Analysis of sediment yield and sediment deposition in Lake Tuni, Bolivia

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1. Introduction

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. In this sense studies directed toward the analysis of the deposition phenomenon will be of great help.

After sediment particles have been removed from the watershed surface, some of them are transported through the river system into a reservoir. Some of the eroded materials are transported to a lower area for temporary storage before they eventually move through the river system for a terminal point of deposition. Thus the amount of sediment deposition to a reservoir depends on the amount of sediment yield produced by the upstream watershed although this relationship was not yet clearly quantified; herein these patterns are analyzed for Lake Tuni.

There are numerous studies on various aspects of soil erosion and sediment deposition that gave sights in the current study. Milan et al. (2007) and Hashimoto et al. (2013) proposed new techniques for field survey to estimate the sediment deposits volume. The sensibility of sediment yield to land use, soil coverage, soil formation, precipitation and area coverage was analyzed in the approaches of Hippe et al. (2012), Walling (1999), Kothyari et al. (1994) and Avendaño et al. (1997). These were very helpful for the interpretation of our results in comparison with the approach of Kawagoe (2012) who reported the current sediment yield of Tuni catchment area.

2. Study Area

In Lake Tuni were found two sand deposits, the sediment deposit of Tuni River and the sediment deposit of a nameless river, which surface area are 0.035 Km^2 and 0.019Km^2 respectively (Fig. 1).

Tuni River originates in Tuni Glacier flows for 5.46 Km before draining into Lake Tuni, and has a contributing catchment area of 10 Km^2. On the other hand, the above mentioned nameless river flows for 0.94 Km before draining into Lake Tuni, and it has a contributing catchment area of 0.65 Km^2.

3. Methodology

Digital Elevation Model

Both sediment deposits were surveyed in early October 2013 with the 3D laser scanner, Quarryman Pro, in three parts to reduce the possibility of unscanned areas due to shadowing effect and with a high

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definition of 0.20 [m] (vertical and horizontal interval between each observation). on each sand deposit respectively. The instrument combines reflectorless laser measurement technology with high-speed automatic robotic surveying to obtain topographical accurate measurements. Later MDL software is used to export that data into Global Mapper format, deriving in a digital elevation model (Fig. 2-3).

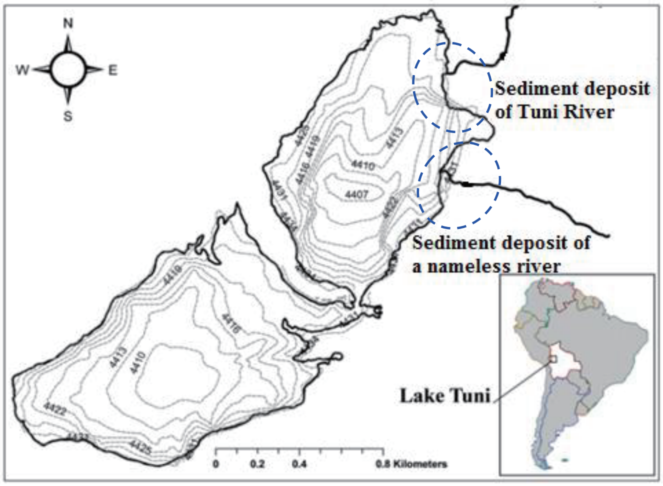

Fig. 1 Location of Tuni River mouth and a nameless river mouth in Lake Tuni

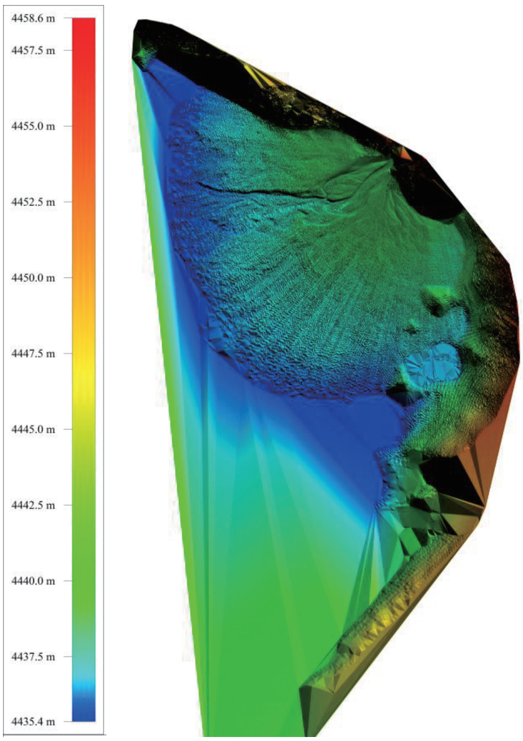

Fig. 2 Topography of the sediment deposit of Tuni River

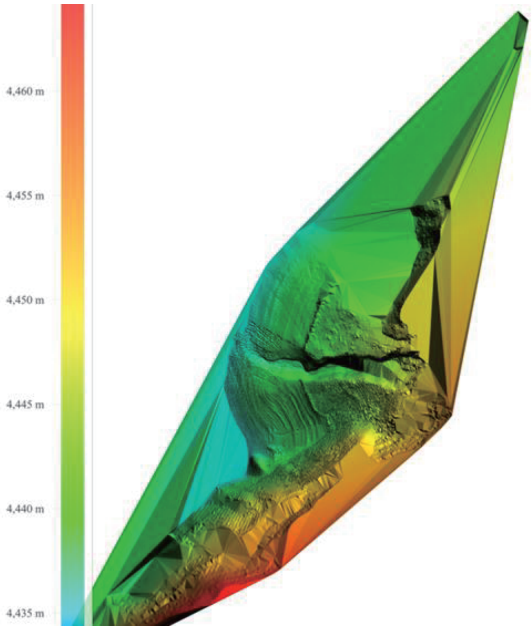

Fig. 3 Topography of the sediment deposit of a nameless river

The bottom level of the sediment deposits

Sediment movement is accompanied by the organization of grains into morphologic elements called bedforms. Hence in this study the bottom level of the sediment deposit is defined as the base over which the presence of bedforms started to be evident. Similar assumption was already validated in the study of Hashimoto et al. (2013).

In the sediment deposit of Tuni River was performed two excavation points (Fig.4). Analyzing the excavation point T2, 4436 [m.a.s.l], was found the predominance of clay, without any presence of bedforms. In the other hand at the excavation point T1, 4437.1 [m.a.s.l], was appreciable the existence of two layers of gravel which thickness are 0.29[m] and 0.22 [m] respectively (Table 1). Below this bedforms, at the elevation of 4436.5 [m.a.s.l.], the composition of the soil suddenly changed from gravel to clay.

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

Table 1 Soil composition at Excavation Point T1

Bedform	1st	2nd	3rd
Thickness [m]	0.29	0.22	0.65
Soil composition	Gravel	Gravel	Clay

For the sediment deposit of a nameless river was performed three excavation points (Fig.5). At the excavation point N1, 4437 [m.a.s.l], clay was found below three layers, at the elevation of 4435.9 [m.a.s.l.]. These layers are composed by mixture sand and clay, which thickness are 0.2 [m], 0.5[m] and 0.37[m] respectively. Although for the cases N2, 4436.3[m.a.s.l], and N3, 4436.5[m.a.s.l], the excavations was less depth than in case N1. Both cases present similar composition in the upper layers, a mixture of sand and gravel, and on the deeper layers a mixture of thinner sand and clay. The thickness of each layer is summarized in Table 2-4.

Therefore 4436.5 [m.a.s.l] is the level assumed as the bottom of the sediment deposit of Tuni River and 4435.9[m.a.s.l] in the case of the sediment deposit of a nameless river. These levels are considered as a constant base height for the estimation of the sediment deposit volume.

Fig. 5 Excavation points on the sediment deposit of a nameless river

Table 2 Soil composition at Excavation Point N1

Bedform	1st	2nd	3rd	4th
Thickness [m]	0.2	0.5	0.37	0.19
Soil composition	Sand	Sand	Mixture of sand and clay	Clay

Table 3 Soil composition at Excavation Point N2

Bedform	1st	2nd	3rd
Thickness [m]	0.12	0.33	0.55
Soil composition	Sand	Sand	Mixture of sand and clay

Table 4 Soil composition at Excavation Point N3

Bedform	1st	2nd	3rd	4th
Thickness [m]	0.06	0.1	0.18	0.6
Soil composition	Sand	Sand	Mixture of sand and clay	

4. Results and discussion

Estimation of the sediment deposit's volume and the rate of sediment deposition

Based on the information collected with the 3D laser scanner and with the help of a tool menu in Global Mapper's setup was estimated the sediment deposit volume. The same base height (the bottom elevation of the sediment deposit) relative to each vertex was specified as 4436.5[m.a.s.l] for the sediment deposit of Tuni River and 4435.9 [m.a.s.l] in case of the sediment deposit of a nameless river. These results were summarized in Table 5.

Finally in order to estimate the rate of sediment deposition due to sediment transport by rivers, the total volume of sediment was divided by the length of time that the Dam is functioning of 34 years from 1978 to 2013, showing the results in Table 6.

Table 5 Volume of sediment deposits until 2013 [m3]

Parameter	Value
Volume of Tuni sand deposit [m3]	4.63×10^4
Volume of a nameless sand deposit [m3]	3.6×10^4

Table 6 Rate of sediment deposition [m3/year]

Parameter	Value
Tuni sand deposit [m3/year]	1363
A nameless sand deposit [m3/year]	1068

Comparison

Kawagoe (2012) reported that the current rate of sediment yield of Lake Tuni catchment area is 76.7 m^3/year. This a much lower value than our estimations of the rate of sediment deposition, summarized in Table 2. Furthermore this value is low if we compared with other approaches with similar coverage area. Therefore the sensibility of sediment yield to different parameters (soil formation, soil coverage and precipitation) was analyzed to establish the reliability of our results.

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 this factors can be explained the low rate of sediment yield reported by Kawagoe (2012). In the other hand it was exposed the necessity to establish the current rate of sediment deposition by other methodologies.

5. Conclusions

The estimation of the sediment deposit's volume and the rate of sediment deposition was obtained by means of topographical measurements on the sediment deposits (performed with a 3D laser scanner) and information about bottom level of the sediment deposits.

It was established that parameters such as: precipitation soil coverage and type of soil formation are influencing the low rate of sediment yield in Tuni catchment area.

In order to establish the rates of sediment deposition with more accuracy it should be necessary to evaluate other techniques such as the comparison of the current measurements made on 2013 with a future one in 2014.

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References

Avendaño, C., Sanz, E., Cobo, R., Gomez, J.L., 1997. Sediment yield at Spanish reservoirs and its relationship with the drainage basin area. 19th Congress of large dams, Florence: 863-874

Hashimoto, K., Goto, K., Sugawara, D., Imamura, F., 2013. Consideration of tsunami deposits distribution in Sendai plain evaluated by sediment transport model, in 2ndG-EVER International symposium and The 1st IUGS&SCJ international workshop on natural hazards, Japan

Hippe, K., Kober, F., Zeilinger, G., Ivy-Ochs, S., Maden, C., Wacker, L., Kubik, P.W., Wieler, W., 2012. Quantifying denudation rates and sediment storage on the eastern Altiplano, Bolivia, using cosmogenic ^{10}Be, ^{26}Al, and in situ ^{14}C. Geomorphology 179: 58-70

Kawagoe, S., 2012. Sediment production in Lake Tuni catchment due to climate change, in Grande Congress, October 5th, Japan

Kothyari, U.C., Tiwari, A.K., Singh, R., 1994. Prediction of sediment yield. Journal of Irrigation and Drain Engendering 120:1122-1131

Milan, D.J., Heritage, G.L., Hetherington, D., 2007. Application of a 3D laser scanner in the assessment of erosion and deposition volumes and channel change in a proglacial river. Journal of Earth Surface Process and Landforms: 1657-1674.

Walling, D.E., 1999. Linking land use, erosion and sediment yields in river basins, Journal of Hydrobiology: 223-240