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PARTICLE SIZE DISTRIBUTION AND MINERAL ANALYSIS OF SEDIMENTS IN NEPALESE HYDROPOWER PLANT: A CASE STUDY OF JHIMRUK HYDROPOWER PLANT

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ABSTRACT

Hydro energy is considered as one of the most economically feasible renewable energy for Nepal. In spite of huge hydropower potential in Nepal, only about 2 % of economically feasible hydropower has been extracted at present. Huge sediment transport has not only caused problem in operation and maintenance of Hydro-Power Plant (HPP), but also reduced hydraulic efficiency of the system. Sediment erosion is one of the most challenging circumstances for hydro energy development in Nepal. Particle size and mineral content of the sediment are the two important sediment parameters to define erosion potential of sediment. In this paper, Particle Size Distribution (PSD) analysis and mineral analysis of sediment samples from two different locations of Jhimruk HPP was carried out to report PSD, mineral content and their variation at different sampling locations. Sieve analysis method was used for PSD analysis which revealed that sediment size range of 0.1 mm to 0.2 mm is critical in terms of sediment erosion. And particle count method was used for mineral analysis which indicated quartz to be the predominant mineral in river sediment. It was also found that mineral content varies as the sediment flows from headwork to downstream.

Keywords: Sediment erosion, PSD analysis, Sieve analysis, Mineral analysis, Particle count method, mineral content

INTRODUCTION

Nepal is rich in water resources with 6000 large and small rivers/rivulets flowing from higher Himalayas to plain Tarai region. The topographical condition and runoff have made Nepal with hydropower potential of 83000 MW. Despite of Nepal's enormous hydropower potential, only about 650 MW has been harnessed by 2011. Erosion of hydro-mechanical components due to large quantities of sediment with hard abrasive mineral/rock fragments in Himalayan Rivers is one of the serious challenge in developing hydropower projects as it cause difficulty in operation and maintenance of the plants. Excessive amounts of sediment in such rivers are due to presence of weak rocks and extreme relief and hence sediment management has become primary. Even with sediment trapping systems, complete removal of fine sediment from water is impossible and uneconomical; hence most of the turbine components in Himalayan Rivers are exposed to sand-laden water and subject to erosion, causing reduction in efficiency and life of the turbine [5, 6].

Sediment erosion rate depends on sediment types and their characteristics, hydraulic design and operating conditions of turbine and material used fot the turbine component [3]. Sediment particle size and mineral content are two of the characteristics factors of sediments to define its erosion potetntial. Size, mineral content and shape of sediment vary at different locations of the same river system, depending on distance traversed by particles, gradient of the river and the geological formation of the river course and catchments area [5].

The main aim of this study is to identify PSD and mineral composition of the sediment samples at various locations of Jhimruk HPP to represent sediment characteristics variation along hydropower plants of Nepal. PSD analysis will predict the sediment size distribution and critical sediment size that passes turbine, whereas mineral analysis will quantify various minerals present in river sediment. This PSD and mineral analysis result will help to define sediment characteristics critical to turbine erosion. Identification of the sediment characteristics will help to improve the turbine design and operating condition to reduce effect of sediment erosion. Also this result will help to define sediment paramenters like size, hardness, density, etc. required in sediment erosion analysis by Finite Element Method (FEM). Thus this study is limited to PSD analysis and mineral analysis of seidment samples.

MATERIALS AND METHODS

A. Sample collection and processing

Representative samples are collected by planning carefully, selecting the appropriate sampling devices, taking measures to avoid contamination and using proper procedures. Grab sampling is a sampling method in which the river bank samples from inside water are directly collected by using shovel or hand. This sampling technique was used as it has advantage of easy collection of representative sample. Two representative samples from different locations of Jhimruk HPP (Headworks and Downstream) were collected. Wet samples were collected from inside water for real life behavior of sediment. Headwork is the first sampling site which lies just above the weir or diversion dam. Downstream (Tailrace) is the final sampling site which lies just below the turbine outlet.

Along with proper collection of sediment samples, it is equally important that it need to be properly processed. Processing of sample includes following steps:

a) Drying of samples
b) Separating debris from samples
c) Proper labeling of samples
d) Safe storing of samples

B. Particle Size Distribution (PSD) analysis

Particle size of sediment is one of the promising factors in which erosion potential of sediment depends. All size range of sediment particles do not reaches turbine and also erosion rate is directly proportional to particle size of sediment. So in any sediment analysis, along with other sediment properties PSD of sediment should be considered to identify critical sediment size that reaches turbine and erode turbine material [3, 4].

Sieve analysis method

Sieve analysis was used for the measurement of particle size because of its simplicity, economic setup and ease of interpretation. Methods may be simple shaking of the sample in sieves until the amount retained becomes more or less constant. A large amount of materials can be readily loaded into 8-inch-diameter (200 mm) sieve trays. The sieve analysis method is enhanced by using shive shaker setup as shown in Figure1 which helps to accelerated the sieving process.

PSD procedure

For the PSD analysis of the sediment sample we have used six sets of sieves as: 1 mm, 0.6 mm, 0.3 mm, 0.2 mm, 0.125 mm and 0.075 mm. These sieves are piled and put in sieve shaker to obtain the retained sediment in each sieve as shown by the Figure 1. The standard sieve analysis procedure followed for our purpose of

Figure 1 Sieve analysis setup

PSD analysis is explained below:

- Note total initial weight of the dried sample.
- Pile the sieves in descending order (larger sieve opening at top and smaller sieve opening at bottom) and fitted in the sieve shaker motor.
- Gradually sieve the sediments in each sieve and collected the mass retained separately in well labeled plastic container.
- Once the sieving process is completed, take weight of retained sediments on each sieve and fill the observation table.
- Calculate percentage of sediment retained on each sieve from mass of sediment retained on each sieve and based on which calculate cumulative percentage of sediment retained.
- Obtain percentage finer of sediment by subtracting cumulative percentage from 100%.
- Calculated percentage of sample loss during sieving by subtracting total final weight from total initial weight which must be less than 2%.
- Finally, plot a semi-logarithm graph between percentage finer and sieve opening to obtain sieve analysis graph.

C. Mineral analysis

Mineral composotion is another important parameter to define river sediment. Different minerals have different properties base on which it can be determined whether it has erosion potential to turbine material or not. Hardness of mineral is one most important criterion to determine its erosion potential. Different minerals have different hardness measured in Mohr's hardness scale. Those minerals which have Mohr's hardness scale greater than that of turbine material can erode the runner material. On average turbine materials have Mohr's hardness of 6 - 6.5 depending on its composition. Thus all the minerals having Mohr's hardness greater than this value has potential to scratch turbine and cause erosion [2]. Quartz is the most common mineral in river sediment with Mohr's hardness of 7 which can easily cause erosion of turbine. Other minerals harder than turbine materials includes feldspar, garnet, tourmaline, etc. whereas mica is softer than turbine material found in river sediments of Nepal [1].

Physical method using Trinocular Microscope

Among various methods to identify mineral and perform mineral analysis, physical method of particle count method was used. In this method, a magnifying microscope was used to observe the sample, identify and count them. Stereo zoom microscope with following specifications was used for this purpose.

Name: Trinocular Stereo Zoom Microscope
Manufacturer: Radical Instruments
Model: RSM-9
M. No.: B-1260
Eye piece:WF 10X
Binocular Head: 0.7 x to 4.5 x
Magnification:7 x to 45x
Camera: IS 300 of 3 Megapixel (USB)

Figure 2 Trinocular Stereo zoom Microscope

Each mineral species has a distinctive set of physical properties, and these properties can be used to identify an unknown mineral specimen. Some physical properties can be determined by the unaided eye or with a strong magnifying lens but others require the use of laboratory equipment. In Trinocular stereo zoom microscope, it is possible to observe sediment samples under high magnification. Through binocular eye pieces the samples could be clearly observed and using third camera piece the samples could be observed in computer screen providing additional facility of recording the sample images.

Sample preparation
Dried sample need to be prepared carefully before observing under microscope. It was required to sieve the sediment before mineral analysis so that all the sediments were of same size range and particle count method can be used for the purpose of mineral analysis. Required amount of sample of constant size was separated in plastic bag and all remaining debris and organic matters were removed. Slides or watch glass with grid lines were used to spread sample for observation or prepared require grid lines in watch glass. Then spread carefully the samples on the slide in such a way that one particle should not overlap other. Prepare four specimen slides for each sample so that average of these results can be obtained as final result. Finally make the arrangement of cover plate so that the particles do not move during observation.

Mineral analysis procedure
Particle count method similar to area count method was used as the mineral analysis method. Based on requirement and available instrument, standard procedure was developed to perform mineral analysis as illustrated below:

- Four samples on the grid line watch glass were prepared for each sediment sample.
- The sample was then observed under microscope and USB camera to identify mineral types based on their physical properties.
- For each sample prepared, each type of minerals was counted and observation table was developed.
- Percentage of each mineral was calculated separately for all four samples.
- Average percentage of each mineral was calculated from above calculated percentages.

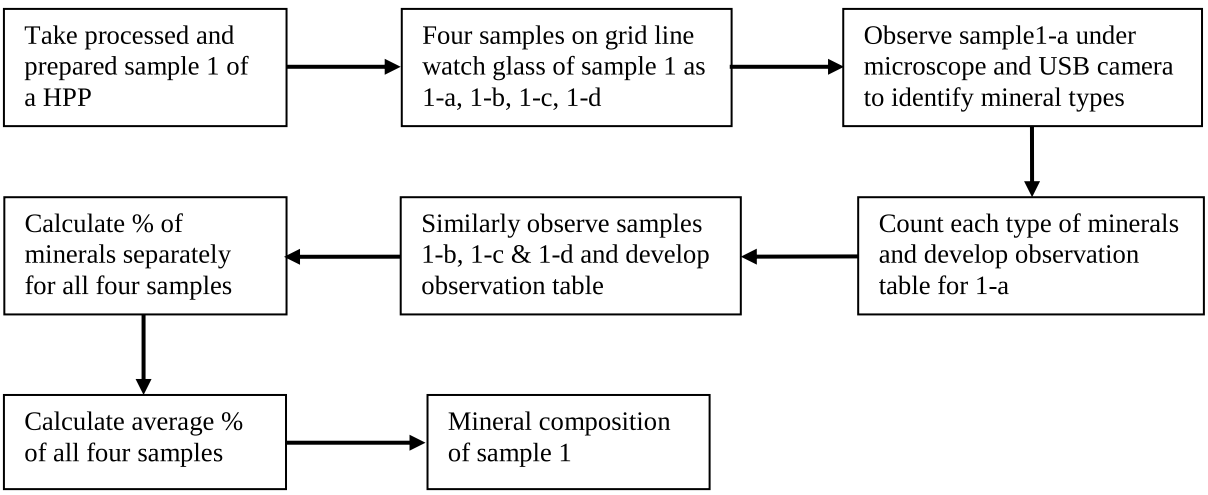

Figure 3 Mineral analysis procedure

RESULTS AND DISCUSSION

A. PSD analysis

PSD results were plotted in a semi-logarithm graph called sieve analysis graph shown in Figure 4. In this graph, particle diameters were plotted in log scale and corresponding percentage finer in arithmetic scale. Main advantage of using semi-logarithm graph is that it can bring out features in the data that would not easily be seen if both variables have been plotted linearly.

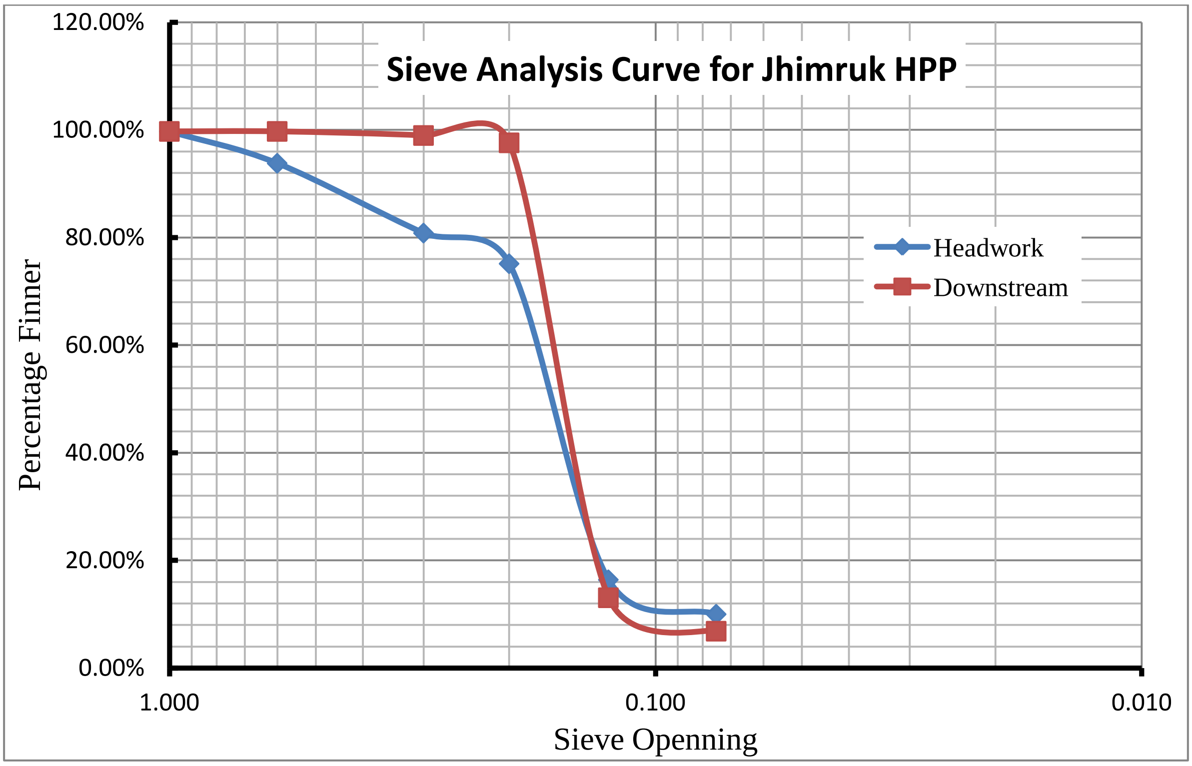

Figure 4 Sieve analysis graph for Jhimruk HPP

Sieve analysis graph shows that percentage finer curves were different for different samples. At headwork, percentage finer curve has steep gradient in the sieve opening of 0.1 mm to 0.2 mm and mild gradient in the range of 0.2 mm to 1 mm. It indicates that about 80 % of the sediment was in the size range of 0.1 mm to 0.2 mm and remaining 20 % larger than 0.2 mm. The sediment size changes as it reaches downstream as indicated by sieve analysis results. About 95 % of the sediment at downstream were in the size range of 0.1 mm to 0.2 mm with only 5% of sediments larger than 0.2 mm. PSD analysis of sediment samples from Jhimruk HPP indicated sediment size of 0.1 mm to 0.2 mm was the most abandon sediment in Jhimruk river and it is considered as the critical size as it easily reaches turbine. Also it was found that sediment larger than 0.2 mm is filtered in headworks and other civil structures. So, at Jhimruk HPP sediment in the range or 0.1 mm to 0.2 mm was predicted to be responsible for erosion of hydro-mechanical components including turbine.

B. Mineral analysis

Mineral analysis results were represented in pie-chart to enhance understanding. All the sediment minerals were represented in percentage to realize relative composition of each mineral type as shown in Figure 5.

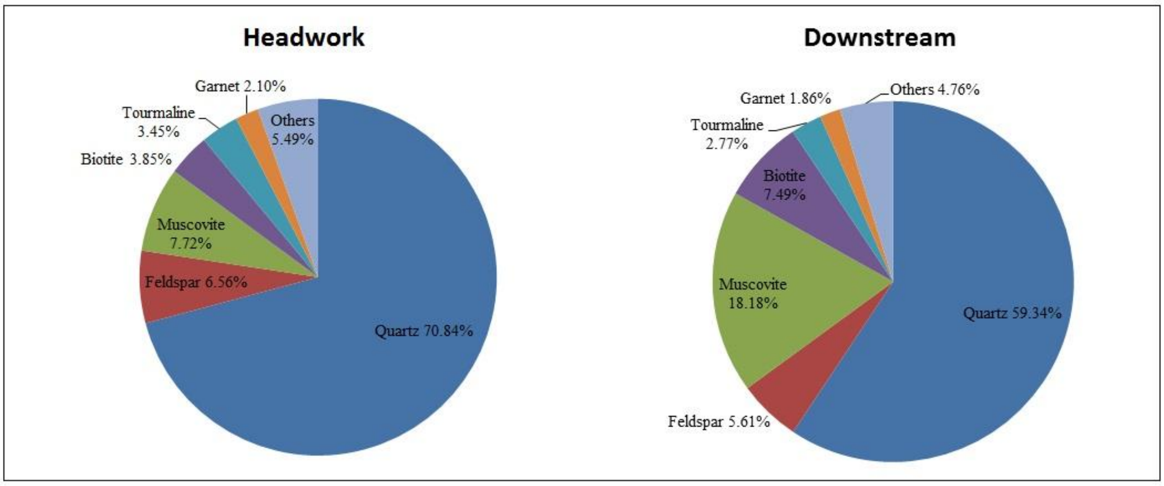

Figure 5 Mineral composition for Jhimruk HPP

Mineral analysis by physical method indicated presence of Quartz, Feldspar, Muscovite, Biotite, Garnet, Tourmaline and some of the other sediment minerals in sediment samples from Jhimruk HPP. Quartz is the most common mineral which was found to be about 70.84 % of total sediment for headwork sample. Its concentration decreases to 59.34 % at downstream. Feldspar was 6.56 % at headworks which was reduced to 5.61 % at downstream. Muscovite and biotite on the other hand tends to increase from 7.7 2% and 3.85 % at headwork to 18.18 % and 7.49% at downstream. There was found little variation in the composition of tourmaline and garnet, on average 3 % of tourmaline and 2 % of garnet were present in sediment of Jhimruk HPP. Other sediment minerals were found to be about 5 %.

According to Bowen's Reaction Series, quartz is the last mineral to crystallize at lower temperature. Also quartz is the most stable sediment and rock mineral on the earth surface which has less weathering tendency compared to other minerals [13]. Due to these reasons it is believed that quartz is the most common mineral in any river sediment. In context of Nepal all the rivers are originated from the Himalayas where quartz is common mineral, so most of the rivers sediments are enrich with quartz.

Above result suggests change of mineral composition as the sediment flows from headwork to downstream. The reasons for this variation in mineral composition was not clearly identified but it is predicted that settling of heavy mineral in settling basin, breaking down of mineral, erosion, action with water sediment passages, weathering by internal temperature variation, leakage and mixing of stream, etc. are responsible for this mineral variation. Due to settling of minerals in settling basin and erosion it is predicted that the quartz content must have been reduced. As mica has perfect cleavage, it is predicted that breaking process and floating nature must have increased the concentration of mica in downstream which we cannot differentiate under 2D view of microscope. Thus in any mineral related analysis of sediments in hydropower plant at least two samples (Headworks and Downstream) need to be considered to obtain representative result.

CONCLUSION

PSD analysis by sieve analysis method shows different particle size at different sampling sites within a HPP. The sediment size was found larger at headwork as compared to downstream. In case of Jhimruk HPP, most of the sediment was in the size range of 0.1 mm to 0.2 mm and these sediments were predicted to be responsible for severe erosion of hydro-mechanical components at Jhimruk HPP.

Mineral analysis by particle count method indicated presence of quartz, feldspar, muscovite, biotite, garnet, tourmaline and other sediment minerals in Jhimruk river sediment. Quartz is the most common mineral in river sediment whose concentration varies depending on the origin of the river and distance travelled by the river. Quartz is harder than turbine material and can easily cause erosion of the turbine material. Due to excessive quartz content harder than turbine material, it is predicted that quartz mineral is responsible for erosion of hydro-mechanical components including hydraulic turbine.

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