Study of the morphological development around river mouth in Lake Tuni, Bolivia

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Abstract

This study is directed toward the analysis of the morphological development around river mouth in Lake Tuni, and attempt to be linked with an evaluation of present reservoir sedimentation. This analysis will be expressed in terms of rate of sediment deposition, evaluating three different methodologies and comparing our results with the rate of sediment yield reported by Kawagoe (2014).

1. Introduction

Most sediment enters reservoirs as a consequence of rainfall erosion and subsequent transport by streams.

Furthermore, because eroded sediments may be flushed downstream trough stream channels over a period of decades or longer, it is essential to differentiate between the volumes of material eroded from the land surface and the amount which is actually transported into a reservoir.

Though that the most representative amount of sediment introduced in a reservoir is located in the sediment deposit, around the river mouth. Surveys performed directly on this area can derive in an interesting overview of the reservoir sedimentation processes.

The first methodology analyzed in this paper is the comparison of topographical information in the sediment deposits for different periods. Fujita et al. (2004) exposed a morphological comparison around the river mouth, giving interesting sights on the relevance of a morphological comparison. Unfortunately investigations have often suffered from poor spatial and temporal sampling resolution morphologic data. However Milan et al. (2007) has proposed the implementation of topographical surveys with a 3D laser scanner to evaluate this kind of studies. The second methodology is based on the approach of Hashimoto et al. (2013), where data collection about the thickness of a sediment deposit was related with the sediment deposition phenomena. And the third methodology is based on the application of Meyer Peter Muller bed load sediment transport equation, a worldwide applied equation. In addition Hippe et al. (2012), Kawagoe (2014), Kothyari et al. (1994) and Walling (1999) provided important information that helped us to understand the linkage of the erosion and deposition processes.

These studies are valuable in quantifying either sediment yield or sediment deposition by different methodologies, but they do not address the relationship between the two parameters nor the final impact on the reservoir. Therefore the purpose of this paper is to present an evaluation of the reservoir sedimentation based on the analysis of the morphological development around river mouth.

2. Study area

Lake Tuni is a very precious water resource that provides water resources to two major cities of Bolivia, La Paz and El Alto. Hence there is a big concern about global climate change not only will accelerate glacier retreat, but also it may result in accelerate sediment deposit, reducing the capacity of the lake.

Lake Tuni is located in the prefecture of La Paz, at the north-west part of Bolivia. The main source of sediment inflow to the reservoir is Tuni River, which originates in Tuni Glacier. Tuni River flows for 5.5 [Km] before draining into Lake Tuni, it has a contributing catchment area of 10 [Km^2], and at the river mouth, was formed a sediment deposit, which surface area is 0.035 Km^2. This sediment deposit is our target area (Fig.1).

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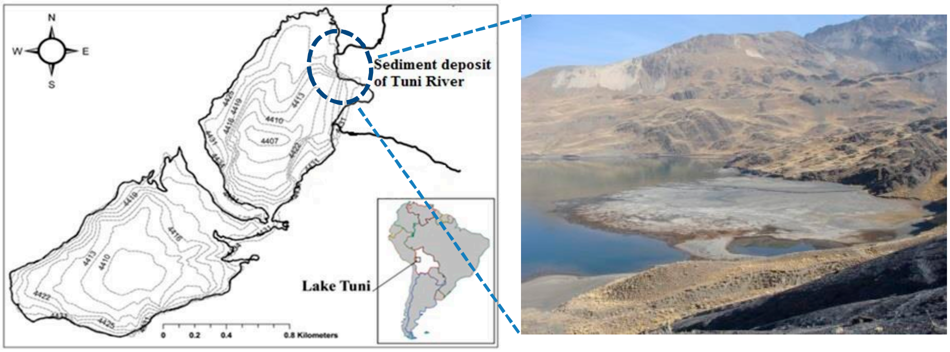


Fig. 1 Location of Lake Tuni and Tuni River's sediment deposit

3. Results and discussion

3.1 Comparison among topographical information

Tuni sediment deposit was surveyed with a 3D laser scanner in August 2012, October 2013 and August 2014. The instrument combines reflectorless laser measurement technology with high-speed automatic robotic surveying to obtain topographical accurate measurements, with a resolution of 1[cm] and a high definition of 0.20 [m] (vertical and horizontal interval between each observation). The effective area of analysis was delimited by the maximum and minimum water levels of the lake, 4440.5 [m.a.s.l.] and 4437.5 [m.a.s.l.] respectively. The grid size was set at 0.5[m] x 0.5 [m]. Later the topographical data was averaged regionally inside each grid cell. Last each grid point was compared by the subtraction of height, for each period respectively (Fig. 2-3), where the positive difference of volume among both periods represents the rate of sediment deposition. In these figures is appreciable the trend of the sediment deposition, right close to the river mouth. The results are summarized in Table 1.

The correction of the topographical data took place simultaneously by the rotation of the data about the three coordinate axes "x", "y" and "z". For example 2012's topographical data was set as the base for the correction and 2013's data was rotated until get the least difference on subtract elevation at the unmovable area, the terrain that is not affected by the water level of the lake. The already mentioned procedure was applied to correct the 2014's topographical data as well.

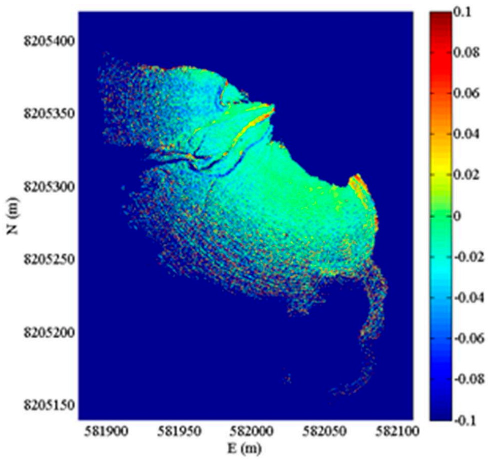


Fig.2 Subtract Elevation of the regional averaged (Tuni 2012-2013)

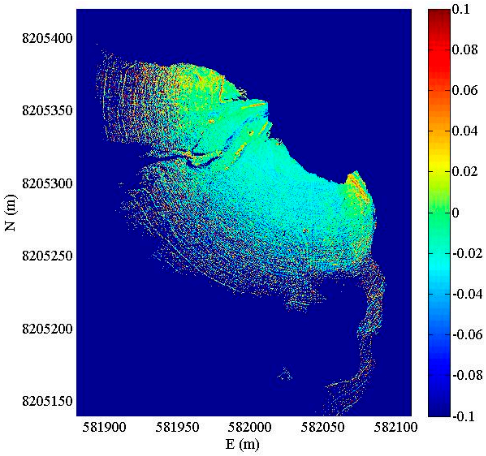


Fig.3 Subtract Elevation of the regional averaged (Tuni 2013-2014)

Table1 Thickness, volume and of sediment deposition rate

Period	Rate of sediment deposition [m^3/year]
2012-2013	$1.2x10^2$
2013-2014	$1.3x10^2$

3.2 The sediment layer thickness

Thus through the analysis of excavation points (Fig. 4) was possible to recognize the presence of bed forms, which are the organization of grains into morphologic elements. Below bed forms the composition of the sediment suddenly changed from gravel to clay, making easier to recognize the total thickness of the sediment layer.

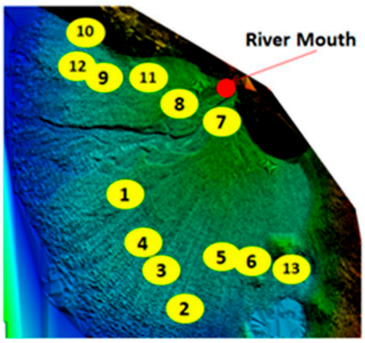
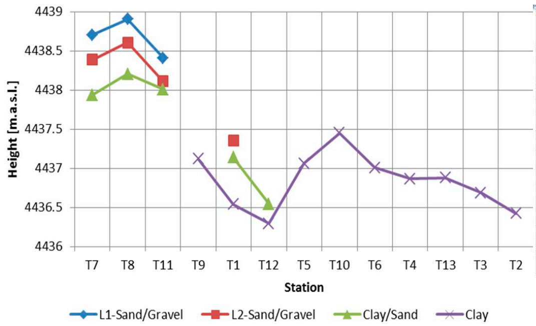


Fig.4 Excavation points at the sediment deposit of Tuni River

Plotting the relationship between sediment layer thickness and radial distance from the river mouth (Fig. 5), can be concluded that the sediment is deposited until a radial distance from the river mouth of 128 [m] approx. and the average thickness is 0.94 [m]. Thus the volume for each sediment deposit was calculated assuming a constant sediment thickness of 0.94[m] and multiplying for the area covered until 128[m] radial distance. This deposition trend was verified after the analysis of the grain size distribution of sediment samples that were taken in situ. The mean diameter of the particles is inversely proportional to the radial distance from the river mouth.

Finally the rate of sediment deposition is the result of dividing the volume per 35 years, the time that the dam is functioning (1978-2014). The values of thickness, volume and sediment deposition rate are summarized in Table2.



Station	Radial Dist. [m]
T7	24.9
T8	39.8
T11	69.7
T9	117.1
T1	118.3
T12	128.0
5	131.2
T10	131.7
T6	133.5
T4	135.4
T13	141.1
T3	144.9
T2	167.9

Fig.5 Relationship between sediment layer thickness and radial distance from the river mouth

Table 2 Thickness, area, volume and rate of sediment deposition

Thickness [m]	Area [m^2]	Volume [m^3]	Rate of sediment deposition [m^3/year]
0.94	17x10^3	16x10^3	4.6x10^2

3.3 Meyer-Peter and Müller equation

Meyer-Peter and Müller based on data obtained from a considerable number of experiments suggested that the bedload discharge by weight per unit time and width can be determined by

$$\gamma \left(\frac{K_s}{K_r}\right)^{\frac{3}{2}} RS = \tau_s^*(\gamma_s - \gamma)d + \frac{0.25\rho^{\frac{1}{3}} q_s^{\frac{2}{3}}}{\left(\frac{\gamma_s}{\gamma_s - \gamma}\right)^{\frac{2}{3}}}$$

Where γ and γ_s = specific weights of water and sediment, (in metric tons/m^3), respectively, R the Hydraulic radius (in m), S the energy slope, d the mean particle diameter (in m), τ_s^*= the Shields critical parameter (0.06), ρ the specific mass of water (in metric tons-sec/m4), q_s the bedload rate in weight per unit time and width [in (metric tons/sec)/m], and $\left(\frac{K_s}{K_r}\right)^{\frac{3}{2}} S$ the kind of slope, which is adjusted such the only portion of the total energy loss, namely, that due to the grain resistance is responsible for the bedload motion.

Applying this equation was computed the bed load sediment transport in Tuni River. The data of instantaneous discharge (every 10 min) used corresponds to almost the whole hydrological year (Nov 2012-Aug2013). The period that has bedload sediment transport is from November to March, which represents almost one third of the year (Fig. 6).

The hydraulic ratio was assumed as equal to the Normal depth which was calculated trough manning equation. Finally the total amount of bedload sediment transport computed for the hydrological year (2012-2013) is 190 [m^3/sec]. However this equation is very sensitive to changes in the hydraulic ratio, which is largely limited by small changes in the manning coefficient of roughness.

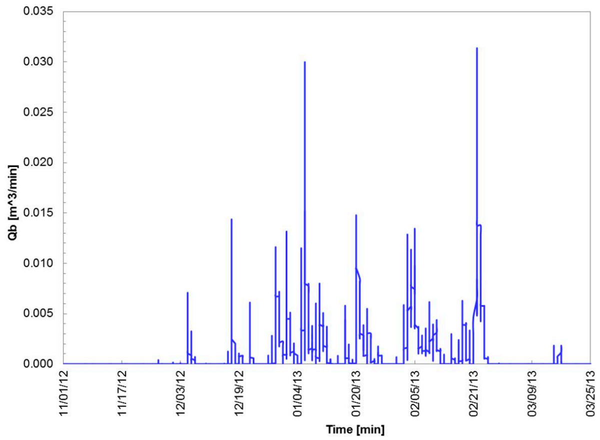


Fig.6 Bedload transport on Tuni River.

3.4 Comparison

Kawagoe (2014) reported that the current rate of sediment yield of Tuni catchment area is 1.7x10^2 [m^3/year].

The amount of sediment deposited to a reservoir depends on the amount of sediment yield produced by the upstream watershed. Thus the proportionality factor between the rate of sediment deposition and the rate of sediment yield must be lower than 1. The methodology that has a better agreement with this principle is the "Comparison among topographical information" (Table 3). As well as the difference of the results obtained between the two periods analyzed is just 10%. However the other two methodologies analyzed support the theory that in general terms the rate of sediment deposition is low.

Table3 Comparison among different methodologies to calculate the rate of sediment deposition

Period	Comp. among topographical inf. [m^3/year]	The Sediment Layer Thickness [m^3/year]	Meyer-Peter and Müller equation [m^3/year]
2012-2013	1.2x10^2	4.6x10^2	1.9x10^2
2013-2014	1.3x10^2	-	-

According to Hippe et al. (2012) the study area belongs to the formation of Paleozoic which indicates a stronger resistance to weathering and erosion processes. Moreover the gradient of precipitation varies monthly from 120 mm in rainy season (Jan-Mar) to 18 mm in dry season (Jun-Aug), which is characterized by episodic, heavy and short duration. Thus the sediment particles removal and the fluvial sediment transport are largely limited to the rainy season. In addition the vegetation on Lake Tuni catchment area is limited to grass and small bushes. This is consistent with results obtained in many different areas of the world, which have already provided evidence that slight land use leads to low erosion rates. Therefore taking into account these factors can be explained the low rates of sediment yield and sediment deposition.

4. Conclusions

The rate of sediment deposition obtained through topographical comparison for different periods showed the best results among the methodologies analyzed. In addition was established that parameters such as:

precipitation soil coverage and type of soil formation are leading into a low rate of Tuni reservoir sedimentation.

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