, it can increase water usage and potentially cause segregation[12].

The primary sources of fine aggregate (sand) in and around Bule Hora are pits and riverbeds. The characteristics of natural sand have not yet been made obvious to stakeholders. The primary determinants of the workability and compressive strength of acceptable grade and good quality concrete are sand gradation, clay and silt content, and organic impurities, which cannot be obtained from vendors even in a single day's supply. Because of the unclear quality of sand supplies, there is also an adversarial standardization among sand suppliers, contractors, customers, and other specialists in the building sector[12][13]. Engineers and experts can choose adjacent sand sources with potential corrective methods, such as blending, washing, and screening, for the intended purpose if the attributes of sand sources are understood[14].

In Bule Hora, the current manufacturing process used for fine aggregate is not up to modern standards. This can lead to inconsistent sizing and exposure to harmful chemicals. One major issue is the lack of quality control, standardization, and a dependable supply from a single location. A comprehensive study was carried out to assess the potential of utilizing natural river-type fine aggregates in concrete production within Bule Hora and the surrounding areas, specifically in the West Guji Zone.

2. Materials and Methods

2.1. Materials

2.1.1. Cement

Portland Pozzolana Cement (PPC) pumice powder used as a natural pozzolan 32.5N grade which comprises of 70%

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clinker, 25% pozzolana (pumice) & 5% gypsum. It conforms to CEM II/B-P in accordance with EN 197:1:2000[15] Cement Part 1: composition, specifications & conformity criteria for common cements. According to ASTM C 187-04[16], using a manual Vicat Apparatus for Dangote PPC cement had a 30% consistency and Specific gravity is 3.15.

Fig. 1. Cement and Consistency of cement.

2.1.2. Coarse Aggregate

Natural granite aggregate having density of 1700kg/m3 and specific gravity was found to be 2.54 and water absorption as 0.502%.

Fig. 2. Specific gravity, unit weight and moisture content coarse aggregate.

2.1.3. Fine Aggregate

Sand was supplied to the market from four different river sand sources: Didiga, Oda, Bokosa, and Sugele. The four samples of river sand were taken from an actual riverbed. The locations of Didiga, Oda, Bokosa, and Sugele were used to collect sand samples. In order to conduct physical and mechanical testing, 50 kg of sand samples are taken from each supply point. A tag was placed on the sample bag. To reflect the supply point and prevent bias, each sand sample was given a tag. Didiga [DD], Oda [OD], Bokosa [BK], and Sugele [SG] were the labels given to each local supply point in the appropriate manner and all physical properties of different sand sources are presented in result section.

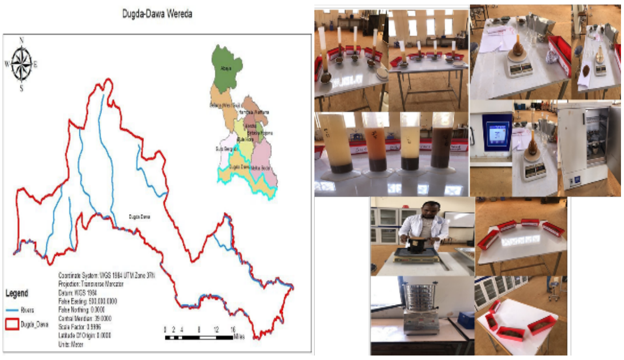

Fig. 3. Sand Sources and physical properties test on sand.

2.1.4. Water

Concrete mixing, curing, and washing are all done with regular tap water from the building material lab at Bule Hora University.

Fig. 4. Concrete mixing and Curing.

2.1.5. Mix Characteristics

Concrete was mixed in batches according to weight. Nine combinations were examined, and a total of 36 cubes were made utilizing a combination of fine and coarse aggregates in a 1:2:3 mix ratio and 0.48 water/cement ratio. This test mixture was created for a volume cube with the dimensions V = 0.15*0.15*0.15. The mix design for C-25 air entrained normal concrete strength was done as per ACI 211.1.mix design procedure manual [17].

Table 1. Concrete material proportion for 1 m^3.

Ingredient of the concrete (in kg)	**Sand source**			
	Didiga	**Bokosa**	**Oda**	**Sugule**
Cement	427	427	427	427
Coarse aggregate	1035.37	1028.53	1079.79	1153.944
Fine aggregate	538.648	499.343	484.585	405.619
Water	191.345	198.87	196.716	196.086

Fig. 5. Cubes mobilization and compression testing.

3. Results and Discussion

3.1. Workability test

The ease with which concrete flows and conforms to its mould is evaluated using a test known as workability. For all trapped air to be released and for the concrete to fully acquire the shape of its mould, workable concrete needs less compaction. When the water-to-cement ratio is the same, concrete with high-quality aggregates will have higher workability, higher compressive strength, less bleeding, and less component segregation than concrete with low-quality aggregates. Figure 6 contains a summary of the slump test findings for the several types of sand sources that were employed. In accordance with the planned slump range of 75mm to 100mm, Figure 6 showed that the results obtained from the workability test. There were good finishes, good visuals, and slumps that were all quite comparable to fresh behaviour. The slump value of 90.5mm of the Sugule river sand was produced by the collapse. Due to the aggregate's spherical form and smooth surface texture, the Sugule river sand high slump was attributed. Due to their physical characteristics (angular forms and rough surface textures), the remaining sand sources have low slump values[9]. From the aforementioned, it is now clear that concrete formed with Sugule river sand is more workable and stronger than concrete produced using Oda, Didiga, and Bokosa. However, in order to obtain a good mix and correct compaction, concrete built from except Sugule sources would need a greater water-to-cement ratio. Due to its physical characteristics (angular forms and rough surface textures), the increased water-to-cement ratio is caused by these characteristics[18].

3.2. Fineness

As per the standard, the fineness modulus (FM) of the fine aggregate should fall between 2 and 3.5, with a tolerance of 0.2. Upon thorough analysis and careful assessment of the results and information provided in reference, it has been determined that all sand sources used in the experiment have met this particular requirement. To elaborate further, the particle size distribution of the fine aggregate used in the experiment has been established according to ASTM 136-14[19] and is available in Table 2. Moreover, the sand module fineness result has been calculated to be 2.98%, which indicates that all the sand sources have complied with the requirement mentioned in reference regarding the fineness modulus of fine aggregate, which should be in the range of 2.3 to 3.1. In contrast to pit sands, which typically include spherical particles, river sands typically contain irregular and angular particles due to attrition and wave action. Compared to smooth and round particles, those with rough and angular surfaces bond more tightly with cement paste and coarse aggregates. Based on this detailed analysis, it can be safely concluded that the fine aggregate used in the experiment meets the standard and follows the required specifications.

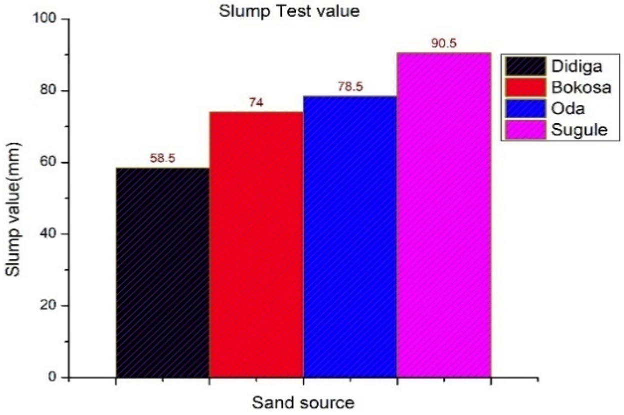

Fig. 6. Slump values.

Table 2. Fineness modulus of sand.

Sand sample site	Didiga	Oda	Sugele	Bokosa	ESC.D3.201
FM	2.69	2.59	2.86	2.91	2.0–3.5

3.3. Silt content

The finer sand particles cause rapid degradation, which reduces the strength and quality of the combination. According to the sand samples examined, the maximum silt concentration was an astounding 17% for the Didiga site and only 5% for the Sugele location (Figure 3). As a result, testing the silt and comparing it to allowable limits is critical. The permitted silt concentration in the sand is 6%, according to Ethiopian standards, as stated in[20]. According to the calculation of the silt content of the sand samples from various sources, the silt content of the three sand samples under examination exceeded the maximum permitted value of 6%[20]. According to Ethiopian standards cited through, only one sand source sample meets this requirement. The ASTM C117[21] and ASTM C33[22] specifications limit the amount of material that can pass through the Silt Content sieve to 5%. Figure 7 demonstrated that, aside from the Sugele sand source, the other sand samples could not meet ASTM standards. This implies that silt and clay impurities make up 170 kg of a ton of sand. When purchasing sand for construction, value for money is not realized because silt and other impurities account for more than half of such sand.

3.4. Gradation

The tabulated findings are provided in Table 3, and they were used to calculate the coefficient of curvature and uniformity. According to Ethiopian Standard cited through[20], none of the sand sample's components fit through the sieve with a 150 mm opening. The Bokosa site met the requirements for the sieve sizes 9.75, 4.75, and 2.36 mm but fell short of the 300 µmm requirement.

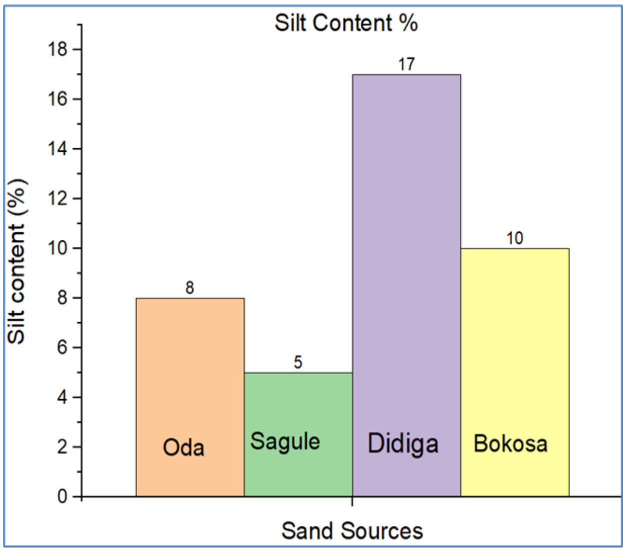

Fig. 7. Silt contents of the sands.

Table 3. Cumulative volume dimensions along with median size

Sand source	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)
Didiga	0.306	0.45	0.921
Oda	0.288	0.429	0.769
Sugele	0.260	0.429	0.857
Bokosa	0.305	0.450	0.963

Where, D60 = Size of the particle corresponding to 60% finer; D30 = Size of particle corresponding to 30% finer; and D10 = Size of the particle corresponding to 10% finer.

Table 4. Coefficient of uniformity and coefficient of curvature

Sand source	$Cu=D_{60}/D_{10}$	Cc	Description	Standard values
Didiga	3.01	0.718	Uniformly graded	Cc =1–3{Well graded} Cu > 5- {Well graded} Cu =1-5{Uniformly graded} Cu <1-{poorly graded}
Oda	2.67	2.948	Uniformly graded	
Sugele	3.296	0.825	Uniformly graded	
Bokosa	3.157	3.094	Uniformly graded	

Cc = (D30)2/(D10*D60)

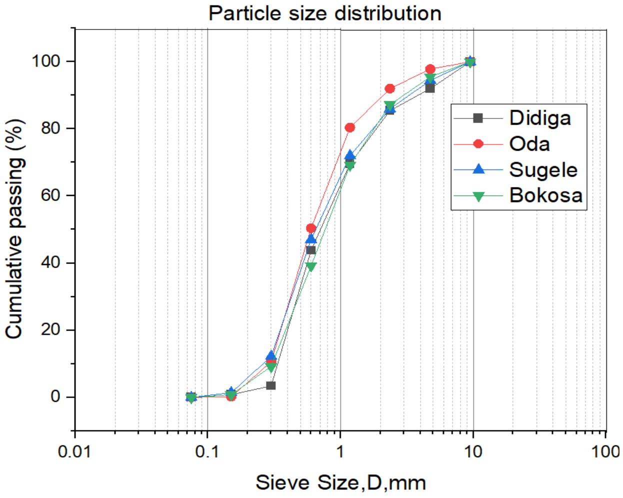

Fig. 8. Particle size distribution of the fine aggregates.

3.5. Specific Gravity

The data presented in Figure 9 indicates that all sand samples evaluated fell within the specified range for relative densities, which is expected for naturally occurring aggregates. The range of relative densities observed was between 2.3 and 2.9, as per specifications. Of the four sand samples evaluated, the Didiga sand exhibited the highest saturated surface dry specific gravity, while the Bokosa sand had the lowest. The specific gravity values for sand used in concrete production must fall within the range of 2.4 and 3.0, as required by the Ethiopian Standard cited through[20]. This indicates that, the sand sources investigated are within the acceptable range for the production of structural concrete. This explains why the slump seen and the water absorption by pores were unique to a given sand sample based on the method of sample production, such as river sand or pit sand.

3.6. Unit Weight

Within the context of this particular research, a sample consisting of aggregates that have been thoroughly dried in an oven was utilized. In order to accurately measure concrete batching, weight amounts were converted into volume amounts through the implementation of the bulk density method. As per the guidelines established by the ACI Committee E-701 in 2007[23], the bulk density of normal-weight concrete aggregates typically falls within a range of 1200 to 1760 kg/m3. Upon reviewing Table 5, it can be determined that all loss and compacted samples possess an average unit weight that is in alignment with this aforementioned range.

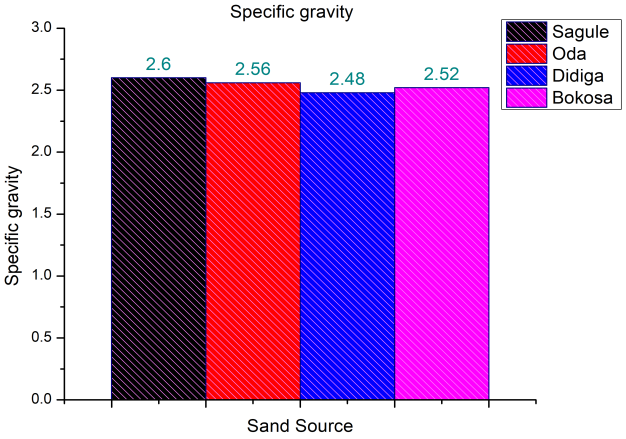

Fig. 9. Specific gravity of the sands.

Table 5. Unit weight of sands.

Source of sand	Didiga	Oda	Sugele	Bokosa
Unit weight of sand (kg/m3)	1563.33	1716.67	1733.33	1653.33

3.7. Water Absorption

To ensure accurate batching weights and maintain precise control over the water content in concrete, it is essential to conduct absorption tests on aggregates using ASTM C 128 [24]. Aggregate particles are made up of solid matter and voids, some of which may contain water. Typically, fine aggregate has a moisture content at SSD ranging from 0.2% to 1.6%. However, as shown in Table 6, it is important to note that Didiga and Bokosa sand have water absorption rates exceeding the limit at 16% and 20%, respectively, due to their higher content of silt. Conversely, other sources of sand adhere to near the limit. The result showed that the water absorption amount of all sand samples is above 6 % than the allowable limit as shown in below Table 6.

Table 6. Water absorption.

Source of sand	Didiga	Oda	Sugele	Bokosa
Water absorption (%)	16	6	6	20

3.8. Moisture Content

When designing concrete, it's common to specify a water-cement ratio with the assumption that aggregates won't absorb or give water to the mixture. However, this assumption doesn't hold for most aggregates, which can come from different sources and have varying moisture levels. The moisture content of aggregates can significantly affect the design water-cement ratio, workability, and strength of the mix. To ensure accuracy and consistency in concrete design, it's essential to determine the moisture content of the aggregates being used. One way to do this is to oven-dry two samples of fine aggregate and divide the weight difference by the oven's dry weight[23]. This will give you the moisture content of the fine aggregates, and corrective measures can be taken for absorption and free moisture to ensure that the water-cement ratio remains consistent with the mix design. The average moisture content of the two samples can be found in Table 7.

Table 7. Moisture content.

Source of sand	Didiga	Oda	Sugele	Bokosa
Moisture content (%)	1.6	0.6	0.6	0.2

3.9. Compressive Strength

The testing for compressive strength was carried out meticulously in accordance with the standardized procedures of ASTM C39-03[25]. Each of the samples consisted of 9 cubes, measuring 150 mm x 150 mm x 150 mm, which were cast and submerged in water at room temperature for curing. On days 7, 14, and 28, the samples were evaluated for compressive strength by loading them at a rate of 13.5 N/mm2 per second, and the average was calculated from the three cubes tested. The results are presented in Table 8. All the specimens were put under axial compression using a compression testing machine (CTM) with a maximum capacity of 2000 KN. The load was applied until the specimen's resistance to the load decreased, ultimately resulting in its failure, and no further load could be sustained. As demonstrated in Table 8 and Figure 10, it is evident that various fine aggregates sources show a cumulative increase in compressive strength over time, at all ages. The maximum compressive strength at all edges is found in Sugele and Bokosa river sand, which is followed by Oda in third, Didiga in last at all ages. However, based on the findings in Table 8, all four samples failed to achieve the minimum strength expected on days 7 and 28. Since all the samples were subjected to the same casting and curing conditions, this failure can be largely attributed to other factors[26][27]. The aggregate physical characteristics, specific gravity, and workability findings values as displayed in Tables 3, Figure 2 and Figure 9 respectively, may be linked to the cause of these trends in compressive strength. Additionally, the mechanical characteristics are significantly influenced by the fine aggregate surface area. The workability of the concrete, the specific gravity of the fine aggregate, and the compressive strength of the concrete all increase as fine aggregate physical qualities improve. The results obtained are given in the figure.

Table 8. Compressive strength result.

Source	No.	Compressive strength (MPa)			Deviation of 28 days MPa from expected
		7 days	14 days	28 days	
Didiga	1	6.849	9.2	13.41	
	2	6.969	9.21	12.911	
	3	6.956	9.17	12.71	
	Avg.	6.956	9.17	13.01	-11.74
Oda	1	14.835	18.52	24.73	
	2	13.893	20.55	21.71	
	3	14.404	19.8	24.31	
	Avg.	14.377	19.623	23.58	-1.42
Bokosa	1	13.191	17.507	19.6	
	2	13.316	17.049	20.69	
	3	13.147	16.609	21.94	
	Avg.	13.218	17.055	20.743	-4.257
Sugele	1	16.355	22.11	26.036	
	2	15.209	21.75	27.56	
	3	15.55	20.76	25.87	
	Avg.	15.704	21.54	26.489	+1.489

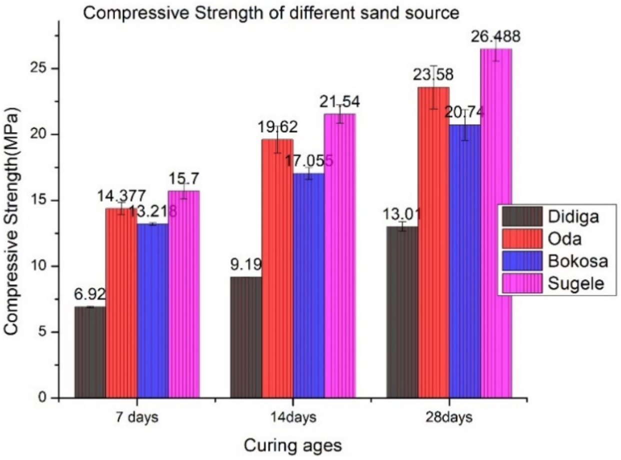

Fig. 10. Compressive strength of the sand.

3.10. Cost-Benefit of Using Natural Sands for Concrete Production

A number of manufacturers and suppliers who deal in aggregates have come forward to disclose the costs and details of the building materials and aggregate products they offer on the market. As per the data presented in Table 9, Bule Hora and Dugda Dawa, two significant producers of aggregate, along with material suppliers, have shared the prices of the components that are utilized in the production of concrete. It is worth mentioning that the cost of transporting natural sand to the desired location is not included in the overall price. The most recent cost analysis was carried out in February 2023, and the prices for cement and aggregate are listed in Ethiopian Birr (ETB) per quintal and cubic meter (m3), respectively.

Table 9. Summary of costs for materials used in cost calculation.

	Bule Hora	Dugda Dawa
Cement		
Dangote PPC (Birr/bag)	1620	1800
Fine aggregate		
Including transport (Birr/m^3)	625	531.25
Coarse aggregate		
Including transport (Birr/m^3)	1687.5	1562.5
Water (Birr/litre)	0.5	0.5

When calculating the cost of producing concrete, it is essential to consider the price per unit of each component used in the mix. To achieve this, Table 10 is consulted to obtain the pricing for cement, sand, and coarse aggregate. Additionally, a minimal cost for water is also included in the calculation. It is important to note that labor costs are not factored into this calculation as they remain constant. By carefully considering each component's cost, a more accurate estimation of the total cost of producing concrete can be obtained.

The prices for construction materials are as follows: Sand ranges from ETB 0.531 to ETB 0.72 per kilogram, depending on the fineness modulus. Coarse aggregate costs ETB 1.687 per kilogram, while cement costs ETB 16.2 per kilogram. Water is priced at 0.5 ETB per kilogram. Please note that the price of sand may vary depending on market conditions.

Table 10. Quantities per unit volume of concrete constituents, the total cost for one cube and cost-benefit ratio.

Ingredient of the concrete (kg)	**Cost (ETB)**	**Sand source**			
		Didiga	**Bokosa**	**Oda**	**Sugule**
Cement	16.2	427	427	427	427
Coarse aggregate	1.687	1035.37	1028.53	1079.79	1153.944
Fine aggregate	0.531-0.72	538.648	499.343	484.585	405.619
Water	0.5	191.345	198.87	196.716	196.086
F.M.		2.69	2.91	2.59	2.86
Total cost for cube		29.15	28.73	28.88	28.92
Compressive strength@28 days		13.01	20.743	23.58	26.489
Cost/Benefit		2.24	1.385	1.22	1.091

The aforementioned rates and quantities from the mix design are used to compute the cost of concrete. The cost-benefit ratio is computed using the cost of concrete and the associated 28-day compressive strength. Concrete prices are computed based on the quantity of raw materials utilized and the market rates mentioned above.

Cost Benefit Ratio is calculated as:
C/B ratio = Total cost of Concrete/28 days Compressive Strength

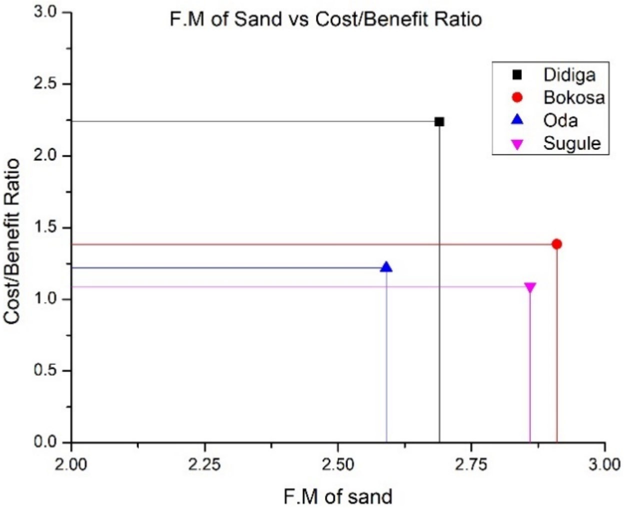

Fig. 11. FM of sand Vs. C/B Ratio.

As depicted in Figure 11, there is a distinct correlation between the CB ratio and the FM of sand. It is worth noting that the C/B ratio tends to decrease as the FM of sand increases, except for the Didiga site, which contains high levels of silt. This indicates that the source of sand has a significant impact on the C/B ratio. Moreover, there was a notable reduction of 42.86% in the C/B ratio between FM 2.4 and 2.7. Hence, it is highly recommended to employ coarser sand in concrete applications to achieve optimal outcomes[28].

4. Conclusions

This study primarily focused on the physical properties of river sands, such as their moisture absorption, moisture levels, specific gravity, grading, and silt content. The study also analyzed how these characteristics affect the workability of fresh concrete (measured by slump) and the compressive strength of hardened concrete. Additionally, the study considered the fineness modulus and 28-day compressive strength of sand from four different quarry sites to determine the cost-benefit ratio of each one.

- The study found that construction sand was sourced from the Didiga, Bokosa, Oda, and Sugele Rivers in the Dugda Dawa district and West Guji Zone. However, the sand from these sources had silt and clay contents that exceeded the allowable limits, ranging from 5% to 17% for unwashed sand.
- The water absorption amount of all sand samples was also found to be 6% above the allowable limit due to their higher silt content.
- The particle size distribution and fineness modulus (FM) of the sand were checked according to ASTM C 33/ESC.D3.201 standards, and all samples were within the range of geological grading set by Ethiopian standards for the four sand sources. Oda and Bokosa sands were identified as the finer and courser sand sources, respectively. Unfortunately, all concrete cubes made from river sand with varying impurities failed to meet the design strength of 25 MPa at 28 days old. Based on these results, it can be concluded that the sand samples did not meet the necessary standards for construction.
- According to the result obtained, Sugele sand source has the highest compressive strength with 26.489 MPa attributed to its lower silt content meanwhile Didiga sand source has the compressive strength with 13.01 MPa.
- Higher the silt content and finer sand sources resulted in lower compressive strength which subsequently yield higher cost/benefit ratio. Accordingly, Didiga sand source has maximum cost/benefit ratio of 2.24 while Sugele sand source has the least value of 1.091.

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