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Research Article

Unlocking the Secrets of Residential Construction: Investigating Aggregate Properties for Optimal Building Performance

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ABSTRACT

The objective of this study was to find the strength of aggregates from selected three rivers and suggest to use aggregates for construction from the rivers, where better quality and strong aggregates exists. Aggregates from three selected rivers were tested for, size distribution, aggregate impact value (AIV), Los Angeles abrasion test (LAA). Natural and crushed aggregates were collected and tested for preparing the M20 grade concrete. The mean compressive strength of the concrete made from natural aggregates at 7 and 28 days was fond as 16.72 N/mm2, 16.5N/mm2 and 14.11N/mm2 and 26.22 N/mm2 , 24.29 N/mm2 and 23.69 N/mm2 for Danda, Jharahi and Boulaha rivers respectively. Similarly, mean compressive strength of concrete made from crushed aggregates at 7 and 28 day was found to be 16.06 N/mm2 , 16.43N/mm2 and 15.16N/mm2 and 26.29 N/mm2, 24.95 N/mm2 and 24.36 N/mm2 for Danda Jharahi and Boulaha rivers, respectively. The null hypothesis (H0) was rejected and alternative hypothesis (H1) was accepted that there exist significant difference in mean value of compressive strength among the river aggregates from selected rivers. However no interaction among the river aggregates was found as Fcalc<Fcrit and Value was found > 0.05 hence null hypothesis was accepted. The higher strength aggregates were found in Danda river whereas lower strength aggregates were found in Boulaha river.

Keywords: Concrete, Coarse aggregates, Compressive strength, Nawalpur, Suitability of aggregates

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Introduction

The most fundamental material used in construction is aggregate. They serve as the basis for buildings, bridges, and roadways. They are also used in making up over 90 % of an asphalt pavement and up to 80% of concrete mix. One lane mile of a national roadway requires an average of 38,000 tons of aggregates. The typical size school or hospital requires 15,000 tons of aggregate for construction, compared to 400 tons for the average houses (Feuling, 2024).

Aggregate is an essential component of concrete. The properties of the aggregate used in the concrete, their sizes and their texture, whether angular or sub-angular, additional factors that should be taken into consideration are the type of cement used, the ratio of water to cement used, the mixing technique employed, curing of concrete, relative humidity and temperature. These factors must be adequately controlled to ensure that the desired quality of the concrete is obtained (Jimoh & Awe, 2007).

Aggregates can exist in two forms, either naturally occurring like sand, gravel, and crushed stone, or artificially produced like slag, fly ash, and recycled concrete. Determining the properties of aggregates is crucial as they make up a significant part of concrete. These properties have a significant impact on the performance and longevity of concrete in different aspects. The overall form and dimension of course aggregates are crucial factors as they affect the longevity and robustness of concrete (Sravani, 2024).

The form and size of the aggregate have an important effect in the durability and strength of the concrete. Aggregates with smaller and angular particles require more water and cement to achieve workability, increasing strength and durability, whereas bigger and rounded particles require less water and cement, lowering strength and durability. The surface texture of aggregates affects the bond strength between the aggregate and the cement paste or other binding material. Surface texture depends on hardness, grain size, pore structure, structure of the rock and the degree to which forces acting on the particle surface. Rough textured course aggregate surfaces can provide better interlocking and improve the overall strength of the resulting material (Sravani, 2024).

Coarse aggregate generally accounts for 60–75% of the volume of the concrete and have influence on the concrete's properties. Krishna et al. (2010) investigated the effect of coarse aggregate sizes of (10, 12.5, 16, and 20 mm) on properties of both normal and self-compacting concrete. The main conclusions of them are that the all the strengths (compressive strength, split tensile strength, and flexural strength) of both normal concrete and self-compacting concrete (SCC) are achieved by using a coarse aggregate of 20 mm maximum size and the increase in strength of concrete is proportional to the size of coarse aggregate directly. The compressive strength increased with increasing the maximum size of the coarse aggregate for all mixtures an for the different quantities of cement entering in volume unit (Mohammed, and Al-Mashhadi, 2020; Jonnala et al., 2024).

Ezeldin, (1991) Compared concretes with the same mix proportions containing four different coarse aggregate types. He concluded that high-strength concretes, higher strength coarse aggregates typically yield higher compressive strengths, while in normal-strength concretes, and coarse aggregate strength has little effect on compressive strength.

Concrete therefore is the most used construction material in construction industry. Aggregate is one of the key ingredient in concrete in terms of volume as well as strength. The scarcity of good and quality coarse aggregates has now become primary issue to construction sector mostly in many construction processes. Natural coarse aggregates are generally extracted from different rivers or boulders collected from the rivers are crushed manually or by machine to prepare different size of aggregates to be used in residential building construction. The purpose of this study was to find out whether the aggregates used in residential buildings of study were good quality or not as specified by IS codes and to recommend the suitability of aggregates available in Nawalpur districts from selected three river quarries.

Only few researches have been carried out within the Nepal to find the effect of mechanical properties of aggregate and source of aggregate on compressive strength of concrete. In the research paper published by Prajapati & Karanjit, 2019a , showed that coarse aggregate source had significant impact on the compressive strength of various grade of nominal concrete mix. However, such type of research are more focused in major urban areas like Kathmandu valley, Pokhara valley and other urban and sub urban areas. So the quality of Aggregates near the new emerging unban and sub-urban areas like Nawalpur, Kawasoti and other sub urban areas of this district are not covered. Therefore, this study would fulfill the research gap in aggregate quality of the sources of old urban cities and emerging new and suburban areas. This research was carried in the rivers sources from where supplies are made in Nawalpur and Kawasoti area

Objective

The main objective of this study is to evaluate the mechanical properties and compressive strength of natural and crushed aggregates from three selected rivers of Nawalpur districts. Hence, analyze their suitability as construction material for residential building construction in Nawalpur district.

Literature Review

Aggregates are natural sand, gravel, and different sized crushed stones that are created during the crushing process. There are numerous applications for aggregates as building materials. In the building and infrastructure industries, aggregates are used to make plaster, light-weight concrete, and concrete (Yirga et al, 2017). 75% of the 1.4 billion tons of crushed stone produced went toward building, according to the U.S. Geological Survey Mineral Commodity Summary, 2018. In the meantime, roads accounted for 24 percent of the nearly 1 billion tons of sand and gravel generated, with asphalt accounting for 12 percent and concrete for 44 percent..

Construction materials have remained in high demand due to escalations in urbanization and the constriction of new buildings, roads, highways, and motorable tracks (Hussain et al. 2022b). Traditionally, alluvial aggregates have fulfilled much of the region's aggregate necessities. However, alluvial deposits have dwindled and are no longer sufficient to fulfill the market's demands (Clinkenbeard et al. 2012). As a result, the pattern of aggregate supply has changed in recent years. Growing contributions of crushed rock aggregate from the boulders of different rivers sourced supply aggregate demand. These quarries, which are often located near large urban and rural agglomerations, may cause spatial planning issues (Ren et al. 2022)

Testing of aggregates in Nepal from Trisuli River, Shrestha and Tamrakar, 2013, found that the major composition of the aggregates were metamorphosed rocks of the Lesser Himalaya like gneiss, schist, quartzite, sandstone, slate, granite, phyllite, etc. According to the gradation of the samples the aggregates were found suitable for building construction and bituminous bound construction as for base and sub-base course materials. As aggregates were found rich in quartz and are derived from varied sources, it was further recommended to analyses these aggregates for alkali silica reactivity. Thus the aggregates from the banks of the Trishuli River are appropriate for the construction material, only after treatment in grading.

Madai, et al., 2019 found from the study of aggregates from Kavre and Sindhuli district Rivers that it the aggregates from different River in Kavre and Sindhuli satisfies the standard for base and sub-base layers of flexible pavement. Materials from River of Challal Ganesh and Aapghari satisfies the standard for bituminous macadam, dense bituminous macadam and asphalt concrete of surface course of. flexible pavement. The experiment shows that the material of Bhyakure River Quarry fails the standard for asphalt concrete, yet it can be used for bituminous macadam, dense bituminous macadam (The effect of coarse aggregate sources on the compressive strength of various grade of nominal mixed concrete, case study of Kathmandu valley found that, Chaukidada aggregates have better performance in physical and mechanical properties than other River aggregates (Prajapati and Karanjit, 2019)

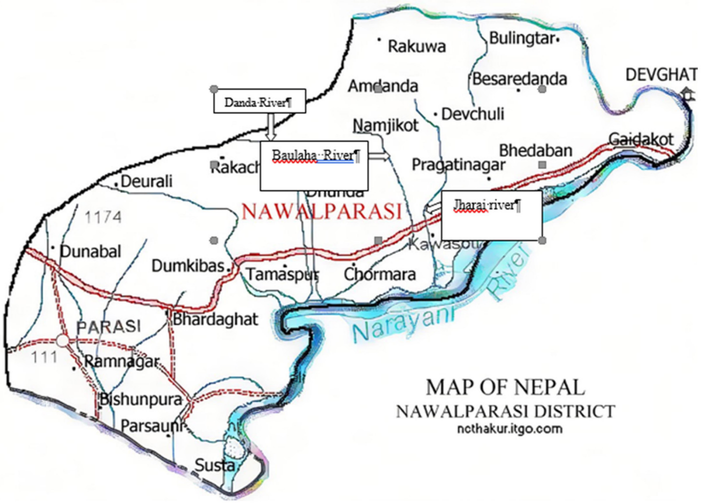
Methodology

Research Area

For conducting this study three different rivers namely, Jharahi khola, Boulaha khola and Danda khola were selected from Nawalparasi district as shown in Figure 1

Figure 1

Research Area



Materials Used

Crushed and natural aggregates were collected from all three rivers. OPC 43 Ambe cement and fine aggregates for preparation of concrete were collected from nearby suppliers.

Data Collection

The nature of aggregates form each source is heterogeneous as it differs from River to River. So, two type of sample (natural and crushed aggregates) were collected from each selected river. Crushed aggregates were collected from crushers while natural aggregates were collected from contractors. From each river 12 cubes of M20 grade concrete were casted at lab keeping water cement ration as constant. Off which six cube specimens were casted from natural aggregates and other six were from crushed aggregates. Again, from each river 3 cube were tested at 7 days for compressive strength for natural and coarse aggregates. Similarly, the rest of 3 cubes from each river were tested at 28 days for compressive strength. The mechanical properties of the natural aggregates were tested as per the IS: 2386 Part I-1963 (reframed 2021), IS 2386-4-1963 (Reaffirmed 2021), and IS 2386 (Part 3) – 1963 (Reaffirmed 2021)

- The fineness test of cement was carried out as per the IS 4031(Part 1): 1996
- Compressive strength of cubes was tested as per the IS 516 (Part-1 Sec-I) - 2021

Hypothesis Setting

Null hypothesis (Ho): $\mu1= \mu2= \mu3$ (There is no significant difference in the mean compressive strength of concrete prepared by the aggregates taken from selected three rivers.)

Data Analysis

The value of compressive strength of concrete obtained from compression testing machine was recorded for 7 and 28 days. The variation in data from different Rivers was analyzed.

Statistical analysis was carried out. Mean and standard deviation was calculated for each Rivers. The mean of each Rivers was compared to each other.

The ANOVA test was carried out to test the significance of result based on set hypothesis. For mechanical test of aggregates the graphs and charts were prepared using MS Excel.

Alternative hypothesis (H1): $\mu 1 \neq \mu 2$ or $\mu 3$ There is significant difference in the mean compressive strength of concrete prepared by the aggregates taken from selected three rivers).

Results and Discussion

Properties of the Materials

Cement, and aggregates were tested for their suitability as construction material.

Fineness Test

Fineness test of cement was carried out following the steps outlined in IS: 4031 Part I. 1996. The fineness value obtained is shown in Table 1. The fineness value varied from 3.4 to 4.3% and average value obtained was 3.51%. For the good quality cement, the amount of cement-retained on the 90 µm sieve does not exceed 10 %. i.e. the fineness of cement should be lower than 10% as per IS: 4031 Part I. 1996. The average value of fineness obtained here is 3.51% so the cement quality is well within the acceptable range.

Gradation of Sand

Sieve Analysis of sand was carried out to find the grading zones. The sieve sizes used were 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 microns, 300 microns, and 150 microns. The tests were performed in accordance to IS: 2386 Part I. 1963 (reaffirmed 2021). The results of sieve analysis are shown in Table 2. All values of sieve analysis lied within the permissible limit of grading zone II as per IS code 383.1970 (2021). The code had also mentioned that if the concrete of high strength and good durability is required, fine aggregate conforming to any one of the four grading zones may be used, however the concrete mix should be properly designed

Table 1

Fineness Test of Cement

SN	Total wt. of sample taken (gm)	Sample retained on 90µ sieve (gm)	Fineness %	Average Fineness %
1	100	3.4	3.4	3.51
2	100	3.85	3.85	
3	100	4.3	4.3	

Table 2

Gradation of Sand

IS sieve size	Wt. of aggregate retained (gm)			% of total weight retained	Cumulative % of total weight retained	% Passing	Permissible value as per IS 383
	I	II	III				
10 mm	0	0	0	0.00	0.00	100.00	100
4.75 mm	48	57	45	5.00	5.00	95.00	95-100
2.36 mm	91	93	88	9.07	14.07	85.93	75-100
1.18 mm	144	170	220	17.80	31.87	68.13	55-90
600 µm	262	293	196	25.03	56.90	43.10	35-59
300 µm	239	244	302	26.17	83.07	16.93	8-30
150 µm	216	143	149	16.93	100.00	0.00	0-10
Total	1000	1000	1000		291.00	409.10	0

Impact value of Natural aggregates from three selected rivers

Table 3

Mean Aggregate Impact Value

Source of aggregates	Mean Aggregate Impact value (%)
Danda river	14.6
Jharahi river	17.1
Boulaha river	18.0

The aggregate impact value obtained for natural aggregates from Danda river, Jharahi river and Boulaha river are presented in Table 3. Impact value of all aggregates falls within a permissible range which is <45% according to IS 2386. Danda river aggregates shows better impact performance compared to Jharahi and Boulaha rivers.

Los Angeles Abrasion Value

The aggregate abrasion value obtained for natural aggregates from Danda river, Jharahi river and Boulaha river are presented on Table 4. Abrasion values of aggregates from selected rivers varied from 18.2% to 22.8 %. These ranges show ability of the aggregates to resist abrasion, and since these values lie within international specifications which is <30% according to IS-2386. Therefore the aggregates are suitable for various uses in construction. Danda river aggregates showd better abrasion resisting capacity and toughness/ hardness than Jharahi river and Boulaha river.

For the Trisuli river Shrestha and Tamrakar (2013) found that the Los Angeles value (LAV) varied from 29.9–36.4%, along the river stretch. As selected rivers are the tributaries of the Narayani river and Trishuli is

Table 4

Los Angeles Abrasion Value of Aggregates

Source of aggregates	LOS Angeles abrasion value (%)
Danda Khola	18.2
Jharahi Khola	19.5
Boulaha Khola	22.8

Concrete Test Results Based on Natural and Crushed Aggregates

A concrete slump test measures the degree of workability of a concrete batch to see how easily the concrete flows. The test not only observes consistency in workability between batches, but also identifies defects in a mix, giving the operator a chance to amend the mix before it is poured on site. The slump values of natural aggregates from three rivers are shown in Table 5. The degree of workability of concrete as per IS: 456-2000 based on slump values are classified as very low 0 -25 mm, low 25-50 mm , medium 50 -75 mm.

Table 5

Slump Values for NATURAL aggregates

Source of Aggregates	Slump (mm)
Danda River	38
Jharahi river	33
Boulaha river	29

The Slump value varied from 29 mm to 38 mm low in Boulaha river and high in Danda river. The slump value of all three rives falls within the low workability. Among them concrete prepared from the aggregates of Danda river showed better workability at constant water cement ratio as shown in Table 5.

Compressive Strength of Concrete

The cubes of concrete were casted in laboratory where aggregates are used from selected three Rivers from Nawalpur district. The cubes were cured and tested in lab at an interval of 7 and 28 days. Test was carried out in lab of Bharatpur Metropolitan city, with calibrated compressive strength test machine of 1200 KN capacity. The result of 7 days and 28 days mean compressive strength of concrete cubes obtained from 3 selected rivers were presented in Table 6.

Table 6

Days Mean Compressive Strength of Concrete from Aggregates of Three Selected Rivers

Source of Aggregates	Natural Aggregate N/mm2	Crushed Aggregate N/mm2
Danda river	16.72	16.43
Jharahi river	16.5	16.06
Boulaha river	14.87	15.76

7-days mean Compressive strength of concrete from natural aggregates varied from 16.72 to 14.87. Higher value of compressive strength was investigated to the aggregates of Danda river, whereas lower value was found in Boulaha river aggregates. Similarly, 7-days mean Compressive strength of concrete from crushed aggregates varies from 16.43 to 15.76. Higher value of compressive strength was found to the aggregates of Danda river whereas lower value was found in Boulaha river aggregates. Comparing the compressive strength of concrete with natural and crushed aggregates of selected rivers, concrete cubes prepared by using natural aggregates from two river, Danda and Jharahi, showed slightly higher compressive strength while concrete prepared by sing natural aggregates from Baulaha river showed slightly lower compressive strength as shown in Table 6.

As per IS code 456-2000, after seven days, M20 concrete's compressive strength is normally about 65% of its 28-day strength. At 28 days, the target compressive strength for M20 grade concrete is roughly 20 MPa. Consequently, after 7 days, one should anticipate that the compressive strength of M20 grade concrete is about 13 MPa. The compressive strength of the M20 grade concrete measured for selected rivers was found above the minimum requirement. So the aggregates from selected rivers were found sound for construction work. Among the selected rivers Danda rives aggregates were found better suitable for construction of residential buildings.

Table 7

Days Mean Compressive Strength of Concrete from Aggregates of Three Selected Rivers

Source of Aggregates	Natural Aggregate (N/mm2)	Crushed Aggregate (N/mm2)
Danda river	26.22	26.29
Jharahi river	23.69	24.36
Boulaha river	24.29	24.95

28-days mean compressive strength of concrete from natural aggregates varied from 26.22 to 23.69. Higher value of compressive strength was obtained to the aggregates of Danda river whereas lower value was found in Jharahi river and Boulaha river aggregates. Similarly, 28-days mean compressive strength of concrete from crushed aggregates varied from 26.29 to 24.36. Higher value of compressive strength concrete was found to the aggregates of Danda river whereas lower value was found in Boulaha river aggregates.

The investigation revealed that compressive strength of concrete prepared from the aggregates of selected rivers were found above the safe compressive strength specified by the IS code 456:2000. However, aggregates from Danda river showed consistently higher values strength compared to other two other rivers Jharahi and Baulaha. The compressive strength data were tested at 95% confidence interval and 5% margin of error. The compressive strengths of concrete made from natural aggregates were 16.72 N/mm² (7 days) and 26.22 N/mm² (28 days) for Danda, with similar trends observed for Jharahi and Boulaha. Crushed aggregates exhibited comparable strengths, indicating the preference for utilizing aggregates from rivers with higher quality for construction purposes. This study aligns with the findings of Khadka et al. (2021), who analyzed the effects of coarse aggregate sources on the compressive strength of cement concrete, and Adhikari et al. (2022), who examined the variation in aggregate strength along different sections of the river basin. By understanding the properties of aggregates from various sources, construction professionals can optimize building performance and ensure the durability and safety of residential structures.

The results are shown in Table 8 where Fcalc>Fcrit, and p-value is < 0.05 for natural and crushed aggregates. Hence the Alternative hypothesis (H1) was accepted (i.e. there is significant difference in the mean compressive strength of concrete prepared from natural and crushed aggregates from selected three rivers). Table 8 shows the mean values of compressive strength for both natural and crushed aggregates the minimum compressive strength for both natural and crushed aggregates (23. 69 N/mm2 and 24. 36 N/mm2) was found in Jharahi river. Similarly, Fcalc>Fcrit was found among the selected three river aggregates and P-value was observed <0.05. Therefore, null hypothesis (H0) was rejected and alternative hypothesis (H1) was accepted that is significant difference in mean value of compressive strength of concrete prepared from the natural and crushed aggregates from selected river was observed. However, no interaction among the river aggregates was found as Fcalc<Fcrit and Value was found > 0.05 hence null hypothesis was accepted.

Table 8

Two Way ANOVA Test Statistics for 28 Days Mean Compressive Strength of Concrete from Three SELECTED rivers (Natural and Crushed Aggregate)

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Natural and crushed aggregate	0.99238	1	0.99238	5.38806	0.038682	4.747225
Among river Aggregates	15.9220	2	7.961029	43.22388	3.28E-06	3.885294
Interaction among river aggregates	0.35186	2	0.175934	0.955224	0.412136	3.885294
Within	2.21017	12	0.184181			
Total	19.47648	17				

Policy for Mining the Sand and Aggregate

Nepal has established, at least on paper, regulatory mechanisms to promote sustainable mining of sand and aggregate. However, river mining activities reveal a large gap between policy and practice. This demonstrates that the lack of sustainable mining practices has less to do with a lack of policy and more to do with the failure to fully implement existing policies. Institutions, especially, at the local level, responsible for managing and monitoring sustainable sand and aggregate mining are constrained by a lack of appropriate human resources and technical expertise.

Sand and aggregate have high demand in the market; so, IEE and EIA policy has created the problems for the poor extractors who were dependent on selling of extracted material and profited the big contractors. While policymakers and activists have primarily focused on sand and aggregate mining in large rivers, mining intensity, both legal and illegal, has increased in small rivers and other small branches. To protect the environment and provide sustainable aggregates, local authorities should follow the environmental policies and regulations adopted by the Government of Nepal.

Conclusion

The study on the properties of aggregates sourced from the Danda, Jharahi, and Boulaha rivers in Nepal provides valuable insights into the suitability of these materials for construction purposes. By conducting a comprehensive analysis of the mechanical properties of the aggregates, including flakiness index, elongation index, impact value, and Los Angeles abrasion value, the researchers have established a clear understanding of the quality and performance characteristics of each river's aggregates.

The findings indicate that the aggregates from the Danda river exhibit superior mechanical properties compared to those from the Jharahi and Boulaha rivers. This superiority is further reflected in the compressive strength of concrete cubes tested after 28 days, where the Danda river aggregates, both natural and crushed, demonstrated higher compressive strengths than the other two rivers.

Interestingly, the study also reveals that for all three river aggregates, the compressive strength of concrete cubes made from crushed aggregates was higher than those made from natural aggregates. This suggests that the process of crushing the aggregates may enhance their performance characteristics, potentially due to the creation of more angular and interlocking particles.

Based on these findings, it can be concluded that the aggregates from the Danda river are the most suitable for all types of construction, including structural and non-structural applications. The aggregates from the Jharahi and Boulaha rivers, while not as high-performing as the Danda river aggregates, can still be utilized for non-structural and light structural work, provided that their limitations are taken into account during the design and construction phases.

The implications of this study extend beyond the immediate geographical context, as it highlights the importance of understanding the properties of locally available aggregates before commencing construction projects. By conducting thorough testing and analysis, construction professionals can optimize the use of resources, minimize waste, and ensure the long-term durability and safety of structures.

Moving forward, it is recommended that further research be conducted to explore the long-term performance of concrete made with these aggregates, particularly in terms of resistance to weathering, abrasion, and chemical attack. Additionally, the study could be expanded to include aggregates from other rivers in Nepal, providing a more comprehensive understanding of the country's construction material resources.

The study on the properties of aggregates from the Danda, Jharahi, and Boulaha rivers represents a significant contribution to the field of construction materials research in Nepal. By identifying the most suitable aggregates for various construction applications, the study supports the development of sustainable and resilient infrastructure in the country. As Nepal continues to grow and develop, research of this nature will be essential in ensuring that construction projects are built to last and meet the highest standards of quality and safety.

Limitation of the Study

The main limitations of this study are:

- Chemical test has not performed for any of the concrete materials (i.e. cement, sand, aggregate and water).
- There were many brand of cement available within local market but this study had used only one Ordinary Portland Cement brand named as Ambe cement.
- Tap water (i.e. potable water) was used for concrete mix as well as curing (i.e. no consideration of pH value).

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