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Desilting Basin Efficiency Estimation for Run-of-River Small Hydropower Plants

E. A. Azrulhisham, M. Arif Azri

Abstract*: Suspended sediment concentration and discharge are important factors affecting the operational reliability of run-of-river small hydro power (SHP) plants. Elimination of sediment transported with the flow across the turbines of run-of-river plants is therefore a critical issue for the sustainability of the SHP industry. Comprise of a small diversion weir throughout a stream, the SHP plants does not have space to pile sediments but should be able to divert the incoming bed loads to the river downstream. Sediments in the water entering through the turbines with extreme velocity erode the contact surfaces of turbine mechanisms which results in reduced hydraulic efficiency and increased maintenance cost. Subsequently, desilting basins have become an essential part of the water conductor system of run-of-river SHP to reduce the impact of damage due to suspended sediment. Desilting basins are devised as settling basins to settle sediments larger than a targeted size. They are constructed just after power intake and discharge is despatched through them before pass into the head race tunnel. This study is aimed to estimate the sediment removal efficiency of SHP desilting basins based on data recorded at the intake of a run-of-river SHP. Considering the hydrological variability, probabilistic approach was used to obtain mathematical function for the probability density of suspended sediment concentration (SSC) based on the recorded data.

***Index Terms*: Suspended sediments, run-of-river, small hydro power, desilting basins**

I. INTRODUCTION

Small scale hydropower has been developed as common substitute to larger scale hydropower project for their lower cost, reliability and environmental friendliness. In Malaysia, small hydropower is defined as hydropower technology based on the run-off-river schemes of sizes of up to 30 MW in capacity. Small scale hydropower (SHP) comprises a cost-effective electrical power generation alternative for rural regions in developing countries. As a still growing sector in Malaysia, the installed capacity from SHP was 32 MW on 2014 and the further potential is projected at 490 MW by the year 2020 [1]. Generally, the SHP plants in Malaysia are of the run-of-river category that produces the energy from running water to generate electrical power without requirement for a large dam and reservoir, which is much different from typical large hydroelectric schemes.

There is no water storage reservoir exist except the small head pond capacity and all diverted water returns to the stream underneath the power house, whereas the environmental impact is nominal. The run-of-the-river system principally exploits the flow rate of water to generate electrical energy in which running water from a river is directed down a channel or head race tunnel. The diverted water is transferred to an electrical power generating house. In this house, the running water energies a turbine, running a generator and generating electrical power. After being used, water is returned back into the river downstream.

Desilting basin is an essential section of the run-of-river SHP since sediment free flow needs to be transferred to the electrical power generating house. Comprise of a small diversion weir throughout a stream, the system does not have space to store sediments but should be able to divert the entering bed loads to the river downstream. Sediments in the water moving through the turbines with extreme velocity erode the contact surfaces of turbine mechanisms leading to drop in hydraulic efficiency and high maintenance expenses. The erosion takes place as a result of the combined mechanisms of gouging and hammering, and the intensity of erosion relies on sediment characteristics, flow properties, material properties and hydraulic design of the turbine [2]. The hydro-abrasive erosion of turbine components leads to abetting of cavitations, pressure pulsations, vibrations, mechanical breakdowns and regular shut downs [3].

Elimination of sediment transported with the flow throughout the turbines of run-of-river mini hydropower plants is therefore an important issue for the sustainability of the SHP industry. There are a host of options are applied in order to minimize the sediment entering into the turbines of run-of-river hydropower plants. At the diversion weir, the entry to the headrace canal is devised to reduce the sediment arriving into the canal. Though coarse sediments are stopped from entering into the canal at the intakes, fine sediments find their way into the canal with the flow. Therefore, desilting basins have become a vital part of the water conductor system of run-of-river hydropower plants to reduce the impact of damage due to suspended sediment.

Desilting basins are devised as settling basins to settle sediments larger than a targeted size [4]. They are constructed just after power intake and discharge is dispatched through them before entry into the head race tunnel. Evaluating the sediment characteristics of a river where a run-of-river SHP is planned is a crucial prerequisite to ensure the sand trapping efficiency of a desilting tank. The size and amount of arriving sediments are also key factors affecting the erosive wear of hydro turbine components [5].

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In the present study, an attempt has been made to estimate the sediment removal efficiency of SHP desilting basins based on data recorded at the suspended sediment monitoring station installed at the intake of Perting SHP facility in Bentong Pahang, Malaysia.

The study is an attempt to quantify and predict statistical parameters of suspended sediment concentration using statistical method. Nevertheless, the variability of sediments approximation varies significantly as a result of hydrological uncertaities and precipitation. In such cases, the statistical method that is founded on method of moments allows the evaluation of uncertainties associated to these hydrological and meteorological irregularity. The parametric cumulative probability curve was derived based on the first four statistical moments of suspended sediment concentration data obtained from the sediment monitoring system. Suspended sediment with median concentration were subsequently used to evaluate the desilting basin efficiency as represented by cumulative probability curves.

II. METHODOLOGY

A. Preliminary Investigation

Sediments have posed great challenges in the operation of run-of-river hydropower plants in South East Asia. Harsh topography and intense seasonal rainfall have made this region vulnerable to erosion and sedimentation. One of the important components of run-of-river hydropower schemes is the settling basin, which protects the hydro mechanical equipment from the harmful silt carried by the conducting system. There were no sediment data exist for the Perting SHP plants during the design and development phase of the power plant. Owing to the absence of sediment data, the design was founded on the common design standards and on the knowledge of design of comparable projects in South East Asia at that time, and on typical references to sediment transport in the Asian Rivers. As a result, the power plant settling basins have been devised to trap 90 % of 0.5 mm size particles.

Preliminary investigation on the suspended sediment at Perting SHP plant has been carried out based on sampled water from the intake stream. To collect information about the sediment, water from the stream was sampled in vertical line at various depths by means of a depth integrating sediment sampler along the whole section of the river. The sampler shown in Figure 1 is made of light weight cast aluminium with a wading rod capable to collect suspended-sediment samples at any point or over a range of depths in a stream.

Fig. 1 Depth integrating sediment sampler

Fig. 2 LISST-Portable|XR instrument

The sampled water is afterwards analysed using LISST-Portable|XR equipment as shown in Figure 2. The LISST-Portable|XR is a battery powered Laser In-Situ Scattering and Transmissometery (LISST) instrument developed by Sequoia Scientific in which laser refractometry is applied to measure size and volumetric concentrations for particles using 44 logarithmically spaced size classes between 0.34 to 500 µm.

In-situ analysis of particle size and concentration is performed by a laser beam directed into the sample volume where particles in suspension scatter, absorb, and reflect the beam. The distributed laser light is received by a sequence of ring-shaped detectors of progressive diameters that permit measurement of the scattering angle of beam. Particle size can be computed from information of this angle either by using the Fraunhofer estimation or the exact Lorenz-Mie solution [6]. Particle size limitation is excluded by establishing concentration measurements on these measured particle sizes, hence permitting both particle size and volume concentration to be simultaneously measured.

The automatic settings as recommended by the manufacturer were mostly applied during the measurement. The integrated ultrasonic probe and mixer was activated at 10 second with 20% power for comprehensive sample dispersion while removing the air bubbles from the suspension. The LISST-Portable|XR equipment particle size identification is based on 2 dimensional of the cross-sectional area of a particle. Measurements of the sediment particles are then translated mathematically to a 3-dimensional volume. Conversion of suspended sediment concentration (SSC) from volume concentration (µl/l) to ppm by mass (mg/l) was accomplished by multiplying the volume of the particles with the density of the particles.

B. Suspended Sediment Monitoring System

The entrainment of sediment particles in the stream flow depends on their size and density. The weight of particles determines the force of gravity pulling them downward. For this reason, a real-time sediment monitoring system which capable to measure the total sediment concentration with regards to flowrate in river is installed at the intake of the Perting SHP plant.

The installed system shown in Figure 3 is capable to measure total sediment concentration of suspended sediments as well as to observe the effects of stream flow on the distribution of suspended sediment at the intake of the power plant.

The system is also aimed to observe the potential impacts of weather on the physical conditions of the intake stream. Particular emphasis is placed on the concentration of suspended sediments on different stream flow conditions.

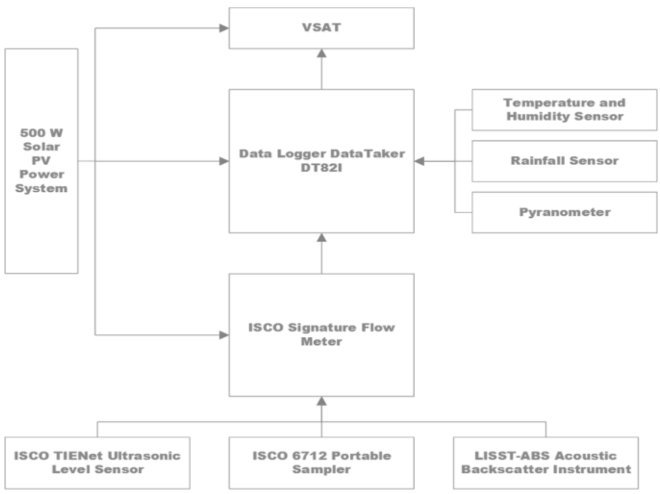

Fig. 3 Suspended sediment monitoring system

Remote monitoring of hydrological factors at particular small hydropower station requires networks of continuously operated in-situ station. The installed monitoring station is capable to monitor standard hydrological parameters and deliver information on the operating condition of the station. The observational data from the station is transmitted via satellite link every hour to a SQL database server for storage and data redistribution. To facilitate ease of access to the data and to be able to quickly search for records from a particular time period, web API and data dashboard were used to manage the data provided by the satellite router.

Data dashboard as shown in Figure 4 is used as a central location to track, monitor and analyse observational data from the hydropower station. A total of nine observational data are included in the data dashboard representing standard hydrological parameters and information on the operating condition of the monitoring system. Apart from data dashboard, the system also incorporates a data grid features with capability to handle and access large volumes of data as well as providing extensions for interfacing with the SQL database allowing any queried data to be exported as comma-separated values (CSV) file.

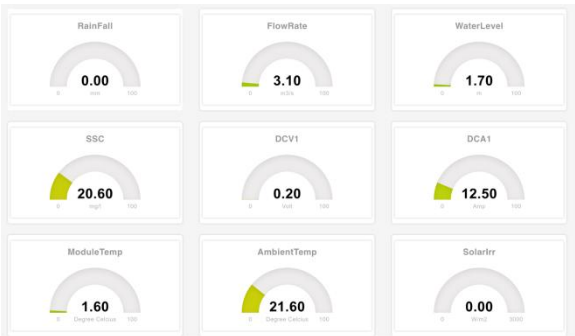

Fig. 4 Data dashboard

C. Probabilistic Approach

Statistical precision is important to any study involving geologically originated material sampling in which large sample sizes are frequently essential to attain a reasonable precision level. Nevertheless, the uncertainties of sediments estimation vary greatly due to the hydrological variability and rainfall [7]. Consequently, the probabilistic approach that is founded on Pearson system permits evaluating the uncertainty associated to these hydrological and meteorological variations.

The Pearson parametric distribution approximation was derived based on the substantial characteristic of Pearson system utilising direct correlation between the first four statistical moments of suspended sediment concentration data acquired from the desilting basin. Further insight into the suspended sediment concentration was evaluated based on 10,000 data approximation generated with regards to the mean, standard deviation, skewness, and kurtosis of the recorded data.

III. RESULTS AND DISCUSSION

A. Particle Size and Distribution

Silt erosion is consequence of mechanical wear of components owing to dynamic action of suspended sediment in stream impacting against solid surface of turbine mechanisms. The intensity of erosion is also directly proportional to the size of the particles. Particle sizes above 0.2 to 0.25 mm are extremely harmful. Large size sediment particles (above 0.25 mm) even with hardness lesser than 5 on Mohr’s scale cause wear. Similarly, fine silt even with size less than 0.05 to 0.1 mm, containing quartz wears out the underwater parts.

The sampled data comprise of 60 observations from five locations of the desilting basin denotes that each sample are dominated by silt and fine sand particle with the mean size range of < 50 µm (or < 0.05 mm). A detailed box-plot representation of the particle size distribution of suspended sediment for different depth level is shown in Figure 5.

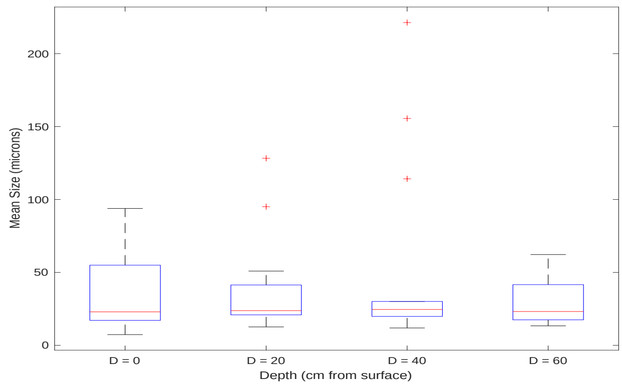

Fig. 5 Box-plot representation of particle size distribution

The box-plots indicates the range from the first to third quartiles, with the median represented by a line. It is discovered that the mean size of suspended particles is approximately the identical for all depth level. The mean size of suspended particles is also found to be scattered at upper range in the sample taken from the surface (depth 0 cm) of the desilting basin. Figure 6 illustrates the distribution of mean size of suspended sediment particles collected from all depth level of the desilting basin.

The mean size of suspended particle is observed to be extremely scattered at the size range of < 50 μm.

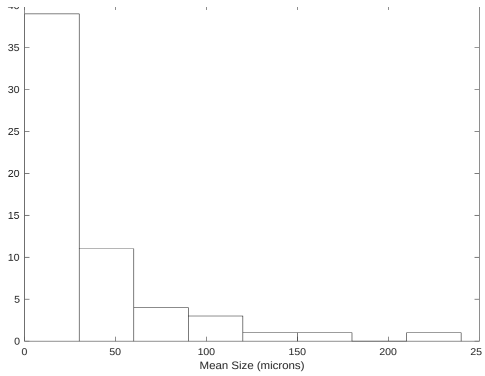

Fig. 6 Mean size of suspended sediment particles

Descriptive statistics was applied to support the interpretation of data from the desilting basin. The descriptive statistics analysis on the recorded data provides the arithmetic mean, standard deviation, skewness and kurtosis as described in Table 1.

Table. 1 Descriptive statistics for the mean-size of suspended sediment particles

Parameter	Suspended Particle (micron)
Mean	38.622
Variance	38.216
Skewness	2.842
Kurtosis	12.423

The characterisitics of sediment differ according to weather influences such as temperature and precipitation. Probabilistic method based on the Pearson system was applied to evaluate the average suspended sediment concentration and the median particle size distribution in which the most applicable distribution to match the data can be identified based on the mean, standard deviation, skewness, and kurtosis. Figure 7 and 8 correspondingly illustrates probability density functions (PDF) and cumulative distribution function (CDF) for the mean size of suspended particle based on 10,000 generated random data using the Pearson system.

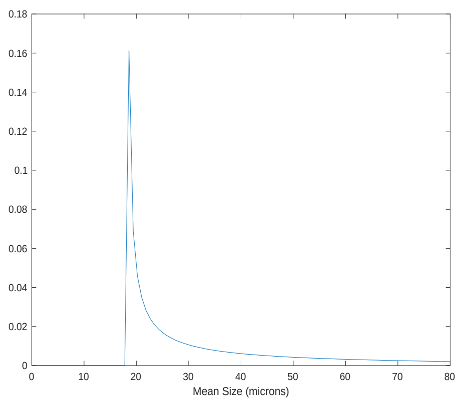

Fig. 7 PDF for the mean size of suspended particle

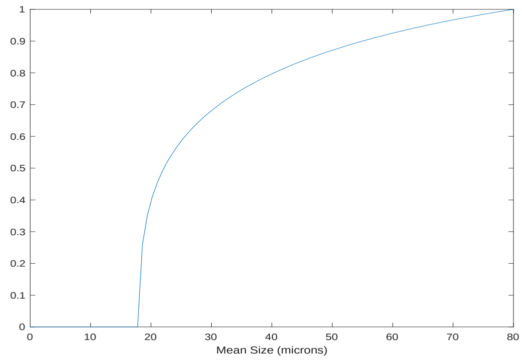

Fig. 8 CDF for the mean size of suspended particle

Figure 7 shows that the PDF for mean size of suspended particle represents a right skewed distribution with concentration in the range of 20 to 40 μm and median of 22.17 μm.

B. Suspended Sediment Concentration

A comprehensive box-plot illustration of suspended sediment concentration distribution for different depth level of the intake stream is shown in Figure 9.

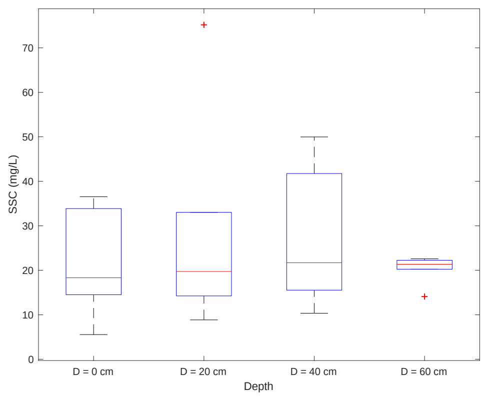

Fig. 9 Box-plot of suspended sediment concentration

Box-plots in Figure 9 indicates the range from the first to third quartiles, with the median indicated by a line. It is discovered that the suspended sediment concentration is about the same for all depth level. The suspended sediment concentration is also found to be scattered at upper range in the sample acquired from the surface (depth 0 cm) and down to 40 cm depth of the desilting basin. The descriptive statistics of suspended sediment concentration at the intake stream and desilting basin in terms of arithmetic mean, standard deviation, skewness and kurtosis are summarised in Table 2.

Table. 2 Descriptive statistics for the suspended sediment concentration

Parameter	Intake Stream (mg/L	Desilting Basin (mg/L)
Mean	24.2625	19.1800
Variance	232.6252	149.6464
Skewness	1.8088	2.7153
Kurtosis	6.5882	12.9967

The Pearson parametric distribution approximation was derived based on the important parameters of Pearson system utilising direct correlation between the first four statistical moments of suspended sediment concentration data acquired from the desilting basin. Figure 10 and 11 respectivley shows the PDF and CDF of suspended sediment concentration accumulated in the intake stream and desilting basin based on 10,000 generated random data using the Pearson system.

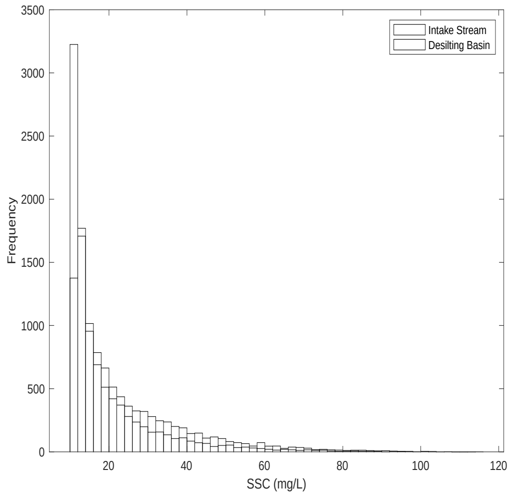

Fig. 10 PDF of suspended sediment concentration in the intake stream and desilting basin

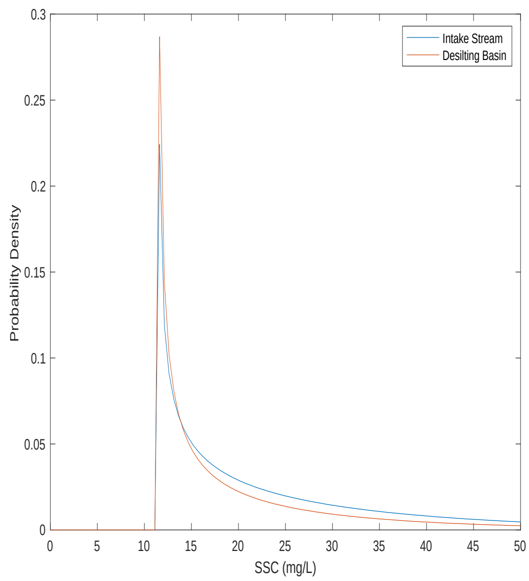

Fig. 11 CDF of suspended sediment concentration in the intake stream and desilting basin

Figure 10 and 11 indicates that the probability density function of suspended sediment concentration accumulated both in the intake stream and desilting basin shows a right skewed distribution with concentration in the range of 10 to 50 mg/l.

C. Desiliting Basin Efficiency

Suspended sediment with median concentration D_{50} were used to evaluate the desilting basin efficiency as represented by cumulative probability curves in Figure 12. The result is summarized in Table 3.

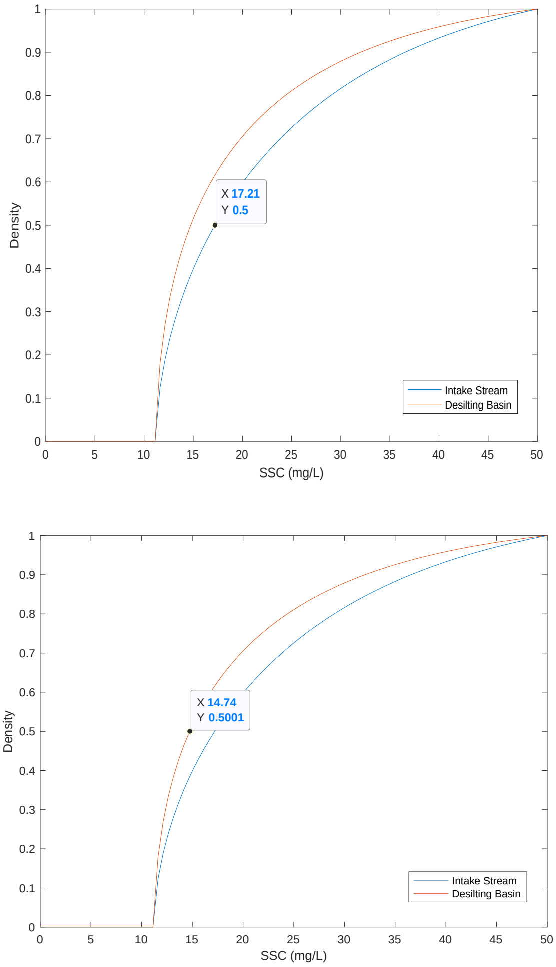

Fig. 12 Desilting basin efficiency derived by median D_{50} of suspended sediment concentration

Table. 3 Desilting basin efficiency derived by median D_{50} of suspended sediment concentration

Intake Stream	Desilting Basin	Efficiency (%)
17.21 mg/L	14.74 mg/L	14.35

The CDF indicates the median particle concentration of 17.21 mg/l and 14.74 mg/l respectively for the intake stream and desilting basin. The results indicate that the desilting basin is capable to reduce the concentration of the suspended sediment particles in the stream moving throughout the turbines at the efficiency of 14.35%.

IV. CONCLUSION

Abrasive particles in the run-of-river hydropower plants decrease unit effectiveness, escalate maintenance expenses and may cause turbine interruption and related production losses. To manage with this condition during the design, operation and maintenance of hydro plants, information of turbine wear needs to be enhanced with regards to relevant suspended sediment characteristics comprising the suspended sediment concentration and particle size distribution.

The acquired suspended sediment concentration and particle size distribution at the intake stream and the settling basin of Perting mini hydro power plant in Bentong Pahang using real-time sediment monitoring system equipped with Laser In-Situ Scattering and Transmissometery (LISST) instrument shows that all samples are dominated by silt and fine sand particle with mean size range of < 50 μm and concentration between 10 to 30 mg/l.

In view of hydrological and meteorological variability, probabilistic analysis method was applied for obtaining probability density of suspended sediment concentration based on the statistical method of moments. Cumulative probability curve with median suspended sediment concentration were used to evaluate the desilting basin efficiency. The results indicate that the desilting basin at the power plant is capable to reduce the concentration of the suspended sediment particles in the stream flowing through the turbines at the efficiency of 14.35%. The proposed method is particularly applicable in assessing long-term suspended sediment concentration at any potential run-of-river hydropower sites using limited available field data.

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REFERENCES

1. Nor Afifah Basri, Ahmad Termizi Ramli and Abubakar Sadiq Aliyu, "Malaysia energy strategy towards sustainabiliy" Renewable and Sustainable Energy Reviews, vol. 42, 2014, pp. 1094-1105.
2. Biraj Singh Thapa, Ole Gunnar Dahlhaug, and Bhola Thapa, "Sediment erosion in hydro turbines and its effect on the flow around guide vanes of Francis turbine", Renewable and Sustainable Energy Reviews, vol. 49, 2015, pp. 1100-1113.
3. Anant Kumar Rai and Arun Kumar, "Analyzing hydro abrasive erosion in Kaplan turbine: A case study from India", Journal of Hydrodynamics, vol. 28(5), 2016, pp. 863-872.
4. M.Z. Qamar, M.K. Verma and A.P. Meshram, "Importance of desilting basin in run-of-river hydro project in Himalayan region", International Journal of Emerging Technology and Advanced Engineering, vol. 4(3), 2014, pp. 407-412.
5. M.K. Padhy and R.P. Saini, "Effect of size and concentration of silt particles on erosion of Pelton turbine buckets", Energy, vol. 34(10), 2009, pp. 1477-1483.
6. Y.C. Agrawal and H.C. Pottsmith, "Laser diffraction particle sizing in STRESS", Continental Shelf Research, vol. 14(10/11), 1994, pp. 1101-1121.
7. Supiah Shamsudin, Abd R.M. Darom, Irma Noorazurah Mohamad and Azmi A. Rahman, "Dentention pond sediment accumulation prediction using Monte Carlo simulation", American Journal of Environmental Sciences, vol. 8(1), pp. 25-34.

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