IREEE

International Journal of
Advanced Thermofluid Research

ISSN 2455-1368
www.ijatr.org

# Estimation of Sediment Deposition at Nausehri Reservoir by Using Multiple Linear Regression and Assessment of its Effect on Hydropower Generation Capacity

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**Keywords**
Sedimentation • Multiple Linear Regression • Reservoir Life • Hydropower.

**Received**
Oct 08, 2015
**Revised**
Nov 22, 2015
**Accepted**
Nov 30, 2015
**Published**
Dec 01, 2015

## Abstract

This article presents investigation of the inflow of sediments depending upon the stream flow, density and kinematic viscosity of water. The process involves Multiple Linear Regression (MLR) technique for estimation of sediment load and volume, by using UNISTAT software (Version 5.6). A general equation is developed for a specific flow rate while considering density and kinematic viscosity of water as other parameters. The developed equation can be applied in future for determining the sediment concentration when the flow rate is known. The daily stream flow and suspended sediment data belonging to the station Nausehri operated by the Water and Power Development Authority, Pakistan is used as case study. The results indicate that the dam site experiences a mean annual sediment load of 3.74mst. With this much incoming sediment load the reservoir life comes out to be 45 years when no flushing is done. The impact of this sediment deposition on hydro-electric energy generation is also determined, which shows a decrease of 113MW (12%) in the production capacity of the power plant over the life of the reservoir.

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**DOI:** https://doi.org/10.51141//IJATR.2015.1.2.4 

## 1. Introduction

Sediment carrying capacity is a comprehensive index that characterizes the account of entrainment and transportation by the flow under the conditions of equilibrium of scouring and deposition (Ni et al., 2014). As natural rivers are subjected to constant erosion and sediment transport processes, the study of sediment transport mechanisms and transport capacity of stream flows is considerably important in river hydraulics and geomorphology. Sediment transport and sedimentation in rivers have serious consequences including formation of sediment bars and reduction of flood sediment transport capacity, affected dams lifetime and their reservoir capacity, severe erosion of hydro-mechanical facilities and damaging field and water structures, sedimentation at flow channels and other hydraulic problems. Also, considering the principles of transported sediments by river flow in design of river structures, the study of various methods to predict river sediment transport rate is quite significant. This topic has been widely studied in the past few decades and there are many theoretical or empirical formulas that could be used with reasonable accuracy to predict the transport rate for sand bed river. A large number of comparative studies have been done to test the accuracy of these methods, yet it is considered to be a challenging question (Hassanzadeh et al., 2011)

Fan and Morris (1992) discussed the hydraulic methods to preserve the capacity of reservoirs including the methods of sediment routing, sediment flushing and density current venting. Similar study on the sediment flushing method was also reported by White (1990). Kummu and Varis (2007), Kammu et al. (2010) and Fu et al. (2008) have done extensive researches on Mekong River, China regarding the deposition of sediments and the evaluation of trap efficiency of the reservoirs. They presented various methods of calculation of sediment load and trap efficiency for individual reservoirs and at each sub basin as well. For the past two decades, besides MLR, Artificial Neural Network (ANN) was often used for the prediction of sediment flow in the rivers (Cigizoglu, 2003 & 2004; Cigizoglu and Alp, 2006; Cigizoglu and Kisi, 2006; Zhu et al., 2007; Kisi, 2007; Rajaee et al., 2009) The ANN modelling proves to be precise in most of the cases but still it has various limitations.

According to Navarro (2014), there is a wide variety of ANN models, which depend on the objective by which they are created, as well as the practical problem they solve. During the last decades, several inconveniences about ANN applications have been found in the literature, as the ANN neither has much relation to the amount of acquired information nor the algorithm detects the information; other issues reported include the selection of the network model, the variables to incorporate on it and the pre-processing of the information that forms the training group. Navarro (2014) has found that the ANN could not perform better than the statistical method, when the system under study was composed of independent stochastic events. However when the events and variables were dependent on each other, these models prove to be efficient. In this study, the variables under consideration are simple independent variables and the relation among them is also not complex, hence the MLR technique is suitable instead of ANN.

The sediment carrying capacity of a river greatly depends upon the topography of the region, environmental temperature, type of soil and rocks existing in the area. The existing literature discusses the areas having large sized sediments ranging from stones to boulders and also the regions under consideration are nearly plain. However the Nausehri region consists of hilly areas and very steep slopes in the river bed as well as in the adjoining bank areas of the river. Also the rock formation of the area mostly contains sedimentary rocks which produces very fine sediments due to erosion (SWHP, 1992). Furthermore, depending upon the available data and various situations the reviewed methods are not found to be applicable for the present study. For instance, the method adopted by Kummu et al. (2007 & 2010) and Fu et al. (2008) was applicable for a number of reservoirs, and hence does not fit for a single reservoir as in the case of Nausehri. Thus the need for specific, realistic and accurate method for the calculation of sediment load in rivers of this region, is quite obvious. Accordingly, the present study proposes a technique for sediment load estimation by using Multiple Linear Regression (MLR), which includes some of the varying parameters of sediment flow such as stream flow rate, density of water at various environmental temperatures during the year and kinematic viscosity of water. Moreover, effect of sedimentation on the hydropower generation has also been studied.

## 2. Methodology

### *2.1 Neelum-Jhelum Hydropower Project*

The Neelum valley is a Himalayan gorge in Azad Kashmir, Pakistan along which the Neelum River flows. The Neelum River enters the Neelum valley from Tao-Butt and continues its journey through narrows and mountains. Different streams in the way add its strength and finally tributes into river Jehlum at Domail in Muzaffarabad. Neelum-Jhelum Hydropower Project (NJHP) is located in the vicinity of Muzaffarabad, which is exclusively designed for hydropower generation. It envisages the diversion of Neelum river water through a tunnel out-falling into river Jhelum. The intake of Neelum-Jhelum is at Nausehri and the Powerhouse is proposed to be constructed at Chattar Kalas.

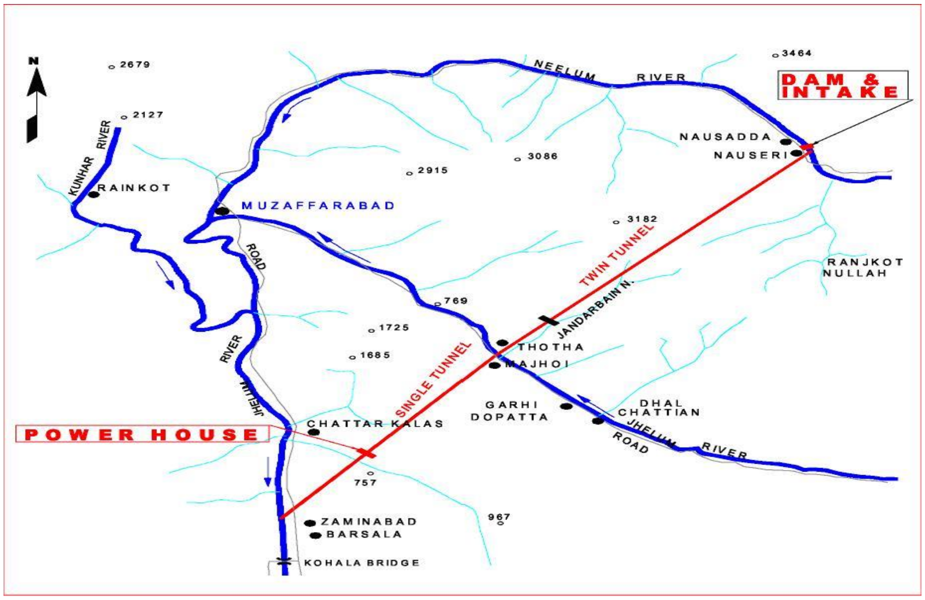



Fig. 1: Location plan of the Neelum Jhelum hydropower project.

The turbine exhaust water is released into Jhelum River about 4km South of Chattar Kalas. It is the first hydropower project in Pakistan which involves the diversion of water through tunnels (Jamil, 2010 & SWHP, 1992). The project consists of the construction of 47m high and 135m long concrete gravity dam having four radial gates each of 12m width. The catchment area for the dam is estimated to be 6800km2 and the dam will create a reservoir of 8Mm3 capacity at an elevation of 1012.5m. The tunnels diverting the water from Neelum river to Jhelum river is designed in two sections. First section consists of twin tunnels 15.1km long with each tunnel of 7.3m diameter. Second section is a single tunnel of 13.4km length with 9.6m diameter. The power station is equipped with four vertical shaft Francis turbines each of 242MW capacity. The gross head above the turbines is 420m. The project is designed for a discharge of 280$m^3$/s with total installed capacity of 969MW (SWHP, 2001).

### 2.2 *Flow and Sediment Data at Nausehri*

All of the river data used for analysis in this research has been obtained from Surface Water Hydrology Project Department of Water And Power Development Authority (WAPDA). The department publishes a document by the end of each year named as An Annual Report of River and Climatological Data of Pakistan (SWHP, 2001, 2003-05). The purpose of the report is to present the data collected by the Surface Water Hydrology Project for each river of Pakistan every year. In June 1990 a gauge was established at Nausehri bridge near the proposed Neelum dam site (SWHP, 2003-05). Both flow and stage are measured below the bridge in a fast flowing section of the river. A second staff gauge was also erected later at the dam site itself about 1km downstream. The data obtained from this gauging station consists of daily water discharge, suspended sediment concentration and water quality analysis reports. On the basis of the complete flow and suspended sediment concentration data extracted from the report for the year 2000 to 2005, a comparison of monthly discharge for all these years is developed in this study, as shown in Figure 2. It is clear from the comparison that the discharge at Nausehri station starts increasing in March and it is maximum in May and June. The discharge is observed to be minimum from the start of October till the end of February.

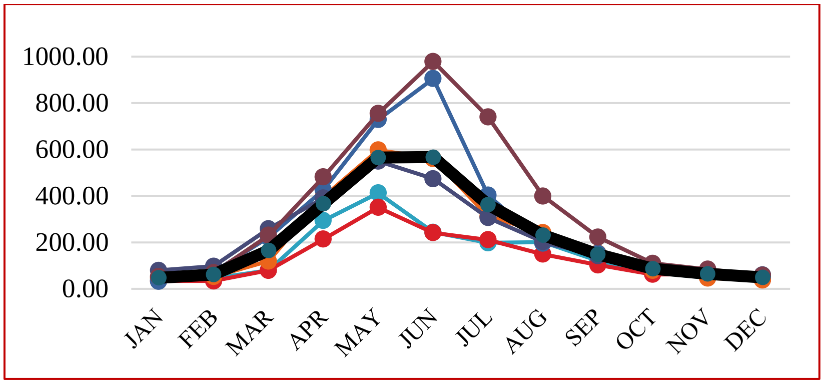



Figure 2: Comparison of mean monthly water discharge during 2000- 2005.

### *2.3 Development of MLR Model*

#### *2.3.1 Suspended Sediment Concentration and Annual Sediment Load*

A mathematical model based on MLR is developed for the prediction of suspended sediments in the Neelum river at Nausehri gauging station by using the available suspended sediment data with the help of UNISTAT software. The transportation and deposition of sediments depend on the characteristics of water carrying the sediments and the sediments themselves. By combining these characteristics a relation for sedimentation parameter (G) was developed by Yang (1996):

$$G = \frac{\rho_w v_k^2}{\gamma_s D_s^3} \tag{1}$$

where $\rho_w$ is density of water in kg/m$^3$, $\nu_k$ is kinematic viscosity of water in m$^2$/s, $\gamma_s$ is unit weight of sediments in N/m$^3$ and $D_s$ is the nominal diameter of sediment particles measured in meters.

It has been deduced from Eq. (1) that the amount of suspended sediments present in the flow ($S_s$) is a function of discharge (Q), and density and kinematic viscosity of water (Sharma and Sharma, 1992; USDBR, 1987). Accordingly, the general form of regression equation has been developed as:

$$S_s = b_1 Q + b_2 \rho_w + b_3 \nu_k \tag{2}$$

where $b_1$, $b_2$ and $b_3$ are coefficients whose values are to be determined. To determine the coefficients, the available data is inputted to the UNISTAT software by keeping $Q$, $\rho_w$ and $\nu_k$ as independent variables and $S_s$ as dependent variable. By this way, separate equations are developed for individual years from 2001 to 2005, by using the data available for the respective year. The annual suspended sediment load ($W_s$) could be estimated by (Yang, 1996):

$$W_s = (\dot{m}_w \times s_s) \times 3.476 \times 10^{-5} \text{ million short tons (mst)/year} \tag{3}$$

where $\dot{m}_w$ is the mass flow rate of water (Kg/s) and $S_s$ is the suspended sediment concentration (in ppm) obtained from Eq. (2); $\dot{m}_w$ is obtained by $\dot{m}_w = Q \times \rho_w$ , where $Q$ and $\rho_w$ are the mean values of discharge and density respectively of water for the year concerned.

*2.3.2 Annual Bed Load Total Sediment Load*

For the estimation of total load, the bed load is required to be added to the annual sediment load. A safe percentage value of bed load in terms of suspended load is suggested as 30% for this purpose (Yang, 1996). This assumption is adopted in the feasibility report of Neelum-Jhelum Hydropower Project published by WAPDA, in (USDBR, 1987) and by Garg and Jothiparakash (2008). Accordingly, the annual bed load ($S_{Bed}$) could be obtained as:

$$S_{Bed} = 0.3 W_s \tag{4}$$

Thus the total annual sediment load ($S_{Total}$) is obtained by:

$$S_{Total} = W_s + S_{Bed} \tag{5}$$

## 2.4. Estimation of Reservoir Life

In this study, the method of Trap Efficiency ($T_E$) (Brune, 1953; Yang, 1996) is used to estimate the life of the reservoir. It is assumed that the reservoir will have lived its life when it is 80% filled with sediments. In other words when the capacity of the reservoir falls to 20% of its initial capacity it becomes non-operational. The annual trapped sedimentation volume ($V_T$, m$^3$) that contributes to 5% reduction in the reservoir capacity is estimated from which the number of years to fall the capacity by 5% is obtained. This is done for each 5 % reduction in capacity until the total capacity falls to 20%. The following expressions are used to obtain $V_T$.

The trapped sediment load ($W_T$) = $S_{Total,avg} \times T_E$ mst/year (6)

$$T_E = \frac{(C/I)}{\left[0.012+1.02\left(\frac{C}{I}\right)\right]} \quad (7)$$

$$I = Q_{mean} \times 365 \times 24 \times 3600 \text{ m}^3 \quad (8)$$

$$V_T = \frac{W_T \times 907.18\times10^6}{\rho_s} \quad \text{m}^3 \quad (1 \text{ mst} = 907.18\times10^6 \text{ kg}) \quad (9)$$

where C is the reservoir capacity (m$^3$) and $I$ is the annual water inflow (m$^3$), $Q_{mean}$ is the mean of all the mean annual discharges from 2001 to 2005 (m$^3$/s), $S_{Total,avg}$ is average of the combined available and predicted sedimentation loads (mst/year), and $\rho_s$ is the density of initial deposit of sediments (kg/m$^3$), which in this study is 1062.5 kg/m$^3$. Finally, the time (number of years) required for the reservoir capacity to fall by 5 % by dividing the loss of capacity (5% of the total capacity) by $V_T$ of the respective year.

### *2.4 Power Generation Capacity and Head Loss*

Four Vertical Shaft Francis Turbines have been designed for the Neelum-Jhelum Hydropower Project. The design discharge of each unit is 70m$^3$/s. The turbine power ($P$) is given by:

$$P = \eta_T \gamma Q H \quad (10)$$

where $\eta_T$ is turbine efficiency, γ is the unit weight of water in kN/m$^3$, Q is the water discharge (m$^3$/s) and H represents head of water in meters. The capacity of a generator ($C_G$) is given by:

$$C_G = \frac{P \eta_G \alpha}{\cos\varphi} \quad (11)$$

where $\eta_G$ is the generator efficiency, α is the percentage of power at best operating time of turbine (usually taken as 0.95) and cosφ is the power factor (usually 0.8). By combining (5) and (6), the generator capacity is expressed as:

$$C_G = \frac{\eta_T \eta_G \gamma Q H \alpha}{\cos\varphi} \quad (12)$$

It is clear from Eq. (12) that $C_G$ is a function of $H$, when the other parameters are fixed. Therefore the electrical power generation capacity is directly influenced by the head loss. Thus, if the total head loss ($H_{loss}$) is known, the corresponding loss in power generation capacity can be obtained.

$$H_{loss} = h_f + h_s \quad (13)$$

where $h_f$ and $h_s$ are the head losses due to turbine and sediment deposition respectively. In the current study, $h_f$ is obtained from (USDBR, 1987):

$$D = \left(\frac{10.3 n^2 Q^2 L}{h_f}\right)^{0.1875} \quad (14)$$

where n is the roughness coefficient (for steel=0.012), Q is the water discharge, $L$ is the length of penstock, and $D$ is the diameter of penstock. From Eq. (14), the head loss for both twin and single tunnels ($h_{f1}$ and $h_{f2}$ respectively) are estimated to get $h_f$ as:

$$h_f = h_{f_1} + h_{f_2}$$

In order to estimate $h_s$, the total sediment deposition (m$^3$) during the period the reservoir capacity falls to 20% (total reservoir life) is considered, as obtained from Section 2.3. From this value the corresponding head loss can be obtained if the surface area of the reservoir is known.

## 3. Results and Discussion

### *3.1 The Developed MLR Model*

Statistical analysis of the data is done by using MLR technique with confidence interval of 95%. The normal Plot of Residuals obtained (Figure 3) justifies that the values are close enough to show a linear relationship for each year and can be expressed in the form of linear equations having multiple variables. After analysis of the data the unknown coefficients $b_1$, $b_2$ and $b_3$ are determined for each year and the equations for each year are presented as follows (Eqs. 15 to 20).

Year 2000: $$S_s = 0.86Q - 0.08\rho_w + 69.86\nu_k \quad (15)$$

Year 2001: $$S_s = 0.09Q + 0.32\rho_w - 179.36\nu_k \quad (16)$$

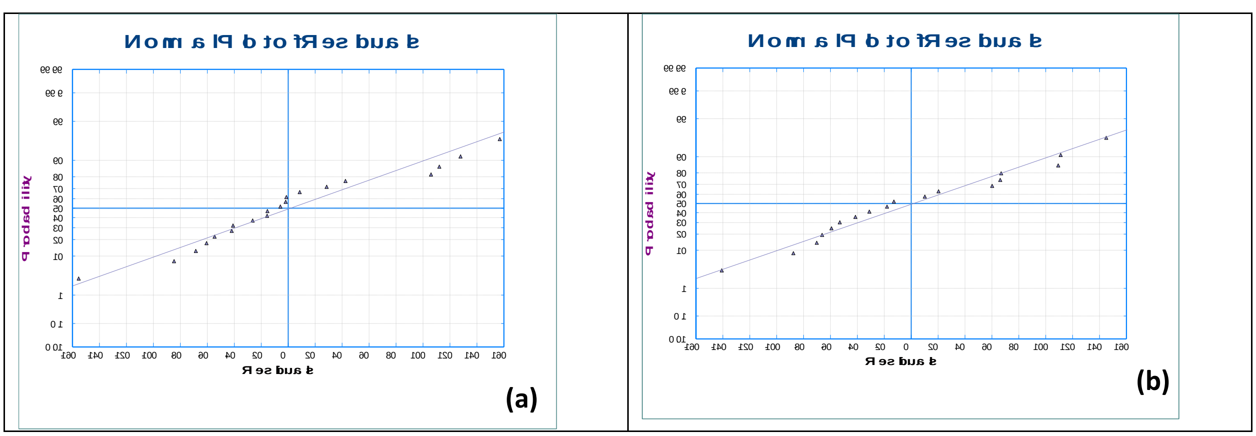
Year 2002: $$S_s = 0.59Q + 0.00\rho_w + 55.77\nu_k \quad (17)$$

Year 2003: $$S_s = 0.35Q + 0.70\rho_w - 454.46\nu_k \quad (18)$$

Year 2004: $$S_s = 0.36Q + 0.25\rho_w - 140.15\nu_k \quad (19)$$

Year 2005: $$S_s = 0.03Q + 0.23\rho_w - 71.51\nu_k \quad (20)$$

where $S_s$ is suspended sediment concentration measured in ppm, Q is the water discharge (m$^3$/s), $\rho_w$ is the density of water in kg/m$^3$ and $\nu_k$ is the kinematic viscosity of water ($10^6$ m$^2$/s); all these are mean values over the year concerned. Each of the above developed equation is applicable for the determination of suspended sediment concentration only for the respective year whose data is used for analysis.



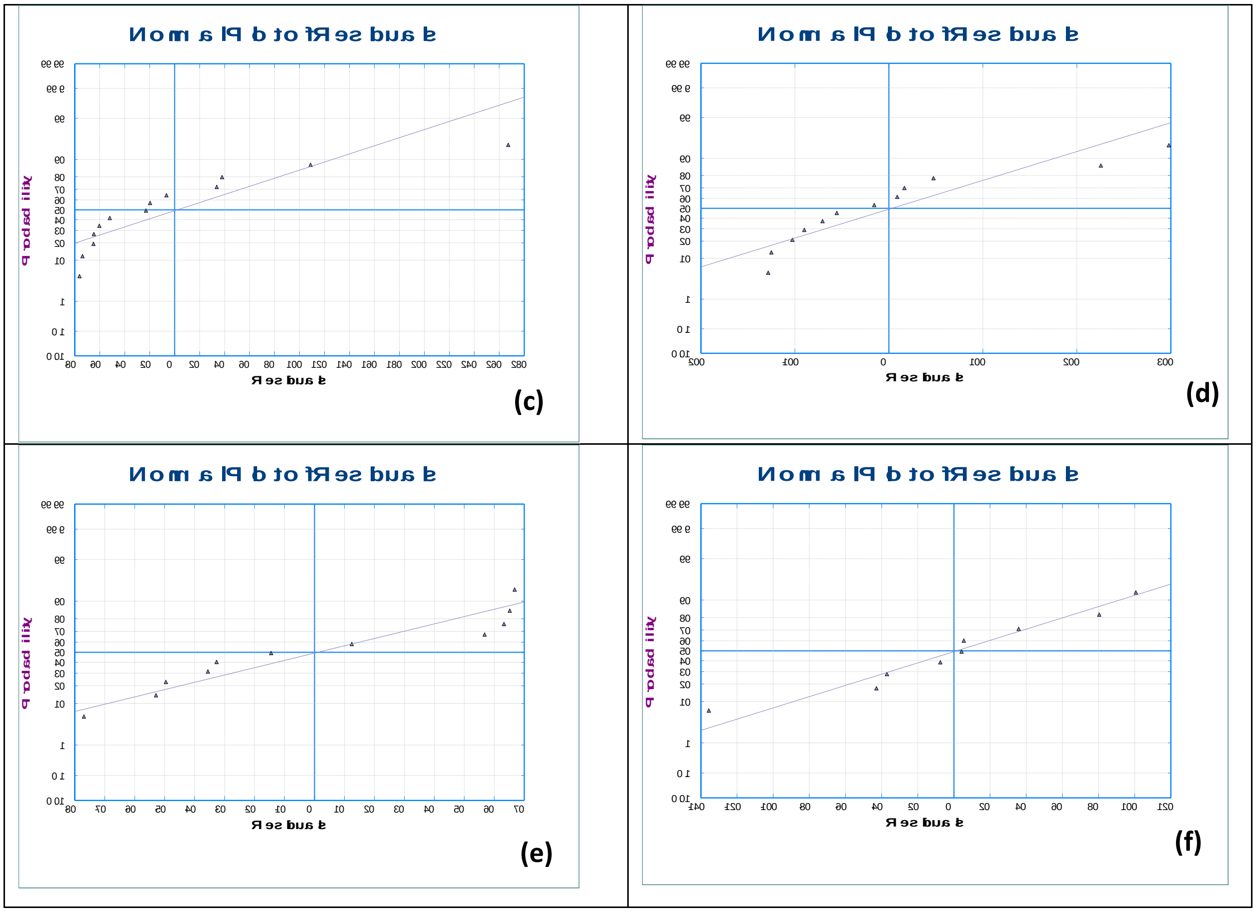



Fig. 3: Linear regression analysis for the years:
(a) 2000, (b) 2001, (c) 2002, (d) 2003, (e) 2004 and (f) 2005.

### 3.2 *Annual Sediment Load*

Table 1 summarizes the suspended sediment concentration (ppm) obtained from Eqs. (15) to (20), the annual sediment load (from Eq. 3) and the total sediment load (from Eq. 5) respectively, which are predicted by the developed MLR model for years from 2001 to 2005. The parameters used for the estimation are also shown.

Table 1: Predicted annual sediment load

| Year | $Q_{wm}$ | $\rho_{wm}$ | $\nu_k$ ($\times 10^6$) | $\dot{m}_w$ | $S_s$ | $W_s$ | $S_{Total}$ |
|---|---|---|---|---|---|---|---|
| | $m^3/s$ | $kg/m^3$ | $m^2/s$ | kg/s | ppm | mst/year | mst/year |
| 2000 | 149.33 | 998.7 | 1.139 | 149135.87 | 128 | 0.66 | 0.86 |
| 2001 | 131.65 | 998.2 | 1.113 | 131413.03 | 132 | 0.60 | 0.78 |
| 2002 | 220.23 | 999.4 | 1.197 | 220097.86 | 197 | 1.50 | 1.95 |
| 2003 | 281.47 | 1001.0 | 1.304 | 281751.47 | 206 | 2.01 | 2.61 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2004 | 227.36 | 1000.0 | 1.232 | 227360.00 | 159 | 1.25 | 1.63 |
| 2005 | 348.62 | 999.2 | 1.158 | 348341.10 | 157 | 1.90 | 2.47 |

### *3.3 Model Validation*

The values of annual sediment load predicted by the present MLR model are validated by comparing them with the available data for the preceding years (1991-1999). This data has been taken from the *Sediment Appraisal of Pakistan Rivers* published by WAPDA in August 2001. Through curve-fitting it is observed that the slopes of the trend-lines of both the data are almost equal with values of -0.26 and -0.25, as shown in Figures 4 and 5. Hence it shows that the values of annual sediment load calculated by equations obtained by MLR are comfortably reliable.

### *3.4 Reservoir Life*

The sediment deposition has significant effect on the reservoir life. In this study, it is assumed that the reservoir life ends when its capacity falls to 20%. Accordingly, the number of years for the reservoir capacity to fall to 20% due to the sediment deposition has been estimated by considering intervals of 5% reduction in capacity as mentioned in Section 2.4. The equations (6) to (9) are used to estimate the trapped sediment volume ($V_T$). While calculating the trapped sediment load in Eq. (6), $S_{Total,avg}$ is taken as the average of the sediment loads from 1991 to 2005. The results obtained are tabulated in Table 2, which also shows the results of all the individual parameters explicitly. It is evident that a total sediment deposition of 2.67×10$^6$ m$^3$ makes the reservoir capacity to fall by 20% in a period of 45 years.

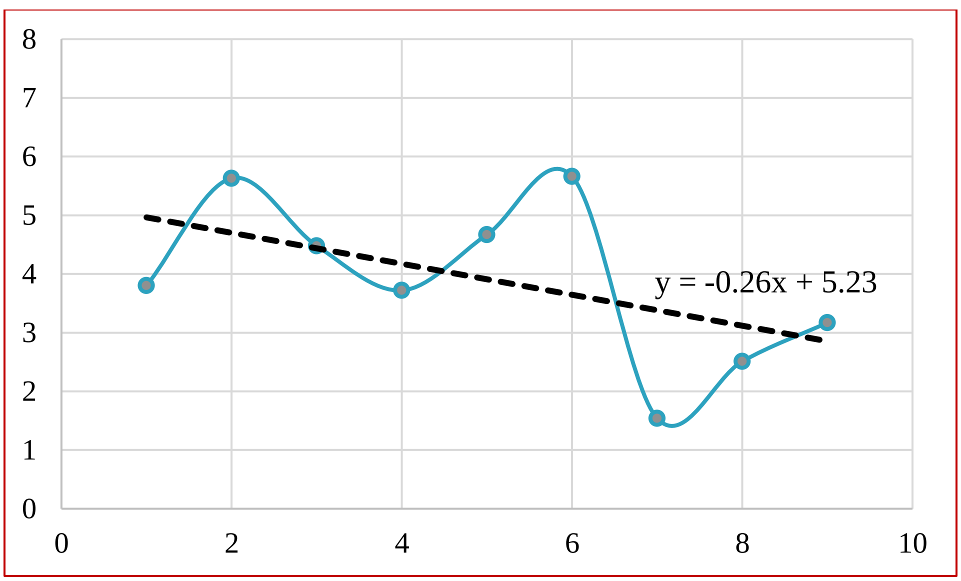



Fig. 4: Available annual sediment load data for the years 1991 to 1999 with trend line.

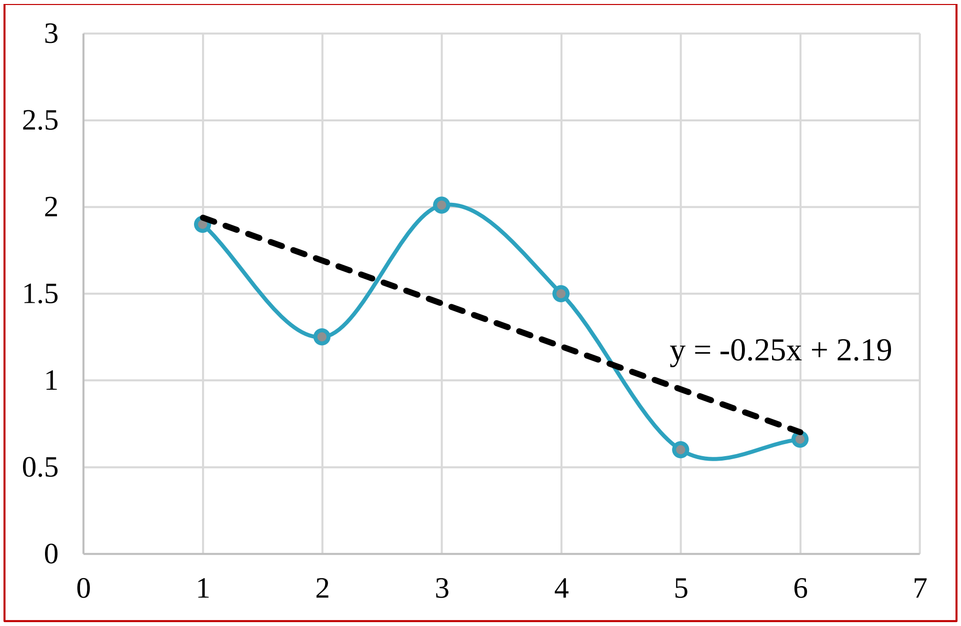



Fig. 5: Predicted annual sediment load for the years 2000 to 2005 with trend line.

Table 2: Summary of reservoir life estimation

| Reservoir Capacity | | C/I | Trap Efficiency (%) | | Annual Sedimentation | | Time for 5% Capacity Loss |
|---|---|---|---|---|---|---|---|
| | | | By Gill's Eq. | Average | $W_T$ | $V_T$ | |
| % | $10^6$ m$^3$ | - | % | % | mst | $10^6$ m$^3$ | Years |
| 100 | 8.0 | 0.0011 | 8.52 | - | - | - | - |
| 95 | 7.6 | 0.0011 | 8.13 | 8.33 | 0.31 | 0.26 | 1.5 |
| 90 | 7.2 | 0.0010 | 7.74 | 7.94 | 0.30 | 0.25 | 1.6 |
| 85 | 6.8 | 0.0010 | 7.34 | 7.54 | 0.28 | 0.24 | 1.7 |
| 80 | 6.4 | 0.0009 | 6.94 | 7.14 | 0.27 | 0.23 | 1.8 |
| 75 | 6.0 | 0.0008 | 6.54 | 6.74 | 0.25 | 0.21 | 1.9 |
| 70 | 5.6 | 0.0008 | 6.13 | 6.33 | 0.24 | 0.20 | 2.0 |
| 65 | 5.2 | 0.0007 | 5.71 | 5.92 | 0.22 | 0.19 | 2.1 |
| 60 | 4.8 | 0.0007 | 5.30 | 5.51 | 0.21 | 0.18 | 2.3 |
| 55 | 4.4 | 0.0006 | 4.88 | 5.09 | 0.19 | 0.16 | 2.5 |
| 50 | 4.0 | 0.0006 | 4.46 | 4.67 | 0.17 | 0.15 | 2.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 45 | 3.6 | 0.0005 | 4.03 | 4.24 | 0.16 | 0.13 | 3.0 |
| 40 | 3.2 | 0.0004 | 3.60 | 3.81 | 0.14 | 0.12 | 3.3 |
| 35 | 2.8 | 0.0004 | 3.16 | 3.38 | 0.13 | 0.11 | 3.7 |
| 30 | 2.4 | 0.0003 | 2.72 | 2.94 | 0.11 | 0.09 | 4.3 |
| 25 | 2.0 | 0.0003 | 2.28 | 2.50 | 0.09 | 0.08 | 5.0 |
| 20 | 1.6 | 0.0002 | 1.83 | 2.06 | 0.08 | 0.07 | 6.1 |
| | | | | | **Total** | **2.67** | **45** |

### *3.6 Effect of Sediment Deposition on Power Generation*

The reservoir with $8 \times 10^6$ m$^3$ of capacity and 47m of water depth has an average surface area of $1.102 \times 103$ m$^2$. From Table 2 the total amount of sediment deposited during the 45 years life of dam is $2.67 \times 10^6$ m$^3$. This much amount of sediment deposition can result in a loss of water depth up to 15.69m. Thus the total head loss could be obtained by Eq. (13), and the resulting decrease in total power generation capacity for the four units is estimated to be 113MW (12%).

## 4. Conclusion

Multiple Linear Regression model has been developed to predict the annual sediment load in the Nausehri reservoir for the period from 2001 to 2005, and the predicted values have been successfully validated by the available data for the preceding years (1991 to 1999). The MLR model has taken into account the stream flow, density and kinematic viscosity of water. The mean annual sediment load of the dam site is found to be 3.74mst, which makes the reservoir life as 45 years when no flushing is done. Furthermore, due to the sediment deposition a decrease of 113MW (12%) in the hydro-electric energy generation is estimated, over the life of the reservoir. The present model can be applied for predicting the sediment concentration for future when the flow rate is known. Based on this study, the following recommendations are made:

- Proper sediment management system for watershed areas must be adopted to control the volume of sediment inflowing into the Nausehri reservoir; this would increase the effective life of the reservoir.

- The inflow of sediments can be controlled by doing plantation in the water shed areas, and by sediment control dams that work as sediment traps.

- Proper maintenance is required for the sedimentation basins. The sediments settled in the basins must be flushed by water on regular basis such that they may not enter the intake tunnels which can cause damage to penstocks and turbines and in order to retain the energy generation capacity of the reservoir.

- The WAPDA data shows sediment concentrations only for some days of the year. So, more gauging stations must be installed upstream of the Nausehri dam site to record the continuous data on daily basis. More gauging stations will also help in recording the data in case of a flood or earthquake.

## References

Brune, GM. (1953). Trap efficiency of reservoirs. Earth and Space Science News. Vol. 34 (3): 407-418.

Cigizoglu, HK. (2003). Estimation, forecasting and extrapolation of river flows by artificial neural networks. Hydrological Sciences Journal-des Sciences Hydrologiques. 48(3): 349-361.

Cigizoglu, HK. (2004). Estimation and forecasting of daily suspended sediment data by multi-layer perceptrons. Advances in Water Resources. 27 (2004): 185-195.

Cigizoglu, HK, Alp, M. (2006). Generalized regression neural network in modelling river sediment yield. Advances in Engineering Software. 37 (2006): 63-68.

Cigizoglu, HK, Kisi, O. (2006). Methods to improve the neural network performance in suspended sediment estimation. Journal of Hydrology. 317 (2006): 221-238.

Fan, J, Morris, GL. (1992). Reservoir Sedimentation II: Reservoir desiltation and long term storage capacity. Journal of Hydraulic Engineering. Vol. 118 (3): 370-384.

Fu, KD, He, DM, Lu, XX. (2008). Sedimentation in the Manwan reservoir in the Upper Mekong and its downstream impacts. Quaternary International. 186 (2008): 91-99.

Garg, V, Jothiprakash, V. (2008). Estimation of useful life of a reservoir using sediment trap efficiency. Journal of Spatial Hydrology. Vol. 8 (2):1-14.

Hassanzadeh, H, Faiznia, S, Bajestan, MS, Motamed, A. (2011). Estimate of sediment transport rate at Karkheh river in Iran using selected transport formulas. World Applied Sciences Journal, Vol. 13 (2): 376-384.

Jamil, R. (2010). An Investigation of Sediment Patterns at Nausehri Reservoir and Its Impact on Neelum-Jhelum Hydropower Project. M. Sc. Research Thesis. University of Engineering and Technology Taxila. Pakistan.

Kisi, O. (2007). Streamflow forecasting using different Artificial Neural Network algorithms. Journal of Hydraulic Engineering. Vol. 12 (5): 532-539.

Kummu, M, Varis, O. (2007). Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River. Geomorphology. 85: 275-293.

Kummu, M., Lu, XX, Wang, J, Varis, O. (2010). Basin-wide sediment trapping efficiency of emerging reservoirs along the Mekong. Geomorphology. 119: 181-197.

Navarro, H, Bennun, L. (2014). Descriptive examples of the limitations of Artificial Neural Networks applied to the analysis of independent stochastic data. International Journal of Computer Engineering & Technology. Vol. 5 (5): 40-42.

Rajaee, T, Mirbagheri, SA, Zounemat-Kermani, M, Nourani, V. (2009). Daily suspended sediment concentration simulation using ANN and neuro fuzzy models. Science of Total Environment. 407: 4916-1927.

Sharma, RK, Sharma, TK. (1992). Text Book of Irrigation Engineering. Volume-II: Dam Engineering (Including Water Power Engineering). Oxford & IBH Publishing Company Pvt. Ltd., New Delhi.

SWHP (Surface Water Hydrology Project). (1992). Feasibility Study of Neelum-Jhelum Hydropower Project, WAPDA.

SWHP (Surface Water Hydrology Project). (2001). Sediment Appraisal of Pakistan Rivers, 1960-1998. SWHP Publication no. 57, WAPDA, Lahore, Pakistan.

SWHP (Surface Water Hydrology Project). (2003-05). Annual report of river and climatologically data of Pakistan. Vol-I, River discharge, sediment and quality data. SWHP, WAPDA, Lahore, Pakistan.

USDBR (United States' Department of the Interior Bureau of Reclamation). (1987). Design of Small Dams, A Water Resources Technical Publication. 3rd Edition.

White, WR. (1990). Reservoir sedimentation and flushing. Proceedings of two Lausanne Symposium on Hydrology in Mountainous Regions, II– Artificial Reservoirs, Water and Slope, IAHS Publ. No. 194, pp. 129-139.

Yang, CT. (1996). Sediment Transport: Theory and Practice. Krieger Publishing Company.

Zhu, Y, Lu, XX, Zhou, Y. (2007). Suspended sediment flux modeling with artificial neural network: An example of the Longchuanjiang River in the Upper Yangtze catchment, China. Geomorphology. 84: 111-125.