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Charcoal in Sediment Layers: A Way to Estimate Impact of Land Use Intensification on Reservoirs Siltation ?

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Introduction

Worldwide, siltation of water reservoirs due to sediment deposits is a common problem as it causes flooding or water shortage due to decreasing buffer capacity (Duck and MacManus, 1990; Chambers 1999). The degree of erosion, however, is not only depending on rainfall patterns and topography but also on the land use around the reservoir. Therefore land use changes, soil erosion and sediment transport studies in regions with intensive agricultural practices are essential for reservoir protection. Charcoal, resulting from slash and burn practices, will accompany sediments derived from erosion events and be deposited. According to Whitlock and Larsen (2001), the analysis of charcoal fragments from lake sediments is the most reliable technique to reconstruct past forest fires as charcoal quality can be related to vegetation. Thus, it is possible to use it as a finger print for reconstructing land use, its history and its impact on erosion and sedimentation. Detailed knowledge of the past supports future land use planning by predicting erosion and deposition of fine sediments. The objective of the study is to link charcoal occurrence in sediment layers and the thickness of the layers with land use history from which the contribution of each land use to reservoir siltation can be revealed. With the annual sediment yield, the lake volume and the trap efficiency (TE) influencing, the future decrease in buffer capacity can be estimated under current cultivation practices.

Methods and Material

This study was conducted in the Chieng Khoi commune, Yen Chau district, Son La Province in Northwest Vietnam where an artificial lake is serving as a reservoir for irrigation purposes. The lake was created in 1963 after damming up a side arm of the Da River. Steep slopes and depleted soils in the surroundings of the lake are prone to erosion, especially during the rainy season (April to September) when heavy rainfall events up to 100 mm and more occur. Main land use systems around the lake are under maize monoculture or maize intercropped with cassava (M1, M2), agroforestry (O1, O2) and secondary forest (mainly bamboo, F1 and F2). Below each land use, two profiles were excavated. The first profiles (M1, O1 and F1) were in a short distance to the former lake shore, located directly under the corresponding land use. The second profiles (M2, O2, F2) were taken at a distance of 10-17 m from the first profile (M1 – M2) or 10 m (O1-O2; F1-F2).

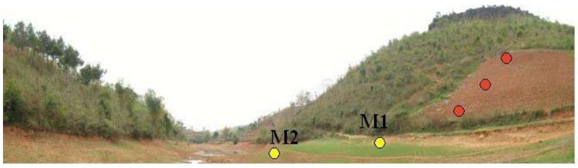

Fig. 1. Positions of augering sites (●) and profile pits (M1, M2; ●) at the Chieng Khoi Lake, Son La province, NW Vietnam. Photo was taken before maize cultivation.

The profiles have a depth of 2 m, except F2 and O2. Due to their position close to the waterline and the raising groundwater level they were dug up to 130 cm (F2) and 80 cm (O2). Different sediment layers were visibly distinguished due to colour and texture and sampled. Furthermore, samples were collected at 2-cm intervals over the entire profiles for detailed analysis on particle size and charcoal content. Additionally augering cores were taken from upper, middle and lower slope position of the fields above the profiles (Fig. 1). To examine sediment transport capacity, the visible distinguishable sediment layers were investigated regarding thickness, colour (Munsell Soil Colour Chart), texture, particle size distribution (Beckman Coulter LS 13 320 Series Laser Diffraction Particle Size Analyzers) and total organic carbon (TOC) measured with LECO RC 612 Multiphase Carbon and Hydrogen/Moisture
Charcoal residues of maize, teak, cassava and secondary forest (mainly bamboo) were sampled as reference material. Visible charcoal in specific sediment layers were isolated and analyzed by Differential Scanning Calorimetry (DSC) using Netzsch Simultaneous Thermogravimetry Differential Scanning Calorimetry - STA (TG-DSC) and compared with the reference material. Land use history maps of years 1963, 1968, 1974 and 1995 were created in a workshop with five elderly farmers, using participatory techniques A bathymetric survey was carried out by means of DGPS (Trimble R3) and the ARGGIS 9.2 software was used for calculating.

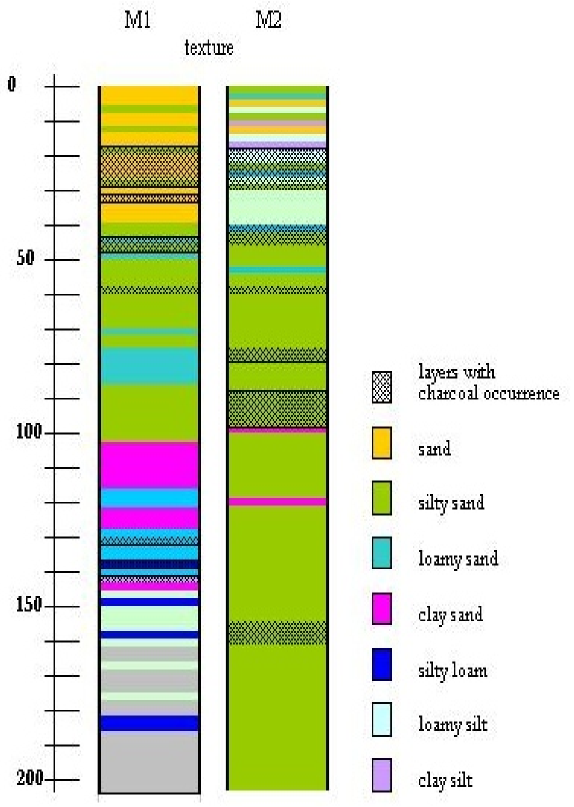

Fig. 2. Charcoal findings in profiles M1 and M2

Results and Discussion

1. Profile texture

Most striking differences in comparison to the other profiles were found between M1 and M2 (Fig. 2). The sand content is high in the first 56 cm of M1, whereas profile M2 shows a higher silt and clay content. This could be due to the fact that the original soil was covered by 56 cm of sediments and the coarser texture is the sediment deposition, whereas in the profile M2 into a 17 m distance silt and clay was deposited. Including local land use history information about maize cultivation would lead to a sediment deposition ration of 4.6 cm/year. On lower depths charcoal was found in these two profiles at depths of 18-30, 32-34 , 44-48 ,132- 134, 138-144 cm in M1 and at depths 18-30, 42-46, 76-80, 86-96,154-160 cm in M2, which may suggest an even higher sedimentation rate in the last decade.

2. Charcoal analysis

Figure 3 summarises all peaks of reference material tested. Distinctive DSC peaks for charcoal from the reference plant materials. The peaks reflect the thermal stability of any compound of the samples to thermal oxidation. High sharp peaks are supposed to be most thermally labile material which is rapid and easy burnable such as cellulose, whereas flat peaks reveal a slow burning material such as lignin. The highest thermal stability of our samples has teak with a single combustion peak of 428°C, followed by maize at 425°C and cassava at 417°C. The lowest thermal stability was in bamboo at 406°C. Bamboo was furthermore characterized by a sharp high peak at around 379°C, whereas cassava is presented with a flat peak between 392°C to 417°C. These peaks could only be identified, when pure charcoal was selected out of the soil material.

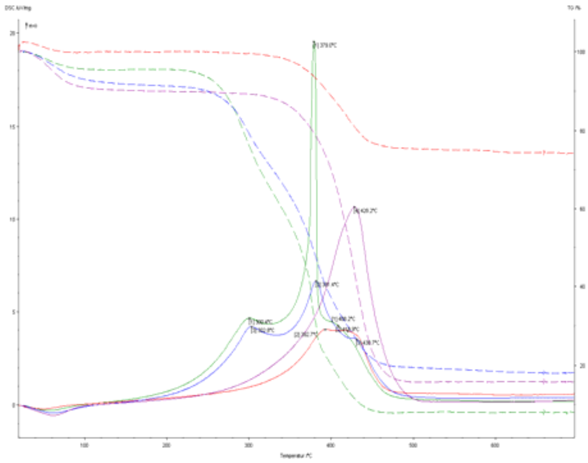

Fig. 3. DSC curves of different plant material
___ Bamboo ___ Teak ___ Maize ___ Cassava
Pointed lines: mass loss

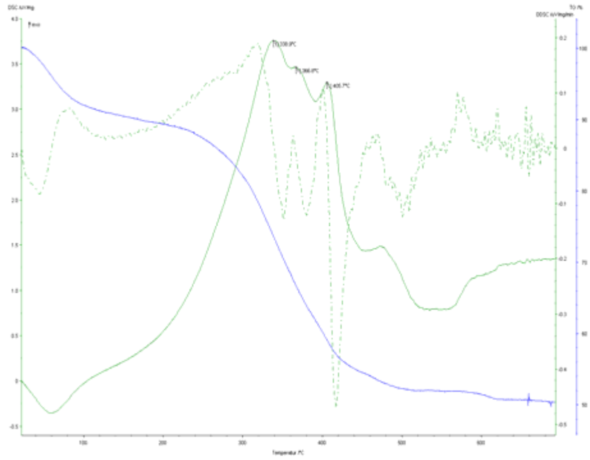

Fig. 4. DSC of charcoal found in 25-29 cm depth in the lower maize Profile (M2)

Table 1 presents the combustion peaks and mass loss from selected samples. DSC analysis of M2, 25-29cm depth, revealed three peaks (Fig. 4) of which second and third were at similar temperatures as bamboo and maize respectively (Table 1). The isolated sediment charcoal could derive from disturbed natural forest or planted teak/maize system

Table 1. Charcoal types referring to peak or mass loss

Profile ID	1. Peak	2. Peak	3.peak	mass loss	possible charcoal type refering to peak	to mass loss
F1 0-5	300	357	403	53.44	bamboo	bamboo
F2 12-14	312	409	476	43.35	bamboo	bamboo
F2 38-40	350	415	495	45.07	bamboo	bamboo
F2 58-60	330	386	465	58.52	bamboo	cassava
F2 96-98	367	409	493	54.8	bamboo	cassava
O1 0-4	330	387	453	41.8	maize	bamboo
O1 28-30	314	381	428	51.9	maize	cassava
O1 36-38	338	387	470	49.2	maize/ cassava	cassava
O2 59-62	345	405	492	64.45	bamboo	cassava
M2 25-29	338	366	405	49.79	bamboo/maize	bamboo
P8 15-17(I)	333	393	462	76.7	bamboo	cassava
P8 15-17(II)	330	398	465	64.3	bamboo	cassava
P8 45-	301	403	477	43.32	bamboo	bamboo
P9 22-29	324	392	476	60.6	bamboo	cassava

Land use change started with planting of teak in 1995. Since 1999 there is maize cultivation on the M2 adjacent upland plot. This suggests that erosion from these plots led to a minimum sedimentation yield of 30 cm in the last decade. When we further assume that there was no teak burning in the last years we could estimate an occurrence of a minimum annual sediment yield of approximately 2.5 cm from maize plots.
Further we can see from Table 1 that charcoal found in the F profiles seem to correspond with the fact, that no agricultural cultivation took place so far on this specific plot as all samples refer to bamboo residues. However, samples taken at a depth of 58-60 cm in the profile F2 could be related to secondary forest (combustion peaks) or cassava (mass loss). This profile was situated in a dell and could thus, also be influenced by the neighbouring field. Since 1995 maize, cassava and teak is cultivated there. Supposing that this charcoal derives from this period and calculating the sedimentation yield since then, we could also estimate an annual sediment yield of 4.6 cm referring to maize cultivation.

Conclusions and Further Outlook

Preliminary results show that different peaks, combustion temperatures and mass loss might be a signal of charcoal composition and thus, used as a fingerprint. Sedimentation events could be derived out of the thickness of the layers referring to the information that land use change started in 1995 and to last burnings.
However, not all charcoal analysis showed strong peaks. To validate these preliminary results charcoal DSC fingerprinting such as analyzing charcoal of other materials is needed in order to strengthen the linkage of charcoal type with peak characteristics.
However, charcoal was found at deeper depths in the profiles. Therefore future analysis of charcoal is needed to exclude if the sediments found at lower depths were a result of maize cultivation and therefore increasing the sedimentation contribution per year or if the charcoal derives from forest residues due to the first clearing of the plot.

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