Sediments problems in ROR Hydropower Project

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Abstract

Sediment, one of the biggest enemy of hydropower project might make project unfeasible due to increase in high cost of the project. Although, Nepal has huge potential for hydropower due to glaciers in the Himalayas, regular monsoon rain and local topography. Most of the hydropower plants in the Himalayan Rivers are affected by excessive sediment which decrease the capacity of reservoir, erode or breach the hydraulic structures such as weir, undersluice, divide wall, intake, etc. and cause erosion of turbine components. The erosion of hydraulic machinery depends on operating environment, properties of eroding particles and substrates. The shape, size and mineral content 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. Few examples of Khimti HEP and Jhimruk HEP , Nepal represents typical high head power plant in the Himalayan River which is affected by river sediment. The laboratory erosion tests of turbine material revealed the dependence of erosion rate with respect to mineral content. Sedimentation problem in Hydropower starts from headwork's to powerhouse. Each and every Structure intact with water is susceptible and vulnerable due to sediment laden water. New technology of sediment trap like Sediment Sluicing Serpent System (S4) used in settling basin for flushing in Jhimruk and also Slotted Pipe Sediment Sluicers (SPSSs) used in pressurized tunnel as sand trap in Khimti are new technology which has also been introduced in the context of Nepal.

1. Introduction

In most countries, sediment can be a major problem when developing hydro power projects. The regions contributing most sediment are western and southern US, southeast Europe, Asia, eastern Australia and New Zealand [Meg B Bishwakarma]. About 20B tones of earth material are carried to the sea every year worldwide, of which nearly 6B tones are from the Indian sub-continent alone [Meg B Bishwakarma] .We all know that due to Topographical condition and runoff made Nepal rich in Hydropower with 83000 MW capacity. Nepal is gifted by nature in terms of water resources because of the snow capped mountains, glaciers, regular monsoon rain with an average annual precipitation of 1503 mm and annual runoff of about 224 billion cubic meters through 6000 large and small rivers/rivulets.

The main sources of sediment in Himalayan rivers are glacial deposits, land slides and intensively cultivated hill slopes. However, little qualitative or quantitative information is available on the sediment released from these sources. To combat further degradation of water resource by the river sediment, detailed knowledge is needed of the rate of supply, the characteristic size and shape of the sediment particles, hill slope and channel storage and downstream transport and attrition particles [Meg B Bishwakarma].Even higher sediment loads may be expected on smaller rivers with higher stream gradients and more potential for landslides blocking the whole valley. Despite of Nepal's enormous hydropower potential, only about 550 MW has been constructed. An important challenge in developing hydropower projects, is the difficulty in operation and maintenance of the plants due large quantities of sediment with hard abrasive mineral/rock fragments in Himalayan Rivers. Excessive amounts of sediment in such rivers are due to presence of weak rocks and extreme relief and hence sediment management has become primary importance for the safety, reliability and life of infrastructures. 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.

The issues of sediment in the hydropower project with emphasis on turbine erosion and case study of 60 MW Khimti project are presented in this paper. The variation of hard mineral content in the sand samples from different rivers of Nepal and erosion rate estimated from laboratory measurement is reported. The trap efficiency of settling basins is a function of fall velocity of sediment particles. For similar hydraulic conditions, bigger particles have higher fall velocity and therefore tend to settle faster whereas smaller particles tend to settle slower and may not even settle within the settling basins. Moreover, the extent of erosion of the turbine or any other hydraulic machinery is also dependent on the size of particles. Generally, bigger sizes of particles generate higher impact and consequently erosion rate becomes higher. The location and pattern of erosion is also dependent on the size of particles. The content of hard minerals in suspended sediments is another parameter, which influences the extent of erosion of hydraulic machineries. Sediments containing high percentage of hard minerals such as; quartz and feldspar cause more erosion than with low percentage even if the total sediment load passing through a turbine is the same. The hardness of quartz is 7 on Moh's hardness scale. Particles with Moh's hardness of more than 5 are harmful to hydraulic machinery. The intensity of erosion is directly proportional to the hardness of the particles irrespective of their size [Meg B Bishwakarma].

2. Sediment problem in Hydropower Plant

The sediment management is challenging discipline in civil engineering especially in the Himalayan region. The storage capacity of reservoirs decreases due to accumulation of sediment. Settling basins extracts clean water by settling particles, which are then drained back to the river by flushing system. The efficient settling and flushing of particles discharge excessive sediment into the river intermittently and on the other hand, poor system causes erosion of turbine components. The erosion of turbine component depend on: (i) eroding particles - size, shape, hardness, (ii) substrates–chemistry, elastic properties, surface hardness, surface morphology, and (iii) operating conditions – velocity, impingement angle, and concentration and like that. Depending on the gradient of the river and distance traversed by the sand particles, the shape and size of sediment particles vary at different locations of the same river system, whereas mineral content is dependant on the geological formation of the river course and its catchments area.

Run-of-river projects are constructed to utilize the available water throughout the year without having any storage. These projects usually consist of a small diversion weir or dam across a river to diver the river flow into the water conveyance system for power production. Therefore, these projects do not have room to store sediments but should be able to bypass the incoming bed loads to the river downstream. The suspended sediments will follow the diverted water to the conveyance system. Settling basins are constructed close to the intake to trap certain fractions of the suspended sediment.

The history of sediment data collection in Nepal goes back to 1963 in Karnali river basin in relation to hydropower development. Marsyangdi hydropower project started regular monitoring of sediment and its effects on turbines since 1989. Sedimentology has emerged as important task in most of the recent hydropower projects in Nepal. Even though Jhimruk, Khimti and some other power plants are monitoring sediment and its effect, still there is a lack of information for scientific analysis for estimation of its effects. Except Kulekhani, all others are Run-off-River (ROR) projects and all of them have effect of sand erosion. Francis turbines of Panauti, Trishuli and Sunkoshi are eroded frequently and mostly refurbished by welding and grinding. Both the Francis and Pelton turbines of Kulekhani reservoir are relatively less eroded compared to ROR projects because coarser particles settle down before reaching the intake. Even with the well designed sediment settling and flushing system, power plants like Marsyangdi, Khimti and Jhimruk are having severe erosion problem. The main strategy to combat erosion effect in Nepalese power plants is repairing the eroded turbines by welding and coating with erosion resistant hard materials.

River (Sediment on the Mountainous Rivers of Nepal)	Area km^2	Sediment Transport [kg]
Karnali Karnali at at Asara Asara	19.260	$17{,}200x10^6$
Seti at Banga	7.460	$19{,}000x10^6$
Karnali at Chisapani	42.890	$105{,}000x10^6$
Rapti at Bagasoti	3.512	$16{,}600x10^6$
Kali Gandaki	7.130	$32{,}200x10^6$
Seti at Pokhara	582	$3{,}310x10^6$
Trishuli at Trishuli	4.640	$3{,}410x10^6$
Narayani at Narayanghat	31.100	$176{,}000x10^6$
Lothar at Lothar	169	$1{,}400x10^6$
Bagmati at Chovar	585	$765x10^6$
Kulekhani at Kulekhani	126	$22x10^6$
Kankai at Mainachuli	1148	$5{,}830x10^6$

Table 2.a Sediment on the Mountainous River of Nepal

[Ref. KP Sharma, Hari Prasad Neopane]

3. Study on Jhimruk HEP [Based on Svein Tønseth & Bishwakarma, M.B]

The 12 MW power station on Jhimruk Khola will start generating electricity in mid 1994 which is located on Pyuthan District, Mid-Western Development Region. New Technology new technology called Serpent Sediment Sluicing System (S4) in the field of sediment handling techniques in Settling basin was introduced in JHEP. Prior to the Jhimruk project, the system had been tested and developed through three physical model studies at SINTEF NHL and a field test programme at Andhi Khola hydropower and irrigation project in Nepal. The system has been in operation for two monsoon seasons at Andhi Khola.

In order to maintain the sediment trapping ability of a settling basin, the settled sediments must be removed from the basin. The Serpent Sediment Sluicing System is an innovative approach to this requirement. "The need for new technology in the field of sediment handling techniques was obvious. Most existing systems for removal of sediments from settling basins under operation work only on the drawing board," says Støle who has covered this area in his thesis for Doctor of Engineering degree.

The main criterion for the development of a new sediment removal system was the need for undisturbed power generation during the sediment removal process. During periods of heavy sediment transport, the basins must be cleaned several times a day. In many hydropower plants, energy production has to be reduced or stopped during flushing of the settling basins because the basins must be de-watered in order to flush out the sediments. The need for continuous and regular power generation overrules the need for sediment removal. The result of this, however, is that the trapping ability of the basins is reduced and the turbines are damaged. With the Serpent Sediment Sluicing System we have eliminated these drawbacks. The system uses less water than any other known flushing system, and it is so simple that the operator can easily monitor the performance of the basin and the flushing process. The low flushing water consumption allows our system to be operated as often as required," explains Haakon Støle [Svein Tønseth].

§ **How the Serpent Sediment Sluicing System works** [Research News from SINTEF and NTH-NTNU].

A flushing channel, with a longitudinal slot on top, is constructed along the bottom of the settling basin, with an outlet that is opened during flushing as shown in the fig. 3.a, 3.b and 3.c.. The level difference between the water surface in the basin and the level of the outlet provides the energy potential needed for flushing. A heavy-duty rubber tube, normally full of water, covers the slot on top of the channel. The tube blocks the passage of sediments and water to the outlet, and the sediments build up around the tube.

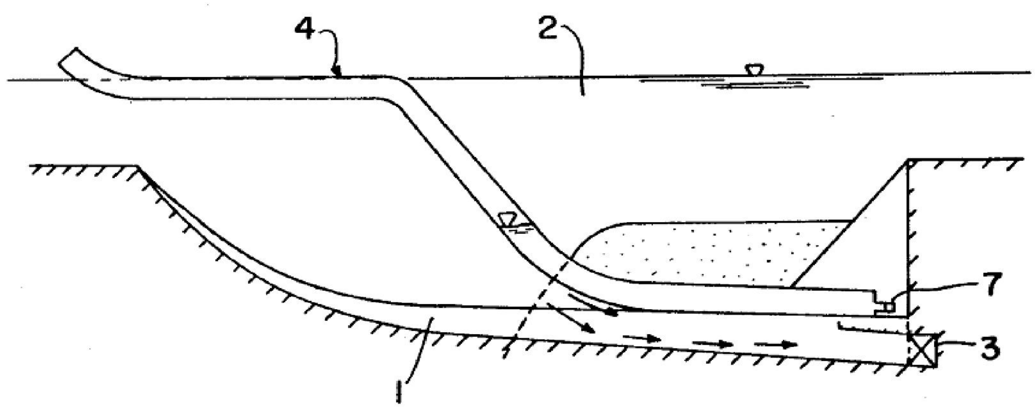


Fig3.a L-Section of the Serpent Sediment Sluicing System
[Ref: Serpent Sediment-Sluicing System-Haakon Stole]

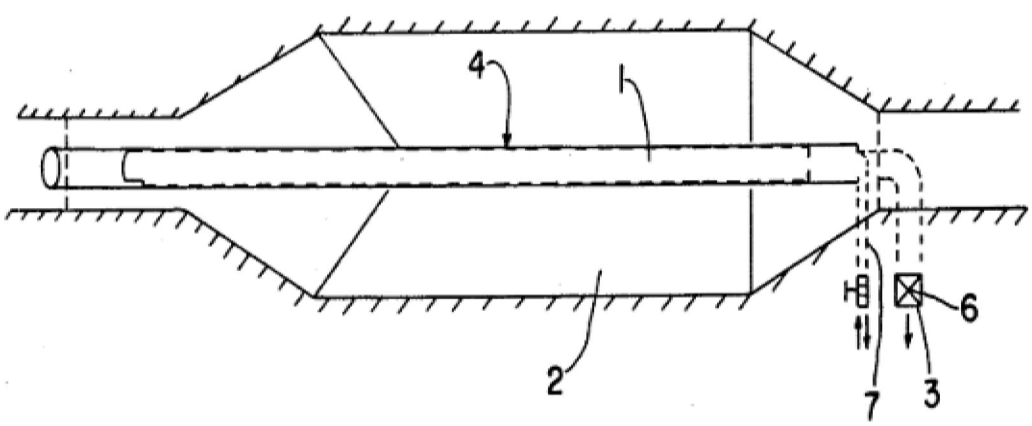


Fig3.b Plan of the Serpent Sediment Sluicing System

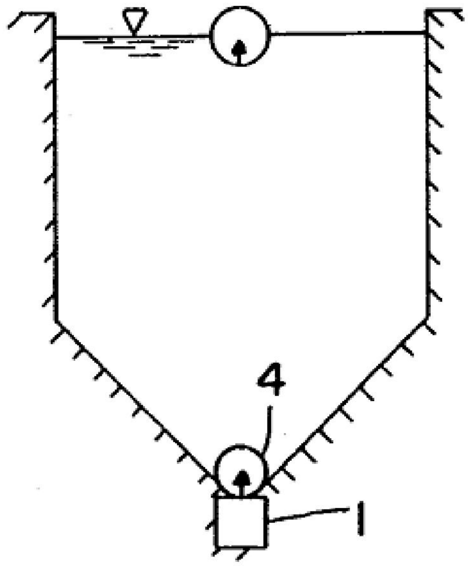


Fig3.c Cross-section of the Serpent Sediment Sluicing System
[Ref: Serpent Sediment-Sluicing System-Haakon Stole]

When the tube is gradually dewatered, the upstream end becomes bouyant and floats up, opening the slot like a sort of zip-fastener.The suction area moves along the length of the basin with the "zipper". This is the key to the high flushing efficiency of the system or, if you like, its low water consumption - one of the most important advantages of the system.The system can also be operated by allowing the tube to lie on the surface while the sediments are settling out. To flush the system, the tube is filled with water, and starts to sink. The "zipper" moves in the opposite direction, moving the suction area along the basin. The system is easy to use, and does not use machinery that requires power.

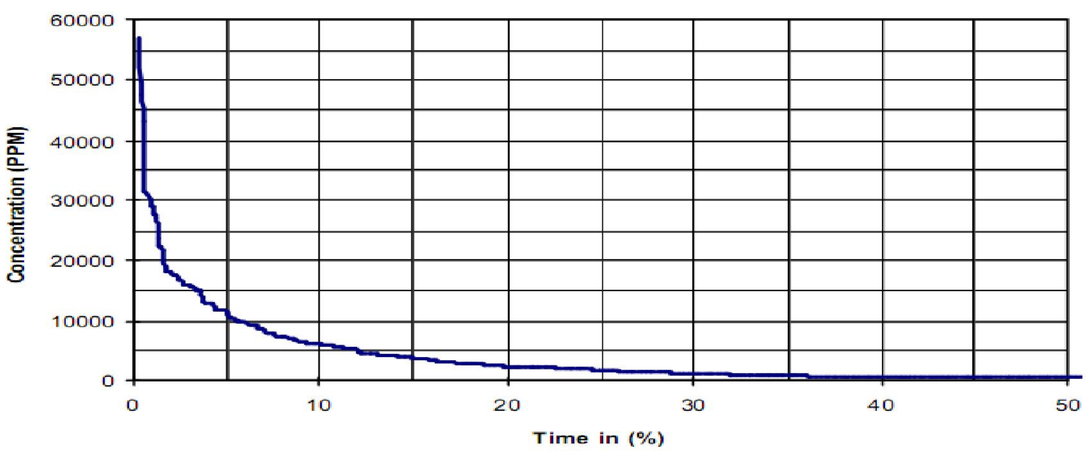


Fig:2.a Sediment concentration duration plot for JHP

Figure 2.a shows a sediment concentration duration plot for Jhimruk River at the intake. The horizontal axis represents percentage of monsoon (mid June to mid September) time and the vertical axis shows the sediment concentration measured at the intake. If 3,000 PPM is taken as the maximum level of concentration at the intake when JHP can be o perational, then the power plant needs to be shutdown for about 20 % of the monsoon time. This means that 20 % of the expected generation during the monsoon is lost. Moreover, Bishwakarma [1999] reported that the sediment concentration as high as 57,000 ppm was observed in the Jimruk river in Nepal during the monsoon of 1996.Therefore, it is important to determine a level of concentration cut-off based on the cost benefit analysis as it has impact on generation losses and also losses caused by the sediment induced wear.

4. Case study on KHP (Based on Bishwakarma, M.B)

Khimti I Hydropower Plant (KHP) represents a typical power plant in Himalayan Rivers with high river gradient and heavy monsoon flow with high sediment concentration of hard abrasive particles. Two parallel sediment settling basins are designed to exclude 85% of particles with fall diameter of 0.13 mm and 95% of particles with fall diameter of 0.20 mm (Bishwakarma, 2003). Minimum discharge of 500 liters per second is released in dry season to maintain downstream water requirements. With the gross head of 684 m, KHP has 60 MW installed capacity and approximately 350 GWh annual energy (5X12 MW Pelton units with rated flow 2.15 m3/s). The power plant has been in commercial operation since July 2000 and the effect of sediment has already appeared in runners and needles and spare runners are already changed in all units.

The sand trap is designed to trap sand and gravel which is released from the tunnel and due to geological condition the tunnel sand trap is designed within the limited size. Due to which the tunnel sand trap is therefore equipped with two Slotted Pipe Sediment Sluicers (SPSSs) as shown in figure 3.a, a technology which permits the removal of the trapped sediment during operation. This is the first time a sand trap has been designed with this technology. The pressurized tunnel is located at the downstream of 11 km headrace tunnel, just before the pressure shaft. The sand trap is of very moderate size; its volume is only 133 m^3. There are two SPSSs situated a short distance above the bottom of the sand trap. Each of them connected to a 260 m long outlet pipe, 100mm in diameter. The outlet pipe discharges into a stilling pond. In addition of to the two SPSSs there is a test SPSS of smaller size. The text SPSS is approximately 2 m above the floor of the sand trap. When a high sediment concentration from the test SPSS is observed, this indicates that the sand trap is full, which again indicates that the main SPSSs should be operated.

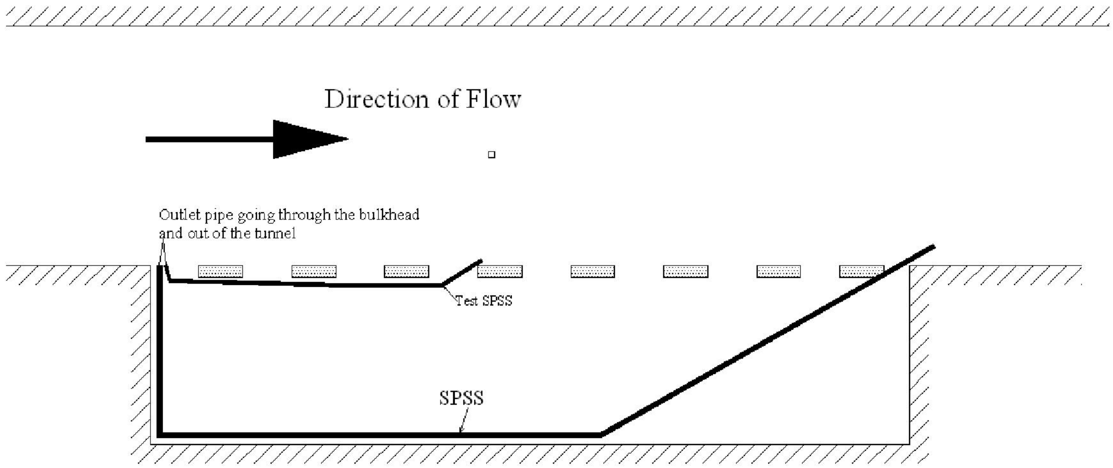


Fig4.a The tunnel sand trap equipped with two Slotted Pipe Sediment Sluicer (SPSSs)
(Source: GTO Sediment AS - Olav Tryggvasonsgt. 24b

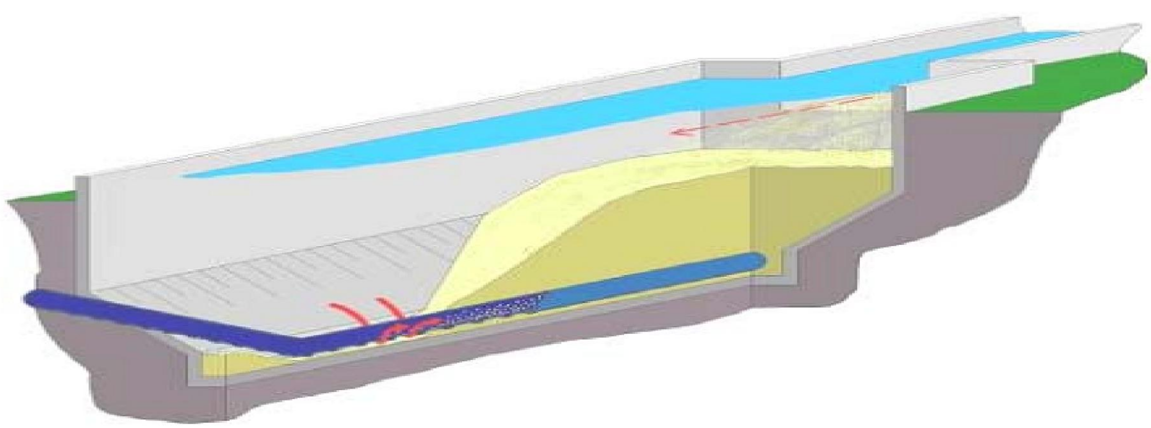
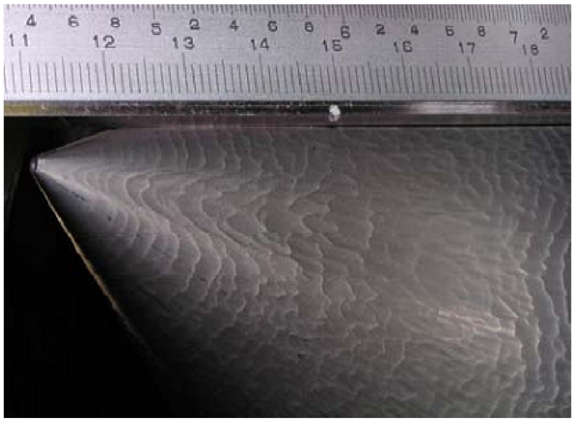


Fig4.b The tunnel sand trap equipped with two Slotted Pipe Sediment Sluicer (SPSSs)
(Source: GTO Sediment AS - Olav Tryggvasonsgt. 24b)

The hydro pipe at Khimti tunnel sand trap has now operated satisfactorily for more than three years. But due to high concentration of quartzite content in the Khimti river is the major cause for the damage of turbine component.

The damage in the turbine components were inspected in July 2003. After 1 year of operation (about 6000 hours), significant amount of erosion had appeared in turbine bucket and needles. The damage of needle and bucket of Pelton turbine due to erosion are shown in figure 4(c,d). The erosion of needle and nozzle destroys the jet and reduces the performance of the turbines. The reduction of bucket thickness is critical due to strength and hence the reliability of the component. The sharp edge of the splitter has blunted and the width became approximately 4 mm. With this 1% loss of relative efficiency can be expected in these runners, which is significant loss of revenue for this power plant. In addition, the maintenance cost also increases. HPL has tried to minimize the effect of erosion by spraying hard ceramic coatings in the bucket and needle surface at the cost of around US$ 25000 per runner, but initial inspection of the coating have not shown promising performance.



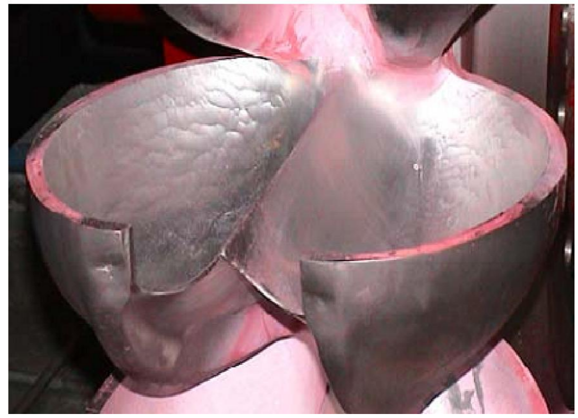


Fig4.c Eroded needle of KHP 1 Fig4.d Eroded bucket of Pelton turbine of KHP

(Ref:Bhola thapa and group University of Science and Technology, Trondheim*)*

5. Results and Discussion:

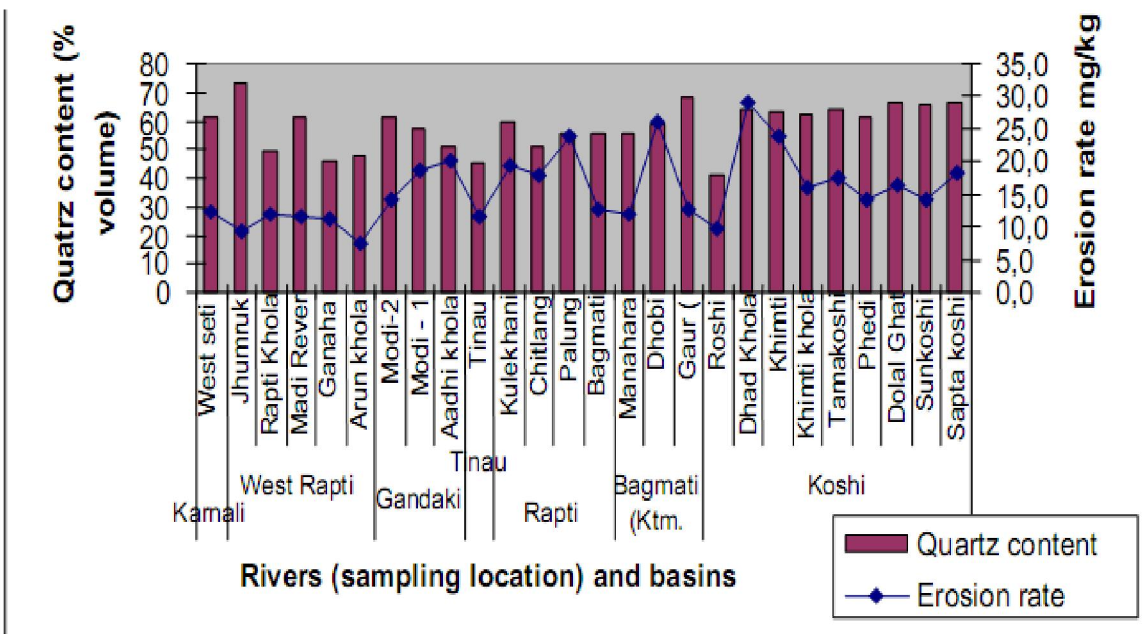


Fig 5.a Quartz content from mineral analysis and erosion rate from laboratory test from corresponding sand samples

(Bishwakarma, M.B., Dhakal, G.P., Pradhan, P., 2003, Headworks Design in Himalayan Rivers)

According to the figure 5.a shown, quantity of quartz content is highest in Jhimruk river which is greater than the 70 % volume of sediment content. Also, erosion rate is greater in Khimti river which is greater than 25 mg/kg. Compared to east, quantity of quartz in western part are varying, but certainly less than that of east. Some of these rivers originate in Middle Mountains and hence local geology may have great influence in the quartz contents. The quartz content in Jhimruk is highest but corresponding erosion rate is small. Bagmati basin, which is in the middle of the country have quartz content in between eastern and western basins. The result shows some trend along length of the country, for instance the erosion rate is almost equal for all the samples in their respective basins in east and west. Eastern basins have higher erosion rate compared to western basin, which can be justified by higher quartz content. The fluctuation of erosion rate in the middle region could be because of origin of rivers in the Middle Mountains with most unstable landscape; hence the properties could be highly localized with fresh sharp edges. Once the particles traverse a certain distance, it will be rounded off and lose its eroding capacity, which can be seen in the result of Bagmati River close to origin and at Gaur. This study hinted that besides quartz content in sediment, the shape of particles could also have significant influence in erosion rate. The relation between shape of the particles with geographical locations, mineral content and erosion rate and so on can be used for ranking the erosivity of different existing and forthcoming power plants.

There are many sources of sand in the earth, but whatever is the source, they are rich in quartz grains, which are formed by weathering of rocks such as granite. The silica is physically stable and it makes sand valuable for several applications such as construction, foundry, production of glass and abrasive materials and so on. Though there are enormous sources, it could be a costly commodity due to recovering, processing and transporting cost. Environmental impact has great price because of unplanned extraction of sand from river channels and flood plains. Mostly sand are used for construction purpose in Nepal, which are basically supplied by river channels. The degradation of river system at Kathmandu valley and other part of the country is basically because of extraction of sand. The estimated industrial consumption of sand in Nepal is about 150 tones of foundry sand and 20 tones for sand blasting, which is basically imported. Sediment in the river is considered as hurdle for the development of hydropower plants in Nepal. On the other hand, its economic value is never thought of. The mineral analysis of sand samples indicates possibility of its use for industrial purpose. With in the range of 1 km from the Sunkoshi power plant, sand is extracted from the Sunkoshi river bed and supplied to Kathmandu valley. If such extraction can be coordinated with the settling basins at power plant, the burden can be used as a by-product.

In order to prevent the sediment entering the generating system, effective settling basin arrangements are important. In the civil design side, Alam [2001] suggests the following design considerations for a run-of-river hydro project:

- Simple structural shapes with adequate transition.
- Efficient sediment flushing arrangements.
- Trapping efficiency of the various particle sizes for a given sediment grain size distribution.
- Total construction cost of the installation, including flushing arrangements.
- Total costs caused by the loss of average annual power production during flushing plus the loss of excess water required for flushing.
- Total estimated costs of downtime resulting from abrasion damage or its repair.
- Total costs of plant shut down during excessive sediment concentrations in the water.

Furthermore, the existing modelling techniques, both physical and numerical, should be used extensively during the project design in order to obtain as much information as possible for the smooth operation of the plant after its completion.

6. Conclusion:

Sediment is a problem for the development of hydropower plants in the Himalayan region and in Nepal.Sediment management is important for longer life of reservoir and turbine components.A common knowledge or general awareness of sediment problems is not enough to tackle this issue. Hydro power engineers must be 'sediment conscious' during investigations, design, operation and maintenance, and even upgrading and refurbishment. More research and development is needed into the causes and mitigation of sediment erosion impacts. Experiments and field observations are needed to understand the true relationship between the sediment characteristics, wear resistance of base material, relative velocity of water, angle of attack of sediment particles, and chemical properties of water. More engineers should be trained in sediment engineering in order to raise a proper consciousness of the importance of sediment problems in the benefit of better planning, design and operation of run-of-river plants. The use of a developed real-time sediment monitoring system for guiding the power plant operation together with an efficient flushing system may contribute immensely in mitigating the sediment-induced problems in run-of-river plants.

References

Bishwakarma, M.B., Dhakal, G.P., Pradhan, P., 2003, Headworks Design in Himalayan Rivers: the Case of Khimti I
Addressing sediment problems-15 May 2007

Serpent Sediment-Sluicing System-Haakon Stole,Fagerliveien 20 D, Trondheim, Norway

Hydropower Project, Nepal, Int. Conf. Hydro 2003, IHA, Croatia. Thapa, B., Dahlhaug, O.G, 2003. Sand erosion in hydraulic turbines and wear rate measurement of turbine materials, Int. Conf. on Hydropower, Hydro Africa -2003, ICH, Arusha.

T.Jacobsen,(GT), "Sediment handling technologies: experience from case studies"

Quantification of Sand Erosion in Francis Quantification of Sand Erosion in Francis
Turbine Turbine, Hari Prasad Neopane PhD Student at Water Power Laboratory
((http://dok.ebl-kompetanse.no/Foredrag/2008/Liverpool/Neopane.pdf)

International Conference on Small Hydropower - Hydro Sri Lanka, 22-24 October 2007
Meg B. Bishwakarma General Manager, Hydro Lab Pvt. Ltd., Krishna Galli, Pulchowk, Lalitpur, Nepal (Present Address: PhD Fellow, NTNU, Norway) (www.iitr.ac.in/departments/AH/uploads/File/.../A7.pdf*)*

Bhola Thapa, Raju Shrestha, Projjowal Dhakal, Biraj Singh Thapa,PhD Student, Norwegian University of Science and Technology, Trondheim- Sediment in Nepalese hydropower projects

Norwegian invention is key to water resources development in Nepal-By Svein Tønseth

Research News from SINTEF and NTH- Professor Ugelstad´s(*1993/1994),* (http://www.ntnu.no/gemini/1993-dec/)