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SAND SHAPE ANALYSIS WITH EROSION ON HYDRAULIC TURBINE MATERIAL: A CASE STUDY OF ROSHI KHOLA NEPAL

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ABSTRACT

Hard particles as Quartz and Feldspar are present in large amount in most of the rivers across the Himalayan basins. In run-off-river hydro power plants these particles find way to turbine and cause its components to erode. Loss of turbine material due to the erosion and subsequent change in flow pattern induce several operational and maintenance problems in the power plants. Reduction in overall efficiency, vibrations and reduced life of turbine components are the major effects of sand erosion of hydraulic turbines. Sand erosion on hydraulic turbines is a complex phenomenon and depends upon several factors. One of the most influencing parameter is the characteristics of sediment particles. Quantity of sediment particles, which are harder than the turbine material, is one of the bases to indicate erosion potential of a particular site. Research findings have indicated that shape and size of the hard particles together with velocity of impact play a major role to decide the mode and rate of erosion in turbine components. It is not a common practice in Himalayan basins to conduct a detail study of sediment characteristics as a part of feasibility study for hydropower projects. Lack of scientifically verified procedures and guidelines to conduct the sediment analysis to estimate its erosion potential is one of the reasons to overlook this important part of feasibility study. These article present, Experimental studies have also been done to analyze the effects of shape and size of hard particles on turbine material. Efforts have also been given to develop standard procedures to conduct similar study to compare erosion potential between different hydropower sites. Digital image processing software and sieve analyzer have been utilized to extract shape and size of sediment particles from the erosion sensitive power plants. The experimental studies of sand erosion of different shapes and sizes of sediment particles on hydraulic turbine material have been conducted by High velocity test rig method at Kathmandu University. Twenty one different sediment shape samples and four different sand size range were studied to correlate the effects of sediment shape and size with the erosion of Hydraulic turbine material. It was observed that the shape of sediment particles have considerable effect on erosion of turbine material which is in between 0.000057 mg to 0.00031 mg and major percentage of abundance of the sand shape is 53, 20, 16 and 11 of circular, elongation, square and triangular respectively. In general Irregular shapes have more erosion potential than regular shapes. It was also observed that the particles with the irregular shape of smaller size induce higher erosion rates than that of the larger size with the different shape. These findings will help to select the proper site of a power plant in erosion prone basins and would also help to design suitable settling basins to trap sediment particles having higher erosion potentials.

Keywords: Digital image processing, sand erosion, Turbine material, Sediment shape

INTRODUCTION

This study was done to study sand particles shape effect in turbine material of hydropower plant. Sand particles have different parameters like size, mineral content, toughness, hardness, coarseness which have directly different impact on turbine material [5], besides these there are many other parameters to consider like turbine material specimen, kind of turbine, velocity, operating condition, operating hours and many more which have great contribution in deteroiting turbine spacimen[1],[5]. Impact on turbine material is of great concern, many researches coherent to this field has been done and had find out different comparative results to the one done in this study. Few researches have only been explored in terms of shape definition of sediment and its effect on turbine. Imaging techniques have been explored to define the sediment shape and its net effect [3], but somehow no single analysis tools have been found to find every parameter of sand and its relation in deterioration of turbine material. Shape of sediment characterized and its effect was analyzed using digital image processing [2],[4] and regression analysis in excel spreadsheet model. During analysis, parameters of different sediments of rivers that include size, shape mineral content and hardness impact on turbine material specimen were accounted with rivers different location and size. But to make the study concise and convenience sand particles size and shape effect was only considered . Related experiment on size and mineral content for different rivers have been considered. This work [5] was performed using experimental data and computational analysis from which sand particles size and shape impact on turbine material was found. To carry out the erosion test sand samples from Roshi were taken. Samples were experimented using sand erosion test rig analyzed by image processing software and microsoft excel.

MATERIALS AND METHODS

Among 6000 perennial rivers of Nepal, most of the rivers flow in western part, some flows in Eastern and Central part of Nepal. Roshi River is one which lies in central region of Nepal. Till date whole Roshi river sediment research has not yet done and this river has uniqueness than other according to origin, it originates and joins the Koshi Basin Rivers in hilly region. So for convenience in this research, sediments characteristics and its nature of impact on turbine material is studied. Roshi Khola has 20 different tributaries that join at 20 different junctions. This river can be utilized for irrigation purpose, drinking water purpose, recreational and hydropower plant generation. Among different surveyed projects in this river 2.4 MW Panauti power plant is generating electricity. Total head of this river is about 600 meter with river water discharge approximately 15.5 m^3/s (source DoED). So it has peculiar distinction to other rivers. Sampling is one of the cautious works that should be taken carefully. Sample were taken from river bed load, central part 1 feet deep below water surface in the centre part with 10 liter jar and both sides end 1/4 corner of the river from 20 each river spots [3]. From Each place 10 Kg of samples were gathered and sterilized in different boxes with each labeled with proper above river section. For instance, Location 20 samples were leveled 20 with sterile bottle of 10 liter jar at both corners of ¼ by loc20 right and loc20 left, bed load by loc20 bl, central deepen with loc20cd which contains fluvial particles.

Shape is one of the important parameter of sand that well damages the turbine material. Few researches have been explored in sediment shape effect on turbine material [3]. This study is an attempt of characterizing the sediment particles and its effect on turbine material using digital image processing. Digital image processing can well process the sediment image and trace out the different shapes of sediments. Shape morphology of sediments was extracted and defined using image processing [3]. Shapes of sediments are of complex nature, descriptor using Fourier Transform was utilizes to derive different descriptors. Complex Fourier function was used to define the sediment image first and then its transform was obtained to clearly define the descriptors of shape, so all the image analysis that defines shape is done in Fourier domain. Firstly a sediment particle was studied by using image processing taking coordinate values as a function in a defined boundary. Different derivatives were obtained from the image giving real and imaginary parts and mathematically governed by the Complex Fourier function defined by equation 1 as

$$x_m + iy_m = \sum_{n=-N/2+1}^{+N/2} (a_n + ib_n)\left[\cos\left(\frac{2\pi nm}{M}\right) + i\sin\left(\frac{2\pi nm}{M}\right)\right] \qquad (1)$$

Where x, y are coordinates describing the particle
N is the total number of descriptors

n is the descriptor number

M is the total number of points describing the particle

m is the index number of a point on the particle

a, b are coefficients for each descriptor

i denotes an imaginary number

Matlab 6.5 platform and Matrox Imaging library tools were utilized for image processing. Image of sand particles were taken and its inherent coordinate were utilized to process and analyze. Sand particles shape perimeter and its different neighbors are accounted which was equally assessed and broken into 128 equal new coordinates. Fast Fourier Transform was carried out after the division of shape to describe and understand the descriptor of shapes. The magnitude and phase angle were equally considered in its frequency domain given by above equation. An image taken first also known as parent image gives the original profile and it is done by image analysis which is shown by below figure 2.2(a). It is the original image being processed and its edges have been fairly traced to give its exact perimeter.

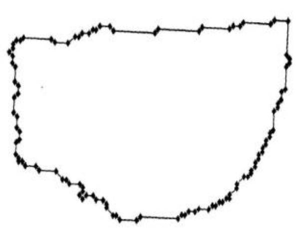

Fig 2.2(a) Original Digitized Outline of Particle

Fig 2.2(b) +/- 64 Fourier Descriptors

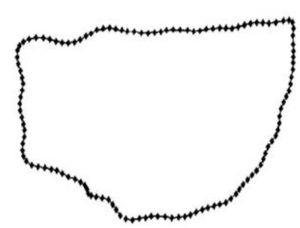

Fig 2.2(c) +/- 24 Fourier Descriptors.

The original image was suppressed using higher order of descriptors. The highest order of the particle descriptors is of +/- 64. The main aim is to have a refined morphology of sediment particle which output is shown by figure 2.2b. Furthermore the image was reconstructed applying fast Fourier Transform with order of descriptors of +/-24, +/-8, +/-5, +/-3, which are shown by figures 2.2c, 2.2d, 2.2 e and 2.2 f respectively.

Fig 2.2(d) +/- 8 Fourier Descriptors

Fig 2.2(e) +/- 5 Fourier Descriptors

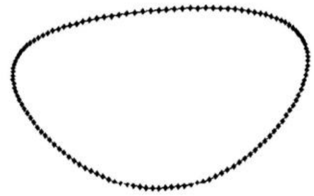

Fig 2.2 (f) +/- 3 Fourier Descriptors

The particle image was reconstructed defining the Fourier descriptors in their respective orders, it is found that the image are suppressed but have retained their original morphology [2]. Its equivalent data were statistically observed and analyzed using digital image processing. This process includes image reading, segmentation, defining classifier and descriptor analysis using image processing. This was done by using MatLab as well as Matrox Imaging Library. Sand shape erosion was studied using erosion test and defining the shapes in parallel [5]. So this work accounts the shape impact on turbine material analytically. Quantity and count of different kinds of shape of Roshi rivers were quantitatively analyzed in Machine Vision laboratory and its effect on turbine material was experimented in sediment test rig at Kathmandu University.

RESULTS AND DISCUSSION

Sediment sampled from Roshi River was characterized according to size and shape and its impact on turbine material was studied separately. The impact of shape and size of sediment were studied according to average of all the locations individual impact on turbine material. Impact of sediment on turbine material is the loss of weight of material expressed in terms of milligram and the sediment size and Shape in micrometer.

Shape is very difficult to define and depict. This research characterizes sediment particles into 21 different shapes and counts amount of particles in sample. Shape of sand is practically and realistically described by other name rather than descriptors, which is very rigorous to define. Different shapes were identified using image processing. Table 3.1 below shows the sand particles shape identified and commonly used shapes. In this table 3.1 a, b, c, d, e, and f is defined by well rounded, rounded, out rounded angular, low rounded angular and high angular respectively shown in horizontal that depicts the each shape column with respect to row parameters described as 1 and respectively representing high sphericity and low sphericity respectively, while as the elongation, square and triangular in row corresponds to column shape defined by 1, 2 and 3 respectively.

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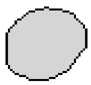
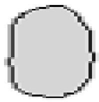
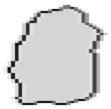
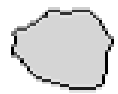
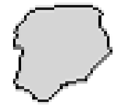
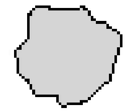
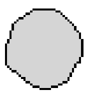
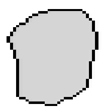
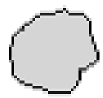
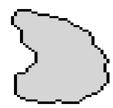
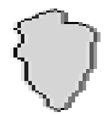
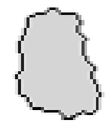
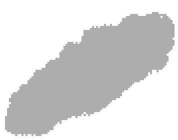
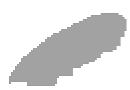
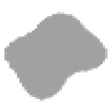
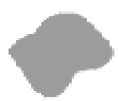
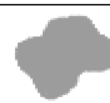
Table 3.1: Different 21 shapes

Roundness/ Descriptor	Well circle rounded (a)	Rounded (b)	Sub rounded (c)	Out rounded angular (d)	Low Angular rounded (e)	High Angular (f)
Circle with high spherecity descriptor (+/-5)	1 	1 	1 	1 	1 	1 
Circle with low low spherecity descriptor	2 	2 	2 	2 	2 	2 

According to elongation, squarness and triangularity sand shape can be termed as;

Elongation (E)	 1	 2	 3
Square(S)	 1	 2	 3
Triangular(irregular)(T)	 1	 2	 3

To convey the result appropriately, particles shape were describe separately by below table 3.2. The table is indexed with reference to above table 3.1 horizontal and vertical shape parameters.

Table 3.2: Sand shape particle description

Shape No Index	Sediment Shape Morphology
1	Well rounded with high sphericity
2	Well rounded with low sphericity
3	Rounded with high sphericity
4	Rounded with low sphericity
5	Sub rounded with high sphericity
6	Sub rounded with low sphericity
7	Rounded angular with high sphericity
8	Rounded angular with low sphericity
9	Low angular with high sphericity
10	Low angular with low sphericity
11	High angular with high sphericity
12	High angular with low sphericity
13	Slight Elongation (E)
14	Moderate Elongation (E)
15	High Elongation (E)
16	Slight Square (S)
17	Moderate Square (S)
18	High Square (S)
19	Slight Triangular (Irregular) (T)
20	Moderate Triangular (Irregular) (T)
21	High Triangular (Irregular) (T)

To analyze the shape of sediment particles, complexity of shape of sediments was reduced to five general shape catagories. Furthermore to interpret the result easily and make concise, its abundance were studied according to percentage and depicted in pie chart in this part. So five different catagories of shapes that resembles more or less were identified as;

1. Circular with high spherecity
2. Circular with low spherecity
3. Elongated
4. Square
5. Triangular

Shape abundance of Roshi River were studied with four different sizes at 20 Different locations. 21 different shapes were found to be most prominent and its abundance were analyzed seperately according to different sizes. Below figures shows the sediment particles count of different shape and size sediment on turbine specimen.

It is very rigourous to define particle shape effect on turbine material. So to determine the amount of particles of different sizes and shape number as defined in table 3.2 were exceled. Particles count for different sediment shapes are shown in figures 3.1, 3.2, 3.3 and 3.4 for four different micron sizes sediment.

Figure 3.1 depicts average particles count of sediment shapes of Roshi River. It is depicted that shape number 8 i.e. rounded angular with low sphericity is highly abundant. It can be seen from the chart that from shape number 12 to 21 amounts is slowly decreasing with similar pattern. Shape number 21 which resembles most triangular and irregular is found to be less abundant. This may be due to sediment transportation, as sediment transport from upstream to downstream section of the river sediment changes its shape from irregular to round so it is seen that round particles are more abundant irregular ones.

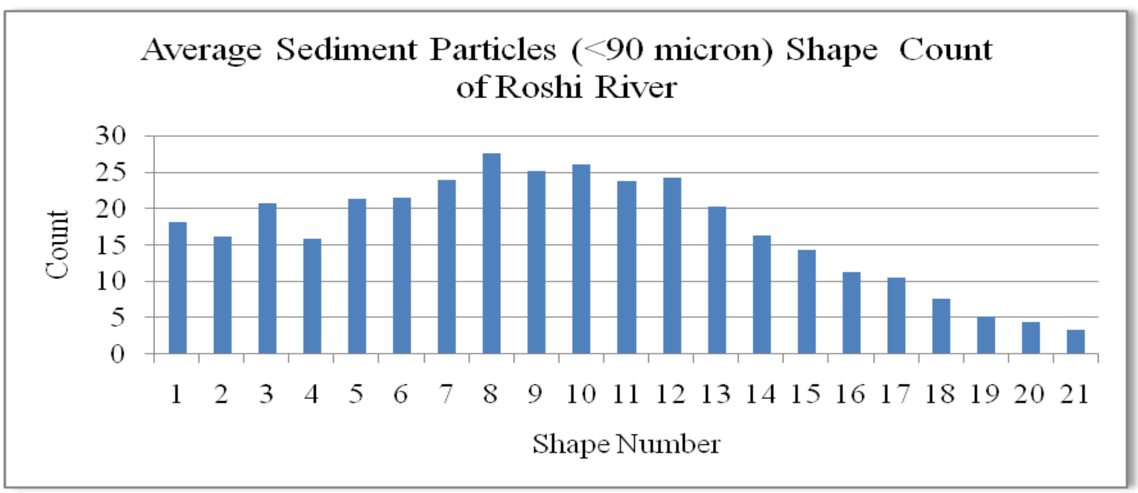


Figure 3.1: Sediment particles count of 21 different shapes of <90 micron of Roshi River

Figure 3.2 shows the abundance of sediment shape of 90-212 micron sizes sediment particles in Roshi River. It is resulted that shape number 7 that signifies rounded angular with high sphericity is in low amount as compare to other sediment shape. It is also depicted that other sediments shapes are relatively in equal amount.

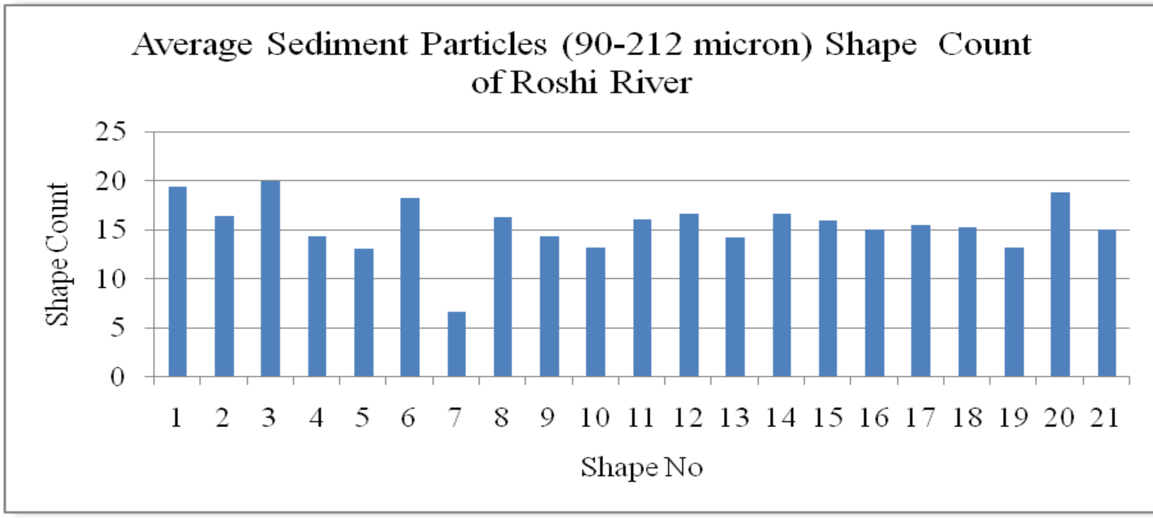


Figure 3.2: Sediment particles count 21 different shapes of (90-212) micron of Roshi River sediments

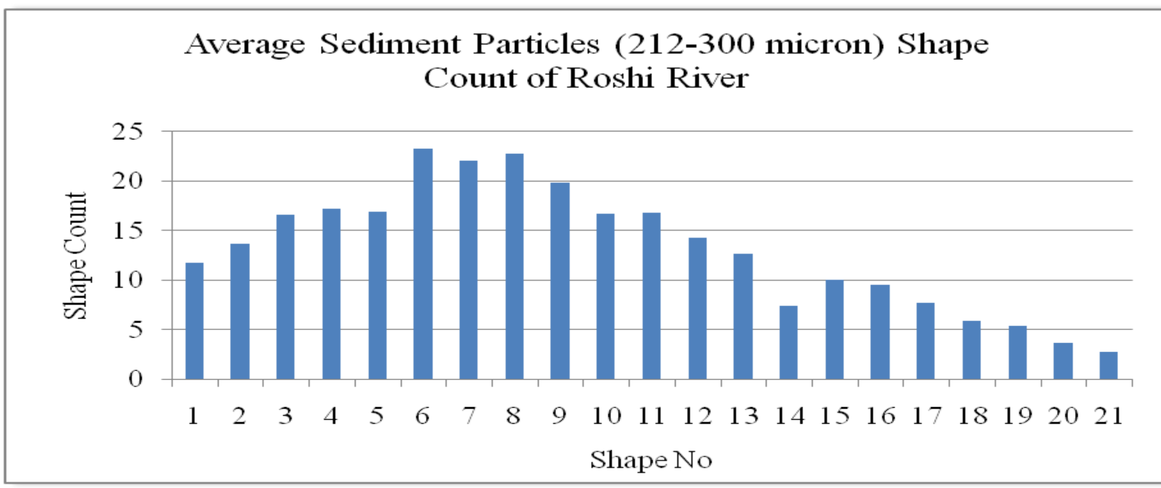


Figure 3.3: Sediment particles count 21 different shapes of (212-300) micron of Roshi River sediments

Figure 3.3 depicts sediment particles count of shape of 212 to 300 micron size of Roshi River. It is found that Shape number 6 (sub rounded with low sphericity) and 8 (rounded with low sphericity) are more abundant. It is depicted that the amount of sediment particles increases from shape number 1 to 6 and gradually decreasing from 8 to 21 shape number. This signifies that size ranging from 212-300 micron sediment particles has peculiar characteristics in Roshi River as abundance of shape increase from 1 to 6 shapes and after 8 it is gradually decreases.

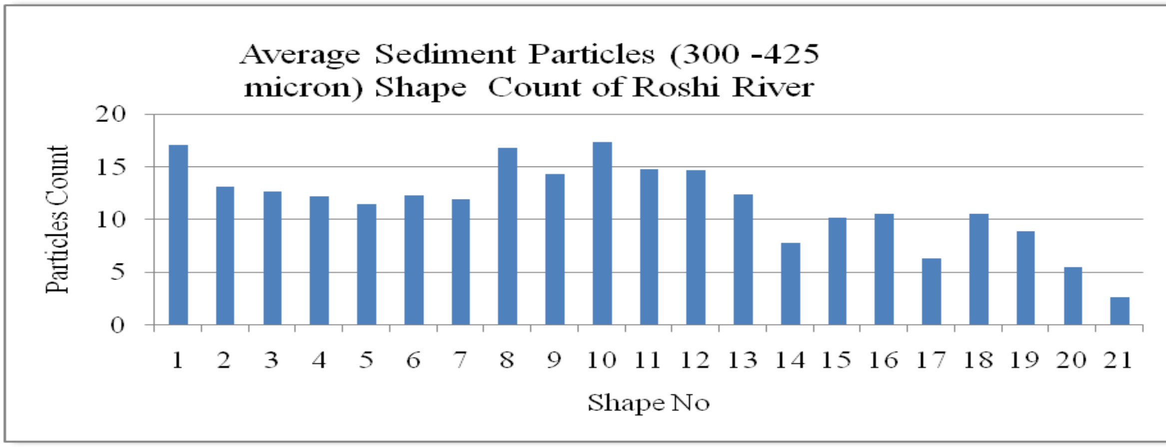


Figure 3.4: Sediment particles count 21 different shapes of (300-425) micron of Roshi River sediments

Figure 3.4 shows shape abundance of 300-425micron sediment particles of Roshi Rover. It is depicted that shape number 1, 8 and 10 are highly abundant. Shape number 3 i.e rounded with high sphericity, 4 (rounded with low sphericity), 5 (sub rounded with high sphericity), 6 (rounded with high sphericity) and 7 (roundedwith low sphericity) are in equal amount. Shape number 21 which resembles most irregulat type of sediment shape was in low amount.

Percentage analysis of twenty one different sediment shapes were reduced to five different shapes and were compared, which were as follows;

Figure 3.5 shows the abundance of sediment shape in percentage of size below 90 micron and 90-212 micron. It clearly depicts that circular with low shphericity contains 33 % in below 90 micron size whereas 18% in 90-212 micron size. It is also found that circular with high sphericity shape sediment is dominant in sediment size 90-212 micron and second dominant shape in below 90 micron size. Triangular shape sediment is the least shape sediment available in below 90 micron size amounting 6%, square is the next leastwith 13 % followed by elongated particles containing 23%. Whereas in sediment size range between 90-212 micron triangular, square and elongated shape sediment are in same amount accounting 20 %for all.

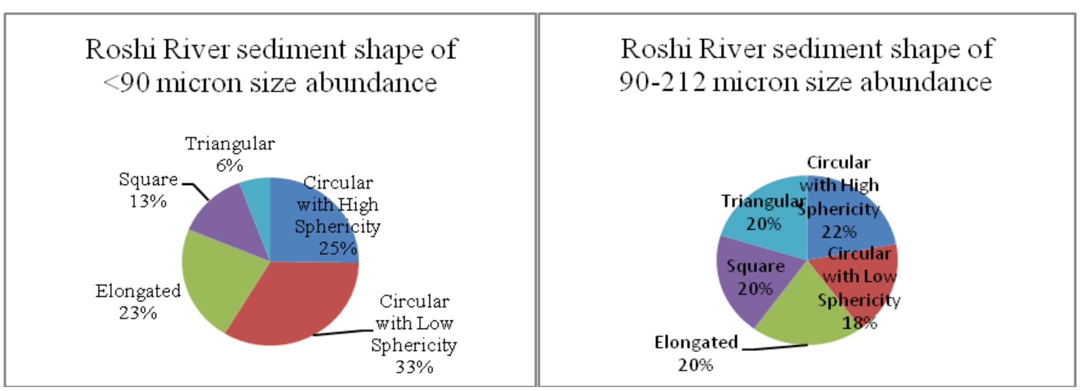


Figure 3.5: Abundance of sediment shape in percentage of size below 90 micron and 90-212 micron of Roshi river.

Alike above chart, shown by figure 3.6 shows the percentage of different sediment shapes availble in Roshi river corresponding to 212-300 micron and 300-425 micron size. It is depicted that circular with low sphericity sediment shapes are more dominant in both size ranges accounting 33% and 28% for 212-300 micron and 300-425 micron sizes sediments respectively. Circular with high sphericity sediment shape is the second most available shapes in both size ranges with its content of 29% and 25% . Elongated, square and triangular shape sediments are below 20% in both size range containing 18%, 13%, 7% and 19%, 17% and 11% for 212-300 micron and 300-425 micron sediment size respectively. It is found that triangular shape sediments are least and circular with low sphericity are most available sediment shapes in both size ranges of sediments.

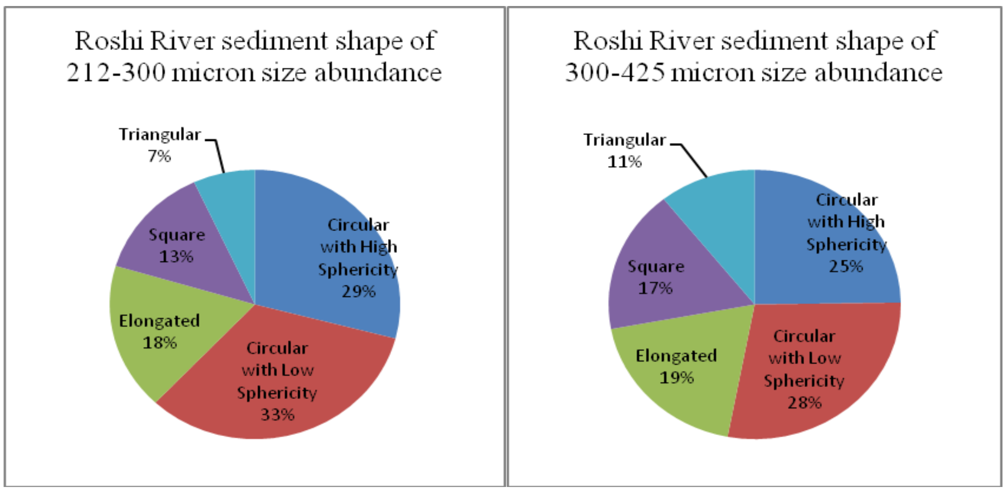


Figure 3.6: Different shape percentage of size between 212-300 micron and 300-425 micron.

Averaging of all the sediment size and shape contents, it is depicted that circular with low sphericty is most available sediment followed by circular with high sphericity, elongated, square and triangular which is shown by figure 3.7

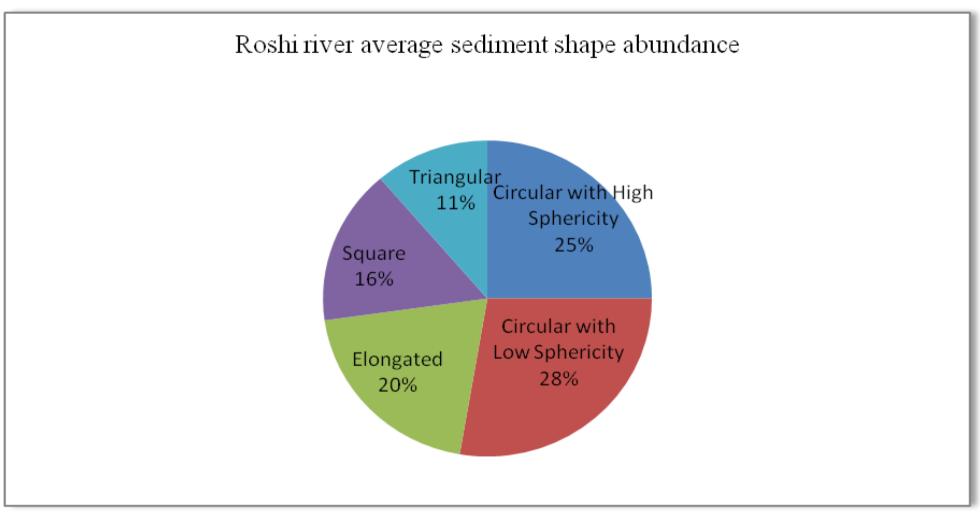


Figure 3.7: Average sediment particles shape abundance in percentage of Roshi River sediments

Its very difficult to define shape and to know the exact impact, but digital image processing technique has been applied to describe different shapes. Matrox Imaging Libraryand MatLab softwares were utilized to define and count the different sediment shape no and its effect. Table 3.1 and Table 3.2 shows the shape morphology and its corresponding shape number. The effect of 21 different shapes on turbine material are clearly shown by figure 3.8 below. The shapes of sediment are indicated by its index no from 1 to 21 and are in horizontal axis and impact on vertical axis in terms of milligram.

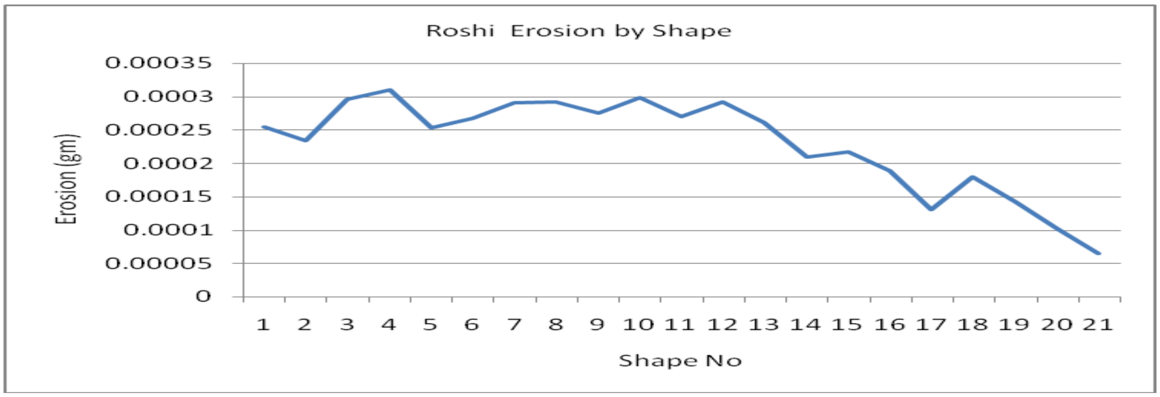


Fig 3.8: Sediment shape effect of Roshi river

Roshi river shape effect is depicted by figure 3.8 which shows a flutuating pattern of line and the shapes are defined in an order rouned, angular, square to irregular shapes with high and low sphericity. The chart clearly depicts that the shape no 4 has highest (of 0.00031mg) eroding property with least by shape no 21 (of 0.000057 mg) which refers to rounded with low sphericity and triangular or most irregular respectively. It depends upon the amount of sediment shape number present in the test. The shape number 21 is very low as compared to shape number 1, 2, 3 and 4.

CONCLUSION

Nepalese hydraulic machine like turbine generally erodes due to sediments, so it is very important to know the characteristics of sediment. Sediment size and shape are considered as most eroding parameter of sediment among its parameter. Sediment shape is considered as complex, it is very difficult to exactly define the shape and include all possible shapes. So far from this study on sediment shape, it is revealed that to some extent we can define particles shape and incorporate it to find its net effect with its abundance. It is also generalized that it is difficult to fully access all morphological information and distinguish the shape exactly, but some domain can be created to describe it. Fast Fourier Transform is one technique incorporated in this study which can helps us to define the shape of particles, furthermore counting of the shapes can be done which helps to find out the erosion of that shape on turbine material. Low degree of sphericity and round particles are mostly abundant in rivers which have high effect and the nature of effect in this study showed that it starts from some higher range and have highest eroding value with shape number 5 to 10 and it slowly decreases after that shape. This reveals that triangular and irregular type of sand is found little though have high erosive effect on turbine material while as square with high elongation are in low amount which is due to sediment transportation.

1. Digital Imaging is one of the techniques that can be well utilized to characterize different shapes of sediments. Different techniques are available but this process of characterizing particles is simple, realistic and more concise in nature. Complex Fourier Transform involves complex equation and it has real and imaginary part which gives the exact particles dimension and particle shape. The result of studies shows different morphological signature or shape differently depending on the type of sand.
    a. Digital image processing can be utilized to count particles that help to find out abundance of sediments. It is depicted that greater the sediment quantity greater is the erosion impact. An angular shape particle yields in high amount than the irregular one. During the course of rolling down of sediments from upstream to downstream of the river, shape of sediments changes. Irregular shapes sediments are more abundant in upstream of the river and slowly changes to less spherical and round shape sediments while travelling to downstream part of the river. So it can be idealized that sand particles shapes changes while being transported due to interaction with each other and changes from its original shape to more round.
    b. It is resulted that sediment shapes can be classified into twenty one different types on the basis of roundness, sphericity, angularity, squares, elongation and triangular irregularities. The extension of all parameters is described in slight, moderate and high type with total 21 shapes. Further particles shape percentage were analyzed using only five basis shapes that includes circular with high spherecity, circular with low spherecity, elongated, square and triangular.
    c. It is found that circular with low sphericity sediment shapes are most abundant in rivers followed by circular with high sphericity, elongated, square and triangular. Triangular particles are very low in amount.
    d. It was observed that the shape of sediment particles have considerable effect on erosion of turbine material which is in between 0.000057 mg to 0.00031 mg and major percentage of abundance of the sand shape is 53, 20, 16 and 11 of circular, elongation, square and triangular respectively.
2. More erosion takes place if the percentage of Quartz content is high (i. e. 7 Moh's scale) with irregular in shape particle content.
3. From the data more than 50 % of sand particles contents circular shape in the river, so that we focused on size impact and shape impact.

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