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GEOLOGICAL ASSESSMENT OF DAM CONSTRUCTION MATERIALS: A FIELD INVESTIGATION FOR THE NAM-A HYDROPOWER PROJECT, LAO PDR

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Abstract—This study presents a comprehensive geological field investigation conducted to identify and classify potential dam construction materials for the proposed Nam-A Hydropower Dam in Khamkhet District, Bolikhamxay Province, Lao PDR. The investigation focused on locating resources of crushed aggregate, sand, and clay essential for dam infrastructure development. Field surveys were conducted, encompassing geological mapping, rock exposure examination, and sediment deposit identification. Results indicate that the project area is predominantly underlain by Ordovician-age sedimentary rocks, including quartzitic sandstone and clay shale formations. Quartzitic sandstone, distributed across the middle portion of the study area, demonstrates favorable characteristics as a potential source of crushed aggregate for concrete production. Three sand deposits were identified along the Nam-A River terrace, with areal extents ranging from 10,000 to 90,000 m², located 1.75 to 4.55 km from the proposed dam site. These medium to coarse grained, well-sorted deposits show promise as fine aggregate sources. However, no clay deposits were identified within the project area, necessitating off-site sourcing for cofferdam construction. The geological mapping provides critical baseline data for resource assessment and construction planning, though laboratory testing is recommended to confirm material suitability for specific engineering applications.

Keywords—Geological Mapping, Dam Construction Materials, Crushed Aggregate, Quartzitic Sandstone, Hydropower Development

I. INTRODUCTION

Hydropower development plays a crucial role in meeting the growing energy demands of developing nations, particularly in Southeast Asia where river systems offer significant potential for renewable energy generation [1]. The successful construction of hydropower dams relies heavily on the

availability and quality of local construction materials, including crushed aggregate, sand, and clay [2]. The identification and characterization of these materials during the pre-construction phase is essential for ensuring project feasibility, cost-effectiveness, and structural integrity [3].

The Nam-A Hydropower Project, proposed for development in Khamkhet District, Bolikhamxay Province, Lao PDR, represents an important infrastructure initiative requiring comprehensive geological assessment. Previous studies have demonstrated that thorough geological investigations can significantly reduce construction costs by optimizing the use of local materials and minimizing long distance transportation requirements [4]. Furthermore, understanding the geological context of dam sites is critical for assessing foundation stability and potential geotechnical challenges [5].

The geological setting of the project area is characterized by Ordovician-age sedimentary formations, as documented in regional geological surveys conducted by the Department of Geology and Mines [6]. However, detailed site-specific investigations were lacking prior to this study. The regional geological map at 1:200,000 scale provides only preliminary information regarding rock types and structural features, insufficient for construction material resource assessment [7].

Crushed aggregate production from sedimentary rocks has been extensively studied in various geological contexts [8]. While carbonate rocks such as limestone typically provide optimal sources for concrete aggregate [9], clastic sedimentary rocks including sandstone can serve as acceptable alternatives when properly evaluated [10]. The suitability of sandstone as crushed aggregate depends on several factors including grain size, cementation type, porosity, and mineralogical composition [11].

This investigation was undertaken to address the critical need for site-specific geological data to support the Nam-A Hydropower Project. The study integrates traditional

field mapping techniques with modern geospatial analysis tools to provide comprehensive resource assessment. This paper presents the methodology, findings, and implications of this geological investigation, contributing to the growing body of knowledge regarding construction material assessment for hydropower development in Southeast Asia.

II. RESEARCH OBJECTIVES

The primary aim of this geological field investigation was to identify and classify potential dam construction material resources within the Nam-A Hydropower Project area. Specific objectives of the study are: (1) To identify the types and spatial distribution of rock units within the study area through systematic geological mapping; (2) To locate and characterize potential resources of crushed aggregate, sand, and clay suitable for dam construction; and (3) To produce a detailed geological map of the project area showing the distribution of construction material resources.

III. RESEARCH METHODOLOGY

A. Study Area

The study area is located in Khamkhet District, Bolikhamxay Province, central Lao PDR, encompassing the proposed Nam-A Hydropower Dam site and surrounding regions. The investigation covered both upstream and downstream areas of the proposed dam location along the Nam-A River. Geographical coordinates and site boundaries were established using GPS technology and verified against topographic maps and satellite imagery.

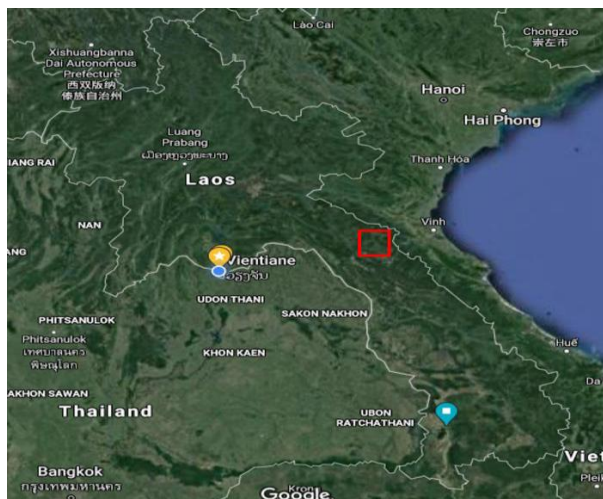


Fig. 1. Location map of the project area

B. Data Compilation and Desktop Study

The geological mapping program integrated traditional field techniques with digital geospatial analysis tools including Google Earth and Geographic Information Systems (GIS). The investigation was conducted in three sequential phases: data compilation, fieldwork, and data integration.

Prior to fieldwork, comprehensive desk studies were undertaken to compile existing geological information. Primary data sources included the regional geological map of Khamkhet District at 1:200,000 scale (Department of Geology and Mines, 2000), aerial photographs, and topographic maps.

This preliminary review established a baseline understanding of regional geology, including rock types, structural features, and spatial distribution of geological units.

Aerial photograph interpretation was employed to identify potential locations of construction materials prior to field verification. Stream channels were analyzed to predict sand deposit locations, while historical borrow pit sites were reviewed to identify potential clay deposits. Landform analysis provided preliminary predictions regarding subsurface geology and sediment characteristics.

C. Field Investigation

Fieldwork was conducted, employing multiple access methods to ensure comprehensive coverage of the study area. Investigation techniques included systematic road traverse surveys, foot traverses along hiking trails to access remote areas, and boat-based reconnaissance along the Nam-A River to examine riverbank and bedrock exposures.

Rock exposures were examined at multiple locations including stream cuts, river banks, road cuts, and trail exposures. At each outcrop station, detailed observations were recorded including rock type, color, texture, grain size, bedding characteristics, weathering degree, and structural features. Rock hardness was assessed using geological hammer tests to evaluate suitability for aggregate production. Strike and dip measurements were taken where bedding planes were clearly visible.

Sand deposits were investigated along river terraces of the Nam-A River. At each sand deposit location, observations included sediment grain size, sorting characteristics, thickness of deposit, areal extent, and accessibility. GPS coordinates were recorded for all significant outcrops and material deposits. Photographic documentation was maintained throughout the fieldwork.

D. Geological Mapping and Data Integration

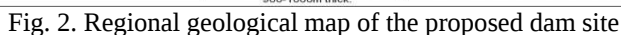
Field observations were integrated with desktop study results to produce the final geological map. Rock unit boundaries were delineated based on field observations and interpolated using aerial photograph interpretation for inaccessible areas. The geological map was compiled using GIS software, incorporating field data points, rock unit distributions, structural features, and locations of construction material resources.

Potential construction material resources were classified and mapped according to material type (crushed aggregate, sand, clay). Spatial analysis was conducted to determine distances between material sources and the proposed dam

Lithologies and their structures presented in the project area were observed and examined from the exposed outcrops during the fieldwork. Types of rock exposures observed include stream cuts, river banks, and trails. Based on field observation results, the project area is dominantly underlain by sedimentary rocks, consisting of quartzitic sandstone, clay black shale, and clay shale. Igneous and metamorphic rocks were not found within the area.

Rock units found in the area play an important aspect in identifying potential resources of dam construction materials. It can be a good indicator to locate the material resources. Boundaries of rock units were identified according to rock distributions observed in the field and aerial photographs for the areas that could not be accessed during the fieldwork.

Due to the lack of a detailed geological map of the project area, regional geological conditions of the proposed dam area were initially studied according to the geological map of Khamkeut District, Bolikhamxay Province at the scale of 1:200,000, the map was prepared by the Department of Geology and Mines, Ministry of Industry and Handicraft in 2000 (Fig. 2). Two rock formations are found in the project area namely Q3-S1nh1 and Q3-S1nh2 Formations. The Q3-S1nh1 Formation ages from the lower to middle Ordovician time. In this rock formation, the lithologic units mostly comprise variegated clay shale, stripped clay shale, black clay shale bearing Graptolithina interbedded with quartzitic sandstone, and limestone lenses, 900-1000 m thick. The ages of Q3-S1nh2 Formation range from middle to upper Ordovician time, and the lithologic units of thick-bedded quartzitic sandstone, quartz-sericite schist with interbeds of compressed intraformational conglomerate and gritstone, and lenses of rhyolite and its tuffs, 700-800 thick. According to the regional geological map, major geological structures such as faults are not found in the proposed dam project area. However, the NE-SW and NW-SE trending faults are observed in the east and west of the region.



Quartzitic sandstone is the rock unit mostly found in the middle of the study area. It was formed during the middle to upper Ordovician period. The quartzitic sandstone found in the project area is a sedimentary rock composed primarily of quartz grains. These grains are tightly cemented together, often by silica or iron oxide, giving it a very hard and durable nature. Its distinctive appearance, often with a gritty texture and a pale color ranging from white to grey, is due to the high concentration of quartz. Additionally, the quartzitic sandstone is a hard, massive, slightly weathered, and medium grained rock which required significant number of blows of the geological hammer to fracture it.

Quartzitic sandstone layers are generally orientated in the NW-SE direction and gently dipping in the NE direction. The dip angle of quartzitic sandstone measured from the exposed outcrops ranges from 75 to 80 degrees. Fig. 3 shows typical outcrops and textures of the quartzitic sandstone.



B. Clay Shale

Clay shale was formed during the middle to upper Ordovician period. This rock unit were observed mostly in the northeast part of the project area. The observed clay shale is a fine-grained sedimentary rock composed primarily of clay minerals. It has a layered or foliated appearance due to the alignment of the clay particles. The clay shale is slightly weathered and generally hard, which required more than one blow of the geological hammer to break it. The color of clay shale can vary widely depending on the presence of other minerals. However, this rock unit found in the project area is largely dark grey in color. Fig. 4 shows typical outcrops and textures of the clay shale. The clay shale layers are generally orientated in the NW-SE direction and gently dipping in the NE direction. The dip angle of this rock unit measured from the exposed outcrops ranges from 70 to 75 degrees.

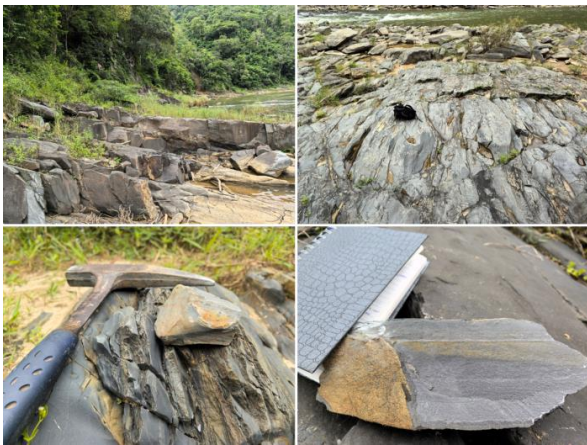


Fig. 4. Typical outcrops and textures of clay shale presented in the project area

C. Tuffaceous Siltstone

Tuffaceous siltstone is the rock unit which was formed during the period of lower to middle Ordovician. This rock unit was mostly found in the southwest of the proposed dam area. The tuffaceous siltstone observed in the project area is a sedimentary rock composed primarily of silt-sized particles with a significant amount of volcanic ash, known as tuff. The tuff is derived from volcanic eruptions and is incorporated into the sediment during deposition. The tuffaceous siltstone is a soft, light grey, and slightly to moderately weathered rock, which required only a single blow of the geological hammer to fracture it. Fig. 5 shows the tuffaceous siltstone outcrops and its textures found along the Nam-A riverbanks. The rock layers are generally orientated in the NW-SE direction and gently dipping in the NE direction. The dip angle of tuffaceous siltstone measured from the exposed outcrops ranges from 50 to 55 degrees.

In the project area, major geological structures such as fault and fold were not observed during the fieldwork. Geological structures found within an area include bedding planes and rock joints. Bedding plane orientations of the rocks are mentioned above. In general, two joint sets were observed on quartzitic sandstone, clay shale, and tuffaceous siltstone. The joints are moderately to widely spaced and opened with no infilling materials between rock joint surfaces. The space of joints is generally between 0.5 m and 1 m, it is however locally less than 0.5 m in some areas.

Fig. 6.a demonstrates the orientations of joints on the quartzitic sandstone body. Joint set 1 is orientated in the NW SE direction and steeply dipping in the NE direction by approx. 77 degrees. In contrast to joint set 1, joint set 2 is orientated in the NE-SW direction and dipping in the NW direction by approx. 18 degrees. Fig. 6.b illustrates joint set orientations that occurred on the rock body of clay shale. Joint set 1 is orientated in the NW-SE direction and steeply dipping in the SW direction by approx. 73 degrees. Whilst, joint set 2 is orientated in the NE-SW direction and steeply dipping in the SE direction by approx. 82 degrees. Fig. 6.c demonstrates the orientations of joints on the tuffaceous siltstone body. Joint set 1 is orientated in the NW-SE direction and steeply dipping in the NE direction by approx. 53 degrees. In contrast, joint set 2 is orientated in the NE-SW direction and steeply dipping in the SE direction by approx. 85 degrees.



Fig. 5. Tuffaceous siltstone outcrops and its textures found along the Nam-A riverbanks

The geological map of the project area is illustrated in Fig. 7. The geological map provides the information of bedrock distribution within the study area and it is important in assessing the type and location of potential crushed aggregate sources.

D. Geological Structures

VI. POTENTIAL RESOURCES OF DAM CONSTRUCTION MATERIALS

The potential of dam construction materials is defined as an estimation of relative probability that crushed aggregate, sand, and clay deposits exist within a given mapping area. In this assessment, only geological criteria were taken into an account. Economic and environmental criteria, for example, location and applicable land use restrictions are not considered in this evaluation of dam construction materials potential. Therefore, the emphasis of this investigation was placed mainly upon the interpretations of geologic evidence at the reconnaissance level, rather than upon cultural or economic considerations. This assessment does not imply that economic crushed aggregate, sand, and clay deposits exist everywhere within a map unit designed as “Potential Resources”.

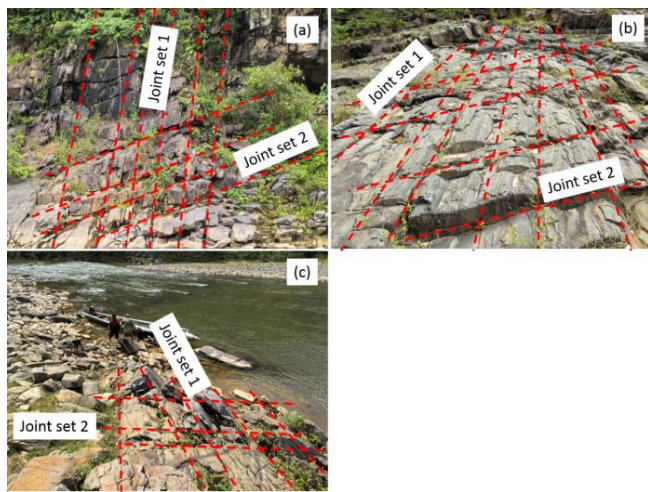


Fig. 6. Orientations of joint sets observed within the project area. (a) orientations of joint sets found on quartzitic sandstone. (b) orientations of joint sets presented on clay shale. (c) orientations of joint sets observed on tuffaceous siltstone



Fig. 7. Geological map of the project area

A. Crushed Aggregate

Crushed aggregate or stone is defined as a product resulting from the artificial crushing of rock, boulders, or

large cobblestones. Generally, rock is crushed to produce construction aggregates for using in cement concrete. Crushed aggregate is normally produced from three main groups of rocks such as sedimentary, igneous, and metamorphic rocks. Sedimentary rocks of limestone and dolomite, composed of carbonates, generally make good sources of crushed aggregate. With the absence of these carbonate rocks, clastic sedimentary rocks of conglomerate, breccia, and sandstone are used for crushing. Of these rocks, when sandstone is hard and dense, it is most commonly used for crushed aggregate and is a major source of crushed aggregate in some areas. Igneous rocks of granite, diorite, andesite and metamorphic rocks of marble and quartzite, are commonly hard, tough and dense and make an excellent source of crushed aggregate, however, these rocks are not present in the project area. Fig. 8 illustrates the example of crushed aggregate produced from sandstone.



Fig. 8. Example of crushed aggregate produced from sandstone

The geological map given in Fig. 7 shows the distribution of potential crushed aggregate sources which is essential for resource assessments. The geological map of the project area serves as a primary source of information for determining the location of potential sources of crushed aggregate. The distribution of bedrock units suitable for crushed aggregates, such as quartzitic sandstone and clay shale presented on the map is sufficient for identifying the general areas where the target rock type is at or near the surface. According to field observation results and information provided in the geological map of the area, two types of rock units can be used as crushed aggregate in cement concrete, including quartzitic sandstone and clay shale. Tuffaceous siltstone is considered unsuitable in this assessment because it is very soft and weathered.

Quartzitic sandstone covers the middle part of the project area; it is hard and dense which requires many blows of the geological hammer to break it. Based on the field observation, the quartzitic sandstone found in the project area

can make a good source of crushed aggregate. The rock unit of quartzitic sandstone found within the project area is composed primarily of quartz, a very durable mineral, it is generally composed of sand grains cemented together by calcite, clay, or silicate minerals that have precipitated between the sand grains. Since the strength and durability of sandstone can vary considerably depending on the size of the grains, grain packing, porosity, and nature of the cement, the laboratory tests are therefore required to confirm its appropriateness for using as coarse aggregate in the cement concrete.

Clay shale is the rock unit mostly found in the northeast part of the study area. Clay shale is generally unsuitable for use as concrete aggregate due to its inherent weakness and susceptibility to degradation. Its soft, friable nature can lead to reduced strength and durability of the concrete. Additionally, clay shale often contains impurities such as organic matter and sulfates, which can react with the cement paste and cause problems like popouts or efflorescence. These issues can compromise the long-term performance of the concrete structure, making it prone to cracking, spalling, and other forms of deterioration. However, The clay shale found on the project area is generally hard and requires multiple hits with a geological hammer to break it. This suggests it could be a suitable material for use as coarse aggregate in concrete.

Even hard clay shale seems strong, it can still cause problems in concrete. It often contains clay minerals that absorb water and make the concrete shrink and crack. In addition, impurities like pyrite can weaken the concrete over time. These issues can make the concrete less durable and more likely to break down. To be confirmed if this type of rock is appropriate for concrete, its absorption, abrasion, and durability have to be tested. Abrasion tests measure how tough the aggregate is and how well it resists wear and tear. If the absorption is too high and the durability and abrasion resistance are lower than that of the crushed aggregate standards, the potential crushed aggregate source must be fallen into the rock unit of quartzitic sandstone.

Fig. 9 shows the areas where potential crushed aggregates of quartzitic sandstone are at. The potential source of quartzitic sandstone crushed aggregates is located in the downstream area of the proposed dam, as it is marked in red polygons, approx. 650 m downstream of the proposed dam location. From the economic point of view, the location of potential crushed aggregate quarries must be selected as close as to the construction site of the proposed dam, if available.



Fig. 9. Area of potential crushed aggregates of quartzitic sandstone

B. Sand

Sand deposit is an accumulation of durable rock fragments and mineral particles. Such deposit results from the disintegration of bedrock and subsequent transport, abrasion, and deposition of weathered fragments. Water is the principal geological agent that affects the distribution of the sand deposit. In the project area, most sand is found along the riverbed of Nam-A River which are called river terrace deposits. Locations of sand deposits found within the area during field investigations are shown in yellow polygons (Fig. 10). The distance of Sand Deposits 1, 2, 3 from the proposed dam site is approx. 1.75 km, 3.15 km, and 4.55 km, respectively.

The sands deposited at these three locations are medium to coarse-grained and well-sorted, which are possibly suitable for using as fine aggregate in cement concrete for dam construction. Therefore, their properties and extents need to be confirmed. The outcrop and grain size of the sand deposits can be seen in Fig. 11. Sand Deposits 1 and 2 have smaller extents when compared with Sand Deposit 3. The areal extent of Sand Deposits 1, 2, and 3 is approx. 10,000 m², 23,000 m², and 90,000 m², respectively.

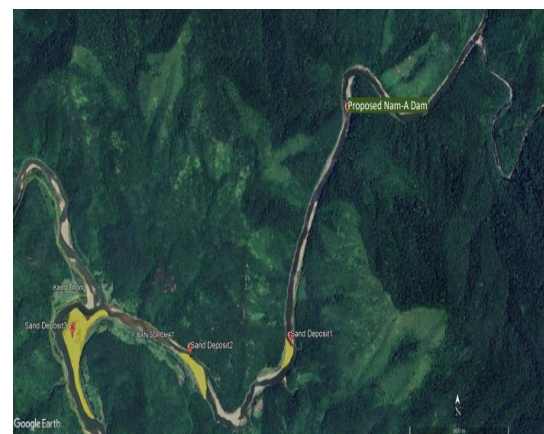


Fig. 10. Location map of sand deposits found in the project area



Fig. 11. Sand deposits found in downstream areas of a proposed dam site along the Nam-A River

C. Clay

The clay material is expected to be used as cofferdam construction during the construction period. Clay is a crucial material for cofferdam construction due to its unique properties. Its low permeability makes it an effective barrier against water seepage, ensuring that the construction site remains dry. However, the geological investigations conducted in the project area for the Nam-A hydropower dam have not revealed any clay deposits. Other sources of clay, such as off site borrow pits will need to be identified and assessed for their suitability to meet the project's requirements.

Although the clay deposits were not found within the project area, this is a positive finding, as clay can pose challenges during construction and operation of dams due to its potential for swelling and erosion. The absence of clay deposits in the project area suggests that the foundation and embankment of the dam will be relatively stable and less susceptible to these issues.

VII. CONCLUSION

This geological field investigation successfully identified and characterized potential construction material resources for the Nam-A Hydropower Project. The study area is predominantly underlain by Ordovician-age sedimentary rocks, including quartzitic sandstone and clay shale formations, with tuffaceous siltstone present in limited areas. The geological mapping revealed distinct spatial distribution patterns of rock units, providing essential baseline data for construction planning.

Quartzitic sandstone, distributed across the middle portion of the study area approximately 650 m downstream of the proposed dam site, represents the primary potential source of crushed aggregate. Field observations indicate that this rock unit possesses favorable physical characteristics including high hardness and density, suggesting suitability for concrete aggregate production. However, the strength and

durability of sandstone aggregate depend on multiple factors including grain packing, porosity, and cementation type, necessitating comprehensive laboratory testing to confirm engineering suitability.

Three sand deposits were identified along the Nam-A River terrace system, located at distances ranging from 1.75 to 4.55 km from the proposed dam site. These deposits exhibit medium to coarse grain sizes with good sorting characteristics, potentially suitable as fine aggregate for concrete production. The deposits vary considerably in areal extent, from 10,000 m² to 90,000 m², with the largest deposit (Sand Deposit 3) offering the most substantial resource potential. Detailed subsurface investigation including test pitting and sampling is recommended to determine deposit thickness, volume, and material quality.

The absence of clay deposits within the project area presents both challenges and advantages. While clay materials will need to be sourced from off-site borrow areas for cofferdam construction, the lack of clay-rich formations in the dam foundation area suggests favorable conditions for foundation stability, reducing risks associated with clay swelling and erosion during construction and operation.

The proximity of quartzitic sandstone resources to the proposed dam site (approximately 650 m) offers significant economic advantages by minimizing material transportation costs. However, the greater distances to sand deposits (1.75- 4.55 km) will require careful planning to optimize material logistics and cost management.

This investigation provides a solid foundation for construction material planning, though several recommendations for further work are warranted. Laboratory testing of quartzitic sandstone samples should include absorption tests, Los Angeles abrasion tests, and soundness tests to confirm compliance with concrete aggregate standards. Sand deposits require grain size analysis, organic content testing, and assessment of deleterious materials. Detailed subsurface investigation using test pits or drill holes should be conducted to determine the three-dimensional extent and volume of both rock and sand resources.

Alternative clay sources outside the immediate project area should be identified and evaluated for cofferdam construction requirements. Economic analysis incorporating material quality data, extraction costs, processing requirements, and transportation distances should be conducted to support final material sourcing decisions.

The geological map and resource assessment presented in this study provide essential information for the Nam-A Hydropower Project, enabling informed decision-making regarding construction material procurement and project planning. The findings demonstrate that adequate resources of crushed aggregate and sand are potentially available within reasonable proximity to the construction site, supporting project feasibility from a materials perspective.



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