

Impacts of artisanal small-scale gold mining on Hkaung Tung Hka Chaung River and recommendations for the conservation of Indawgyi Lake/Myanmar



Hkaung Tung Hka Chaung River at the road bridge in Mine Naung in October 2017
(photo: Nils Kreber)

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Cottbus, 2021

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Acknowledgements

This project was conducted in collaboration with the Myanmar Forest Department, the Indawgyi Wildlife Sanctuary and Fauna & Flora International (FFI). We would like to acknowledge the participation of the Wildlife Sanctuary rangers and FFI staff in data collection and are grateful for the in-country oversight by U Maung Win, the Warden of Indawgyi Wildlife Sanctuary, and U Myint Shwe, FFI's Indawgyi field project coordinator. We especially appreciate the support by Eugen Nowak, director of Spreewald Biosphere Reserve/Germany.



Supported by:



Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

based on a decision of the German Bundestag

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DOI: <https://doi.org/10.26127/BTUOpen-5685>

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1 Introduction

Indawgyi Lake in northern Myanmar was inaugurated as UNESCO Biosphere Reserve in 2017 because the natural landscape of the lake and its surroundings with its high diversity of habitats and species is of outstanding international importance. The lake is of high significance for migratory birds, which use it as an important resting place on the way to their winter quarters (MOECAAF undated, FOREST 2017).

However, the lake is exposed to increasing anthropogenic pressures with population growth in the catchment area, intensification of agriculture and fishing and mining activities (FOREST 2017, Kreber 2018). Artisanal small-scale gold mining (ASGM) in the floodplains of the southern part of the catchment area of the lake leads to a high input of suspended sediments into the lake from Hkaung Tung Hka Chaung (FOREST 2017). Suspended sediments are a highly significant threat to tropical freshwater ecosystems (Wantzen & Mol 2013).

The aim of the studies was to estimate the extent of suspended sediment input from Hkaung Tung Hka Chaung into the lake from a field survey in February 2017 and from results of a one-year monitoring programme. In addition, sediments were analysed for heavy metal content. The results of the study can serve as basis for recommendations to reduce the suspended sediment input into Indawgyi Lake.

2 Indawgyi Lake and its catchment area

Indawgyi Lake is one of the largest lakes in Southeast Asia with an area of 140 km² (Fig. 1, Tab. 1). It is a warm monomictic soft water lake with thermal stratification of the water body during the rainy season in summer. The annual water level fluctuations can reach more than 2.5 m. The current trophic state of the lake is within the transition zone between oligotrophic and mesotrophic (Kreber 2018).

The soils of the 1,120 km² catchment area are dominated by fine-grained and highly weathered soils. They are easily erodible when the protective vegetation cover gets lost.

For major parts of the local population, the lake is the basis of their life due to its high abundance of fish. Wide parts of the lower catchment area are covered by paddy fields (Fig. 2), making agriculture to the most important and still growing economic activity in the area. In addition, logging is also of economic importance (Khaw et al., 2015). In the southern part of the catchment area, in particular at the Hkaung Tung Hka Chaung, illegal artisanal small-scale gold mining is widespread (Fig. 3) (MOECAAF et al., undated).

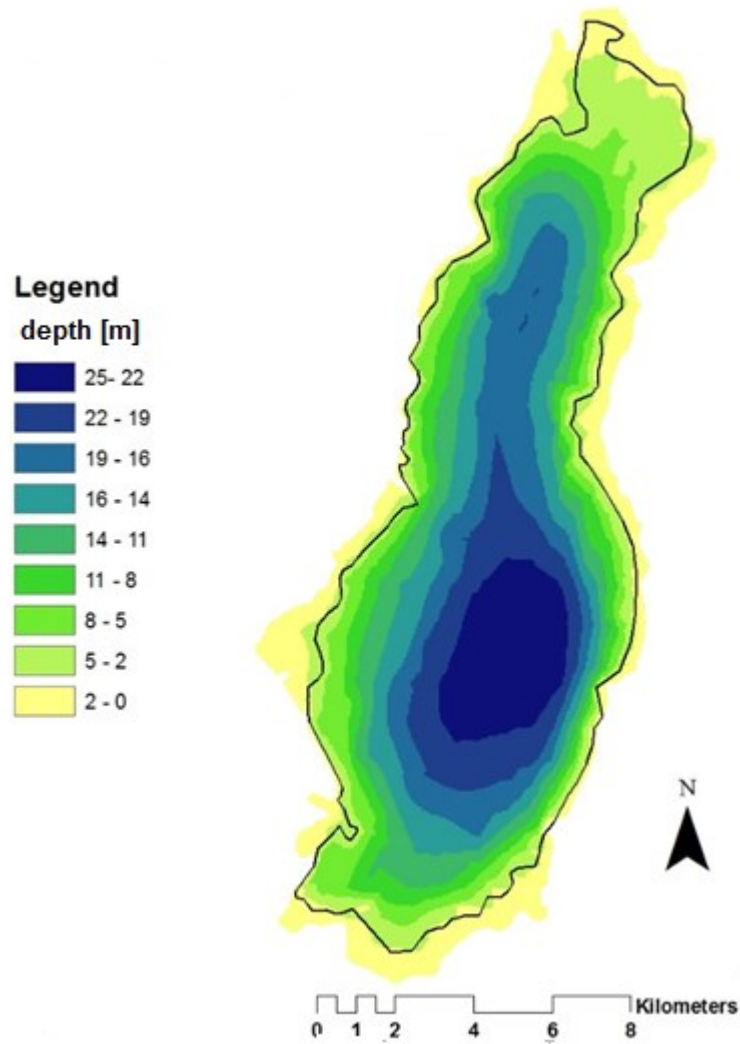


Fig. 1: Bathymetric map of Indawgyi Lake (adapted from Kreber 2018)

Tab. 1: Morphometric data of Indawgyi Lake at high water level of 3.1 m at the gauge in Lonton (data from Kreber 2018)

Area	140 km ²
Volume	1,579 mio m ³
Mean depth	11.3 m
Maximum depth	25 m
Catchment area	1,120 km ²
Theoret. water retention time	approx. 10 months

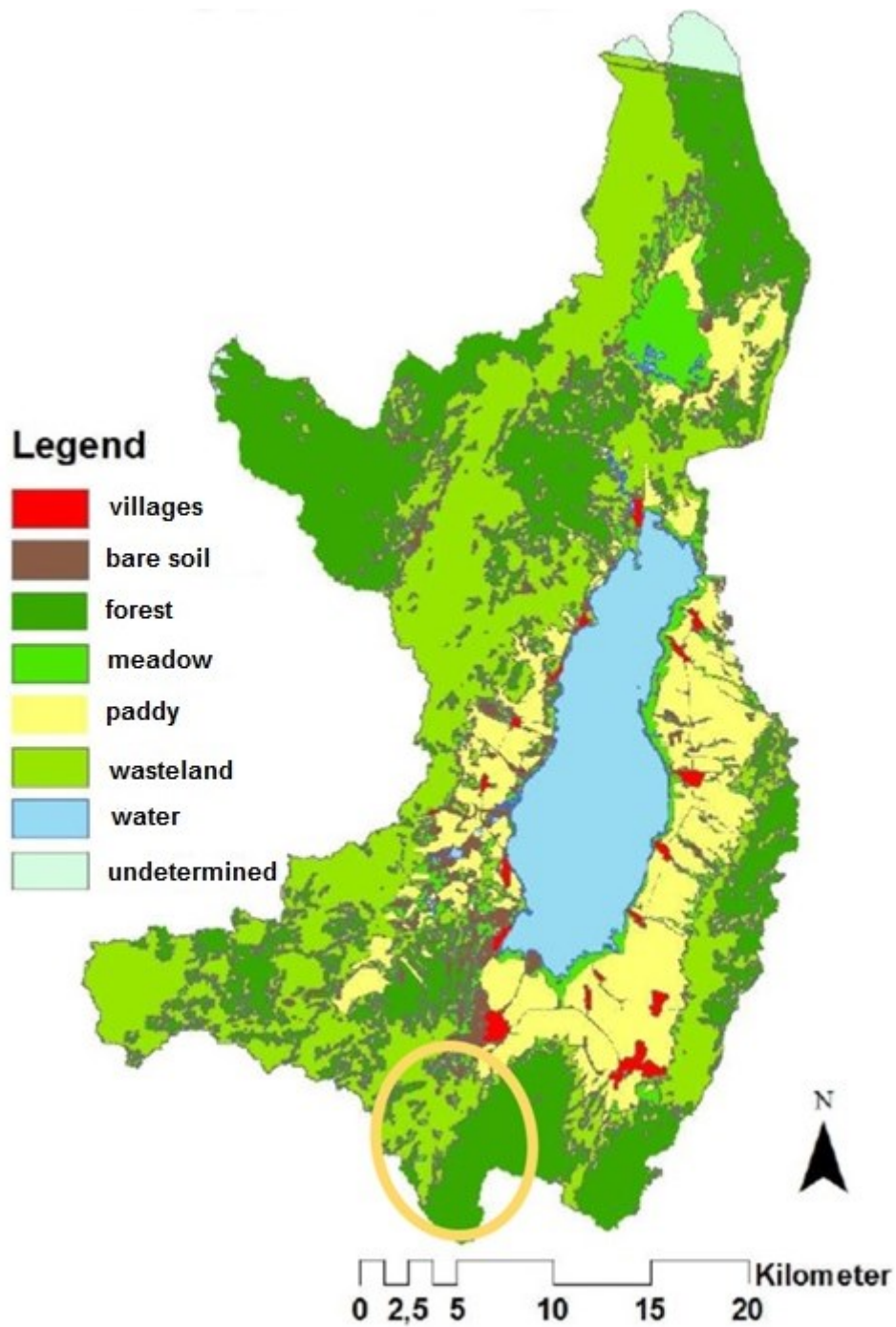


Fig. 2: Land use within the catchment area of Indawgyi Lake and the area of artisanal small-scale gold mining (encircled) (adapted from Kreber 2018)

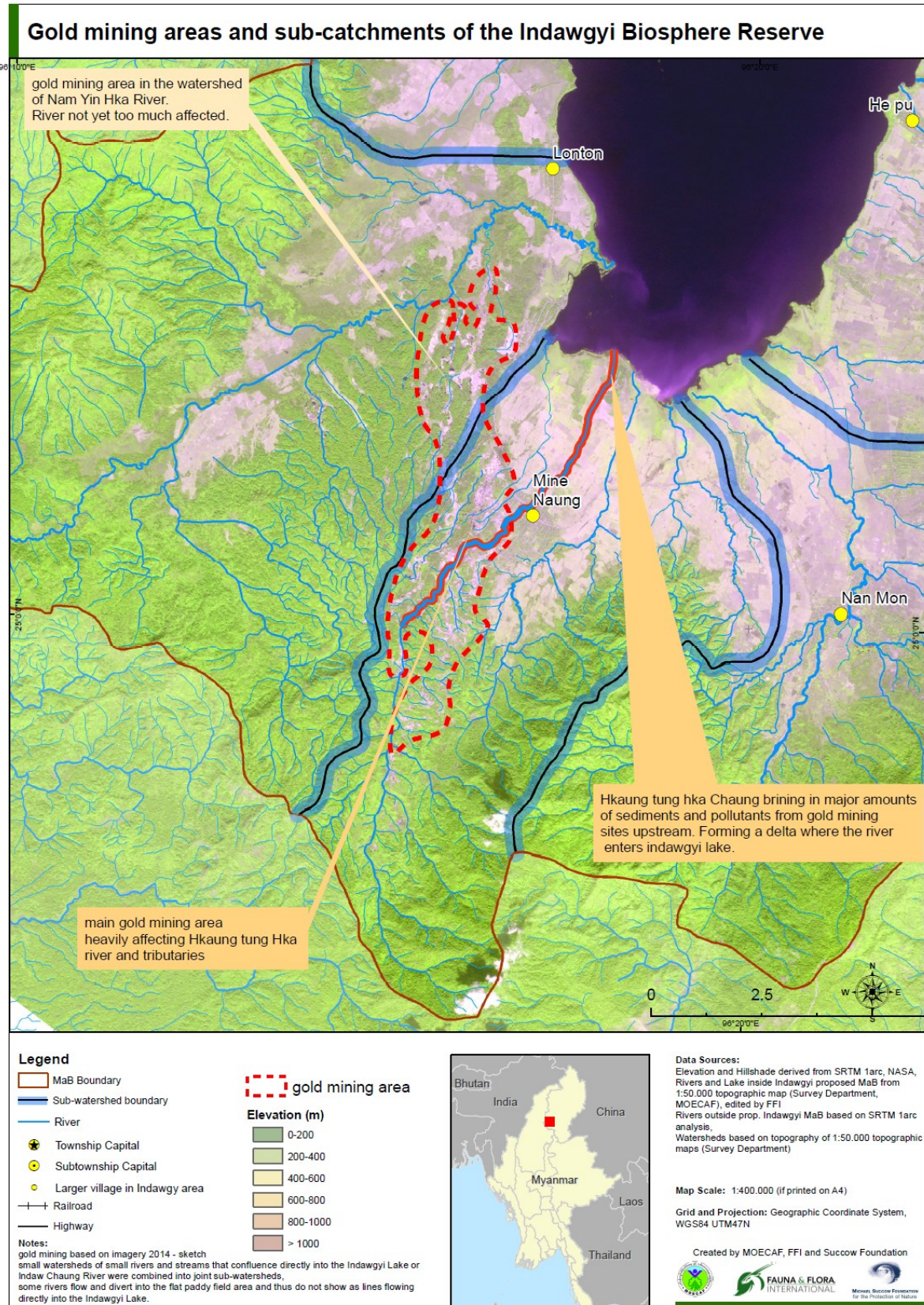


Fig. 3: Southern part of Indawgyi Lake with the catchment area of Hkaung Tung Hka Chaung and the area affected by artisanal small-scale gold mining in 2014 (MOECAF et al., undated)

3 Impacts of gold mining on the freshwater ecosystems

3.1 Impacts on Indawgyi Lake

Gold mining at Hkaung Tung Hka Chaung has substantial impacts on the southern Indawgyi Lake area. Due to the inflow of suspended sediments, an alluvial fan has formed in front of the mouth of Hkaung Tung Hka Chaung, reaching far into the lake (Fig. 4). A comparison of the shoreline at perennial intervals shows significant changes with an increase in the semi-aquatic and terrestrial areas (Fig. 5) which, however, are hardly overgrown by macrophytes, indicating a continuous further deposition of fresh sediments.

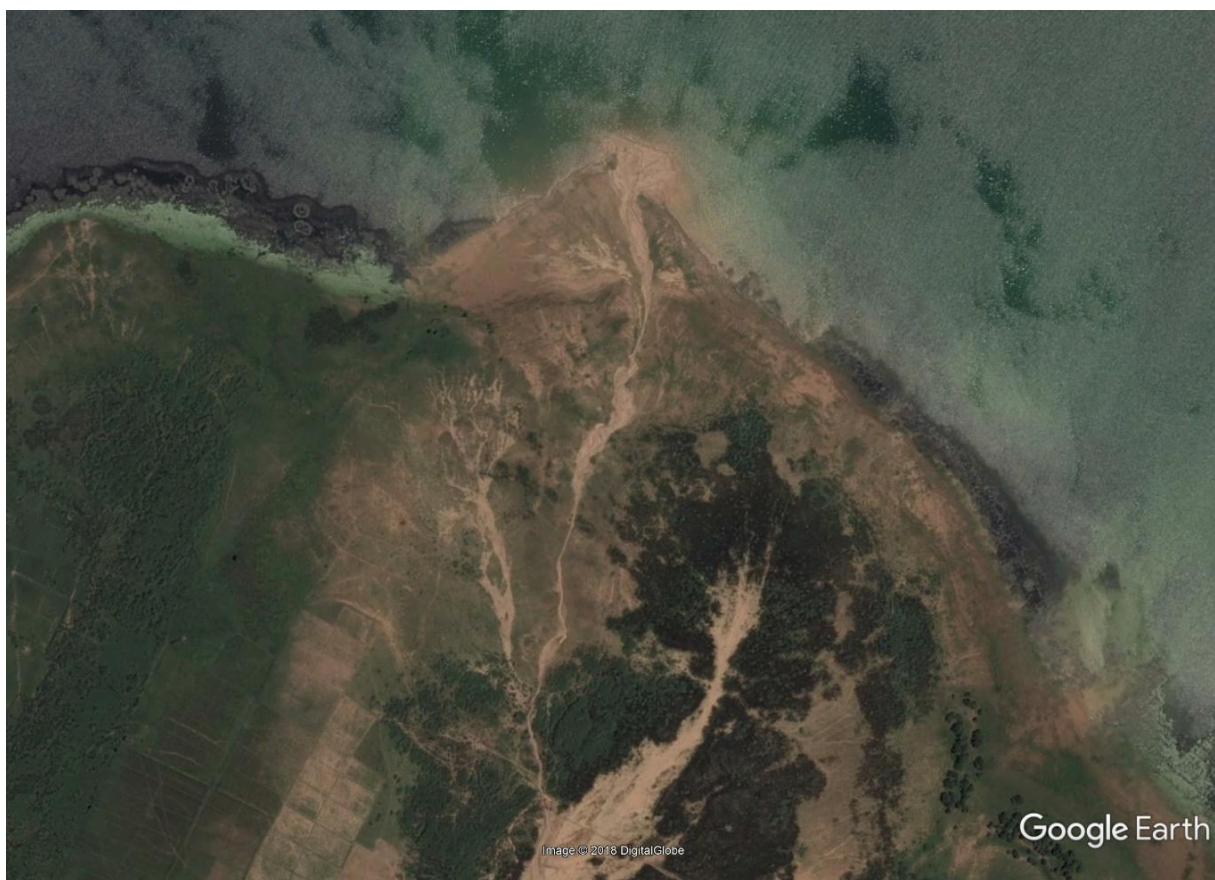


Fig. 4: Satellite image of the delta of Hkaung Tung Hka Chaung in the southern part of Indawgyi Lake (satellite image from 2014)

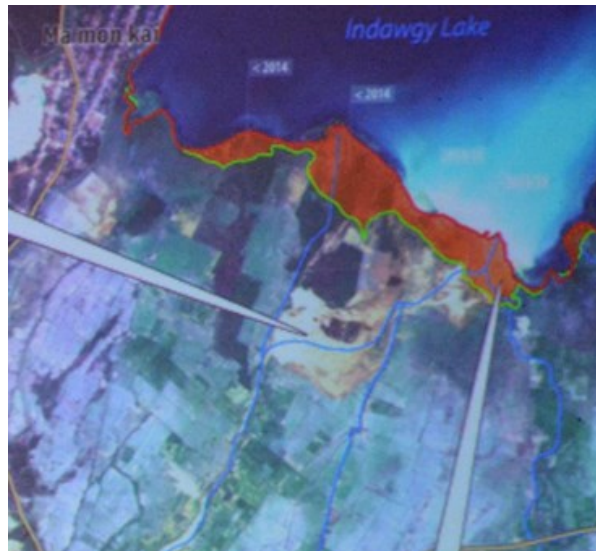


Fig. 5: Change in the shoreline of Indawgyi Lake in the area of the delta of Hkaung Tung Hka Chaung (green line: original former shore line, brown line: shoreline in 2014) (source: FFI)

3.2 Impacts on Hkaung Tung Hka Chaung

In the middle course and in the headwaters of Hkaung Tung Hka Chaung, a high number of artisanal small-scale gold mines have illegally been operated in the floodplain for already several years. The gold mining area directly begins south of the village of Mine Naung and extends along the stream into the upper course.

For gold extraction, sediment is taken from the floodplain and washed by using stream water to separate and afterwards amalgamate the gold (Fig. 6) (for details see UNEP 2012). Water reservoirs in the stream floodplain serve as water source for washing the sediments. Large amounts of fine sediment get into the stream and lead to high turbidity. The material is transported downstream and deposited in the stream bed itself as well as in the southern areas of Indawgyi Lake.

Sediment transport and sedimentation at Mine Naung regularly requires the dredging of the streambed before the start of the rainy season to provide sufficient flow capacity to prevent the village and the area below from flooding. This can lower the bottom of the streambed by up to 2m within the village of Mine Naung. The streambed is more or less filled up again until the beginning of the dry season by settling materials from upstream areas (Nowak, pers. comm.).

The effects of the artisanal gold mining are a small-scale landscape destruction in the catchment area of Hkaung Tung Hka Chaung, accompanied by wide morphological changes and a destruction of the natural streambed (Fig. 7, Fig. 8). Affected are both, the natural streambed as well as the bank areas and the floodplain.

The high suspended matter concentration and the sediment transport have significant effects on the colonisation by organisms. For example, Lowe (2015) found only one species of macrozoobenthos in Hkaung Tung Hka Chaung.



Fig. 6: Washing of sediments during gold extraction at Hkaung Tung Hka Chaung (photo: Frank Momberg)



Fig. 7: Area devastated by gold mining in the middle course of Hkaung Tung Hka Chaung (satellite image from 4 June 2014)

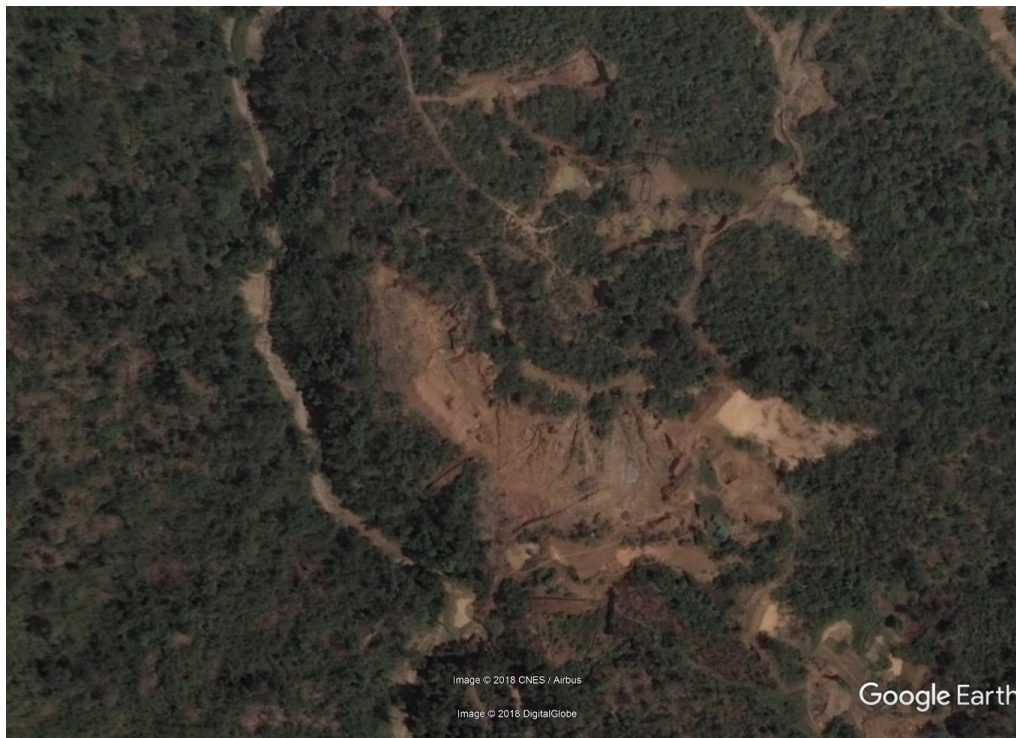


Fig. 8: Area devastated by gold mining in the headwaters of Hkaung Tung Hka Chaung (satellite image from 4 June 2014)

4 Material and methods

4.1 Initial examinations and establishment of a stream monitoring programme

In February 2017, in order to establish a monitoring programme on Hkaung Tung Hka Chaung and to obtain basic data on the sediment load of the stream and on the area of Indawgyi Lake affected by mining activity, lake sediments were sampled and investigations were carried out on the suspended sediments transported by the stream.

As basis for the monitoring, a sampling site at the road bridge over Hkaung Tung Hka Chaung and a stream gauge as discharge measurement site were set up. A section of 100 m was chosen for the measurement of the flow velocity by the drifting body method with the measurement of the time that a buoyant body requires for the distance. The procedure was repeated three times. The average was calculated and multiplied by 0.9 to determine the mean flow velocity in the stream section (EPA 2012). Employees of FFI were instructed in the discharge determination accordingly. Measurement protocols have been provided for them.

4.2 Monitoring of suspended sediments

To determine the suspended sediment transport in Hkaung Tung Hka Chaung, a monitoring programme was established in addition to the discharge measurement. Water samples were taken from the stream by filling several litre bottles (Fig. 9), which were transferred to the FFI station in Lonton where the water was filled into two 1-litre Imhoff funnels.

In February 2017 during the first sampling campaign, the water was left in the funnels for three days under a daily control of the volume of the settled material. After decantation of the liquid phase, the sediments were transported to BTU laboratories for chemical analyses.

As part of the monitoring performed between February 2017 and May 2018 which followed initial sampling, FFI staff read the water level of Hkaung Tung Hka Chaung at the stream gauge in Mine Naung and determined the flow velocity by using the drift body method in weekly intervals. Each time, water samples were taken to determine the dry weight of the suspended sediments and the volume of the settleable material in the Imhoff funnels. For dry weight determination, the settled sediment was transferred into a pot to evaporate the water (Fig. 10). The weight difference between the pot before filling and after evaporation of the water provided the dry weight of the sediment.

All data were recorded and forwarded to BTU for evaluation.



Fig. 9: Water sampling from Hkaung Tung Hka Chaung in Mine Naung in February 2017 (photo: Dieter Lessmann)



Fig. 10: Taking of sediments from an Imhoff funnel for the determination of the dry mass of suspended sediments (photo: Nils Kreber)

4.3 Investigation of lake sediments

Starting from the delta of Hkaung Tung Hka Chaung, sediment cores were taken with a gravity corer along a lake transect from south to north (Fig. 11). The thickness of the sediment deposits from Hkaung Tung Hka Chaung was determined and changes in the chemical composition of the sediments were analysed.

The organic matter content was measured as loss on ignition (LOI) at 500 °C. Total phosphorus was determined by photometry after ignition and extraction in 2N HCl. Metal concentrations were measured by ICP-AES analysis after nitric acid microwave digestion of the fresh sediments.

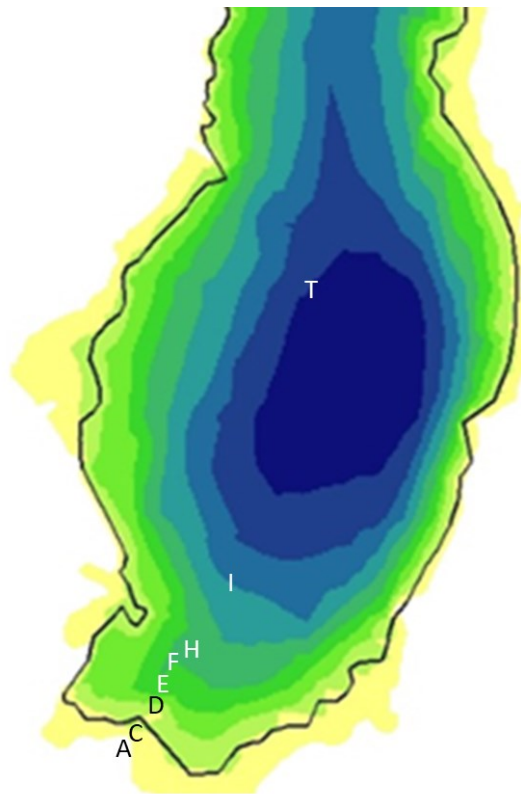


Fig. 11: Sampling sites (A to T) for sediment analyses along a transect from the delta of Hkaung Tung Hka Chaung to the north

5 Results

5.1 Results of the initial examinations

5.1.1 *Dispersal and composition of suspended sediments from Hkaung Tung Hka Chaung in Indawgyi Lake*

As part of the sediment sampling in Indawgyi Lake, it was shown that the characteristic light coloured suspended sediments from Hkaung Tung Hka Chaung were clearly visible in the uppermost layer of the sediments up to several kilometres north of the stream delta (Fig. 12). The thickness of the stream sediments was several metres directly in front of the delta, but gradually decreased to the north.

A turbidity plume, visible on satellite images, indicates that the suspended sediments from the stream are preferably transported in eastern and north-eastern direction. Thus, it can be assumed that the sediment accumulation in north-eastern direction may be higher than documented at the transect sampling sites.

The analyses of the chemical composition of the sediments showed that the surface sediment close to the stream delta was characterized by clay minerals and by high potassium, aluminium and iron contents. With increasing distance from the stream delta, the phosphorus and organic matter content as well as the contents of most heavy metals increased (Fig. 13). It is likely that this is due to the increasing influence of the sedimentation of organic detritus (dead algae) and vice versa the decreasing "dilution" of the autochthonous lake sediment by the clay minerals from Hkaung Tung Hka Chaung.

Mercury could not be detected in the surface sediment (at a detection limit of the ICP-AES of 0.001 mg/L, which corresponds to a dry matter element content of about 1.4 µg/g).

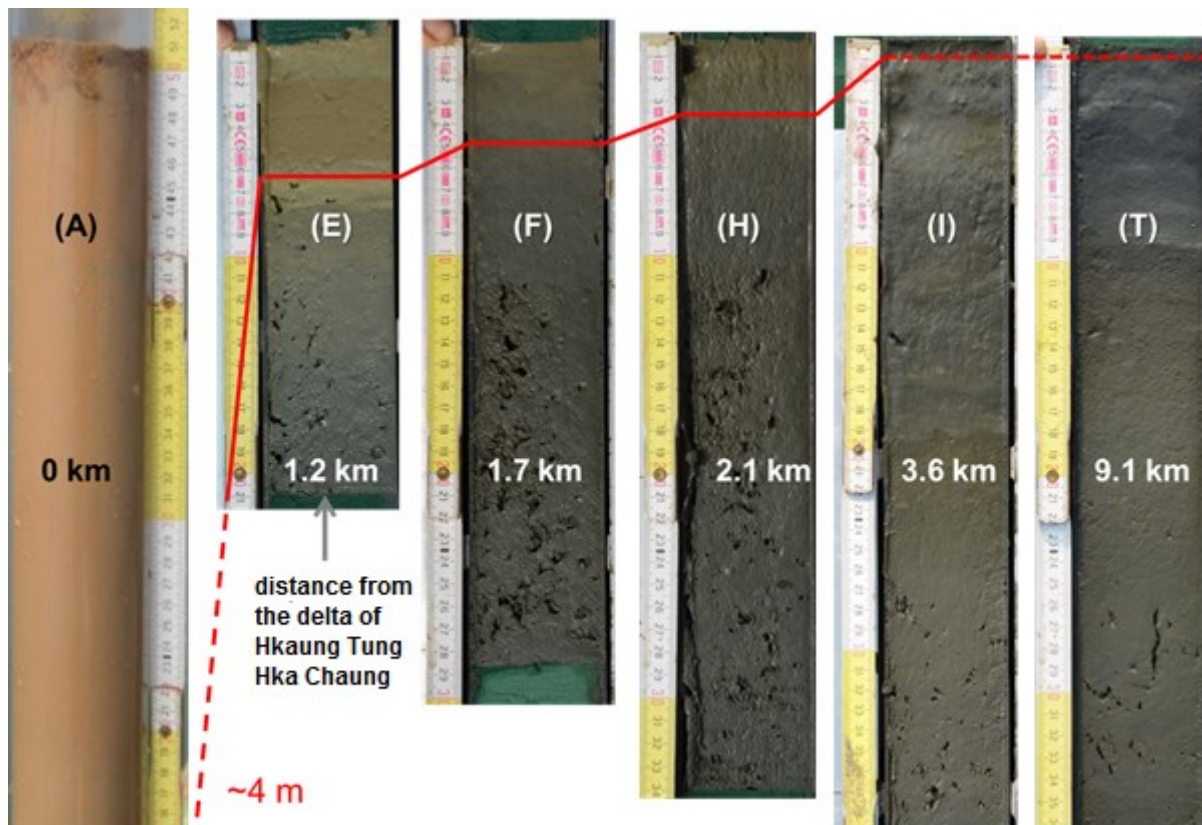


Fig. 12: Images of the sediment cores taken on a transect from the delta of Hkaung Tung Hka Chaung to the deepest point of the lake with demarcation of the surface layer highly influenced by the stream sediments (for the location of the sampling sites see Fig. 11)

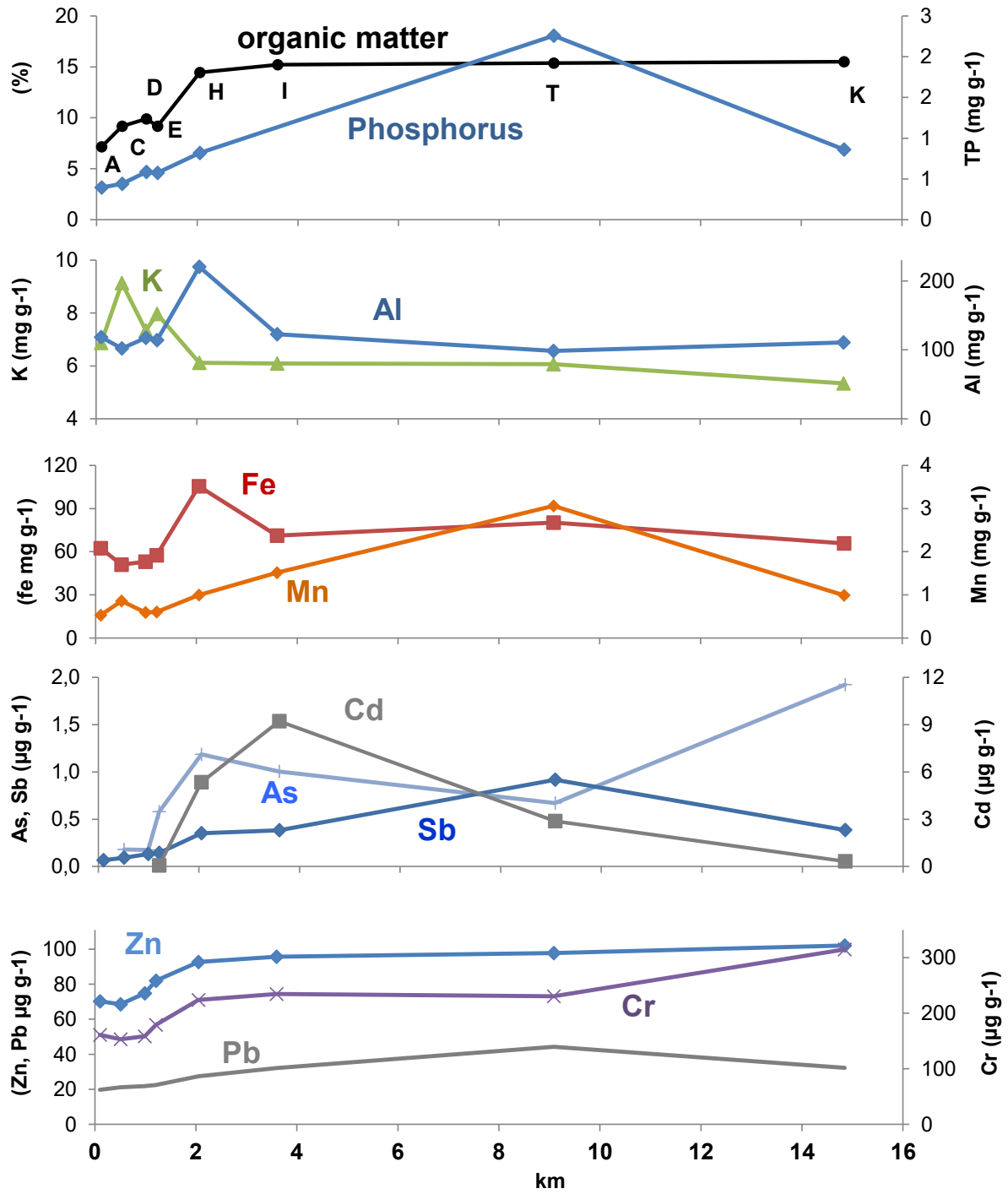


Fig. 13: Dry matter content of selected elements in the surface sediments (0 - 3 cm) along a transect from the alluvial fan of Hkaung Tung Hka Chung (km 0) to the northern part of Indawgyi Lake

5.1.2 Sedimentation experiment

The sedimentation experiment with water samples from Hkaung Tung Hka Chaung in Mine Naung clearly showed the extremely high suspended matter content of the stream water, which is caused by particles of different size and with different sedimentation characteristics.

Within four days, only a sedimentation of the suspended fractions of sand and coarser silt occurred. Finer particles, especially of the clay fraction, remained suspended in the supernatant water and led to a persistently high turbidity of the water (Fig. 14).

In the one litre Imhoff funnels, three zones could be distinguished. In the lowermost zone, predominantly black-brown sand-sized particles were found with a volume of 20 mL, above them 130 mL of finer dark brown particles. The upper zone consisted of a suspension of very fine light-coloured, yellow-brown particles.

The separation into the three zones occurred within about 12 hours. After that, there were only minor changes in the volumes of the three fractions. A decrease in turbidity in the uppermost layer was optically not recognizable during the experiment. According to FFI employees, in later runs, even after seven days, there was still a high turbidity in the upper water layer.

Transferring the findings of the sedimentation experiment to the lake, it became obvious that coarser particles (sand, silt) are deposited close to the stream delta, a typical process leading to a growing alluvial fan. The slow-settling fine particles of the clay fraction can be transported for long distances depending on the occurring currents and affect large areas of the lake (see also Chapter 3.1)

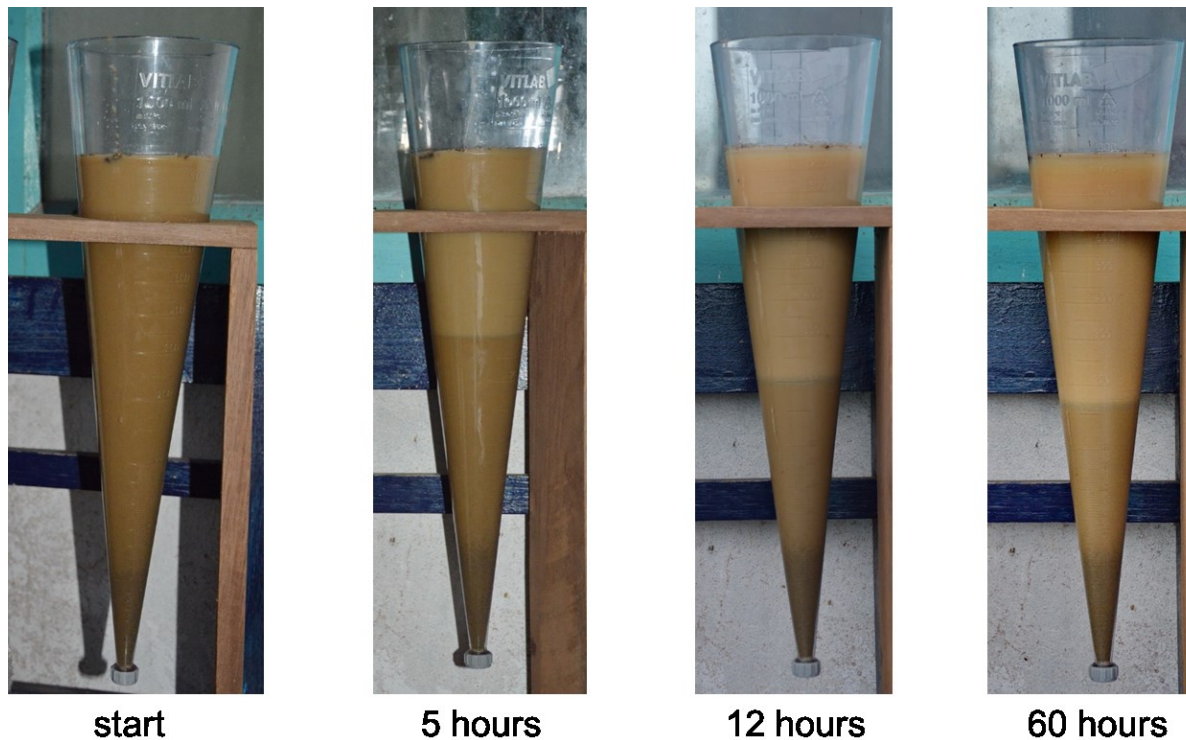


Fig. 14: Sedimentation experiment with water from Hkaung Tung Hka Chaung from the sampling site in Mine Naung using Imhoff funnels

5.1.3 Elemental contents of the suspended sediments of Hkaung Tung Hka Chaung

Chemical analyses showed that the clay fraction of the stream sediments and the suspended solids contained high contents of most heavy metals (Table 2). For example, the precautionary threshold values of the German Federal Soil Protection Act for clay soils (BBodSchG 1998) for cadmium, copper, nickel, chromium and lead were clearly exceeded. The high cadmium contents are particularly noteworthy because of the high toxicity of cadmium. However, it must be taken into account that the high heavy metal contents resulted from the total suspended sediment fraction due to the separation of the clay fraction. For the coarser fractions and correspondingly for the entire bulk sediment, the heavy metal contents were much lower.

At pH-neutral conditions in stream and lake water, heavy metals normally permanently bind to mineral particles. Thus, heavy metal concentrations in lake water are low while heavy metal contents in sediments increase. Organisms can absorb metal-containing particles, which results in bioaccumulation in various animals within the food web. Special attention should be paid to fish, which are an important food source for the people living at Indawgyi Lake.

Tab. 2: Elemental content of the clay and sand/silt fraction of the water samples from Hkaung Tung Hka Chaung in Mine Naung in comparison with precaution threshold values of the German Federal Soil Protection Act (BBodSchG 1998) for clay soils and with the natural background contents of lake sediments (acc. to Hakanson & Jansson 1983)

Element	Unit	Clay fraction	Sand / silt fraction	Precaution threshold (BBodSchG)	Natural background
Ca	mg/g	3,3	0,4		
Mg	mg/g	8,2	0,8		
K	mg/g	4,9	0,7		
Na	mg/g	0,31	0		
Fe	mg/g	78	6,2		27 - 43
Al	mg/g	183	9,9		
Mn	mg/g	0,41	0,1		0,8 - 0,9
Zn	µg/g	-	7,1	200	111 - 118
Cd	µg/g	38	<1,4	1,5	0,4 - 0,6
Cu	µg/g	162	6,9	60	29 - 45
Ni	µg/g	183	12,2	70	50 - 66
Cr	µg/g	208	15,8	100	49 - 62
Pb	µg/g	107	2,6	100	35
Hg	µg/g	<1,4	<1,4	1	0,1 - 0,4

5.2 Results of the monitoring programme

5.2.1 Discharge

From own observations, the description of people living in Mine Naung and the results of the monitoring, it became clear that Hkaung Tung Hka Chaung can show high fluctuations of the discharge within a short period. On the one hand, the discharge is determined by the precipitation, which is subject to the changes between dry (November to March) and rainy season (April to October) (Fig. 15). On the other hand, especially during the dry season, the runoff is influenced by the intermittent discharge from the artisanal mining activity.

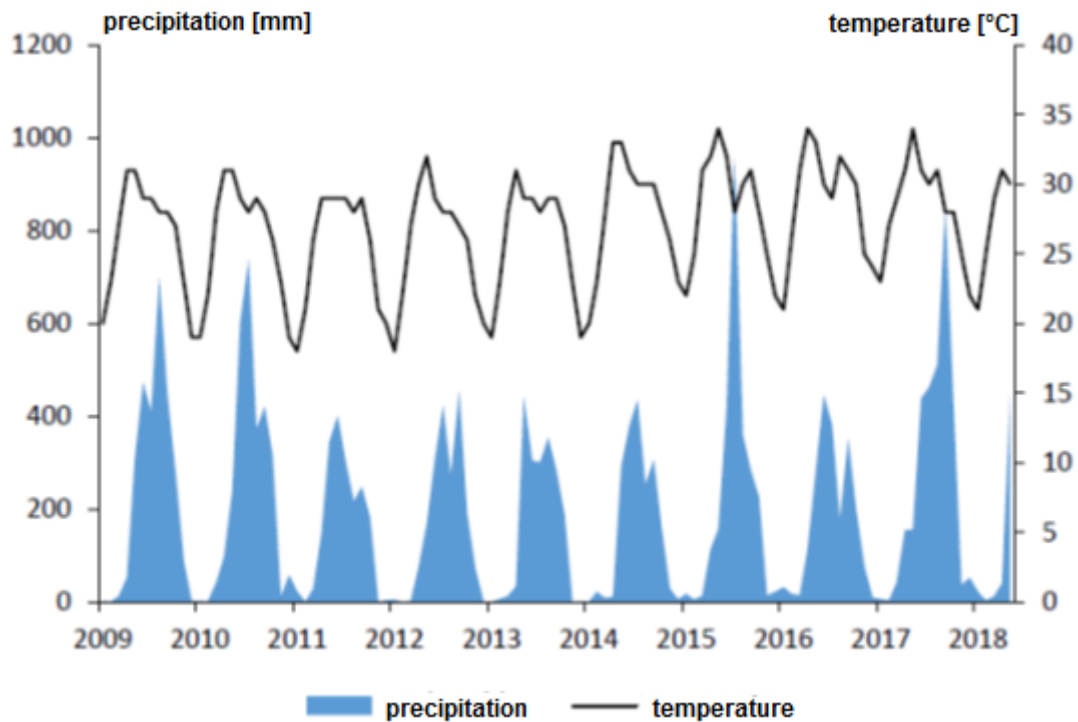


Fig. 15: Monthly means of precipitation and temperature at Lonton from January 2009 until May 2018 (from Kreber 2018, data: worldweatheronline.com)

It could frequently be observed that the discharge changed within short periods (mostly hours) due to the surge-like introduction of water from the gold mining activities. Small watersheds, such as the one of Hkaung Tung Hka Chaung, also react very quickly to changes in the water supply from precipitation, leading both to a rapid multiple increase and afterwards a rapid decline in stream discharge.

Against this background, the determination of reliable hydrological data for Hkaung Tung Hka Chaung without permanent high resolution discharge measurements is extremely difficult and accordingly fraught with considerable uncertainties. As part of the monitoring, the discharge could only be determined once a week by a very rough method.

The monitoring data revealed discharge fluctuations between 0.04 and around 6.5 m³/s. Based on reports of intermittent rainfall in the rainy season, leading to water levels as high as the lower edge of the bridge in Mine Naung, it can be assumed that peak flow rates of up to about 40 m³/s occurred. The average of the measured data was 0.8 m³/s, the median was 0.2 m³/s. The runoff was largely determined by the precipitation with the highest discharge during the rainy season (Fig. 16, Fig. 17).

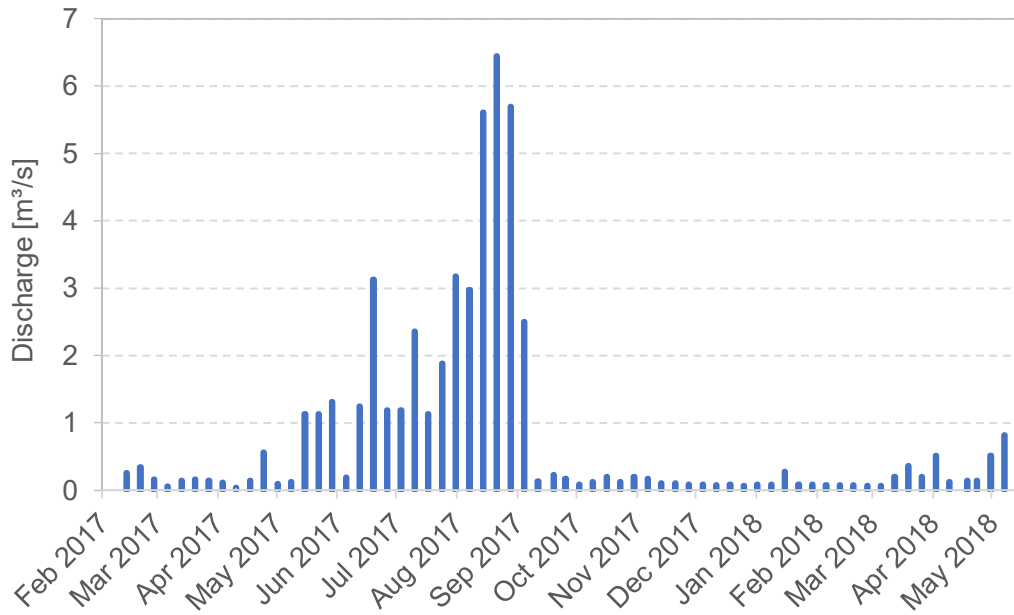


Fig. 16: Weekly reference date data of the discharge of Hkaung Tung Hka Chaung at the stream gauge in Mine Naung between February 2017 and May 2018



Fig. 17: View on Hkaung Tung Hka Chaung in the dry period (left-hand images) in February 2017 and in the rainy season (right-hand images) in September 2017 (left-hand photos: Björn Grüneberg, right-hand photos: Nils Kreber)

5.2.2 Suspended sediment load

Because of methodological problems of the dry mass determination of the suspended sediments in the stream water, which became obvious not earlier than some months after the start of the monitoring, reliable data for the analysis of the suspended matter transport on the reference dates were only available for the period after 11 September 2017. For the period from February to September 2017, based on the accumulated dry weight of all sampling dates until then, a constant dry weight of 15 g/L for each reference date sampling was used for further calculations.

5.2.2.1 Relationship between discharge and suspended sediment concentration

In the evaluation of the monitoring data, no correlation between the discharge and the suspended sediment concentration of the stream water was found. High and low concentrations of suspended sediment were recorded at both low and high discharge (Figure 18). The suspended dry sediment concentrations ranged between 1.0 and 15 g/L with an average of 9.6 g/L, which is an extremely high value.

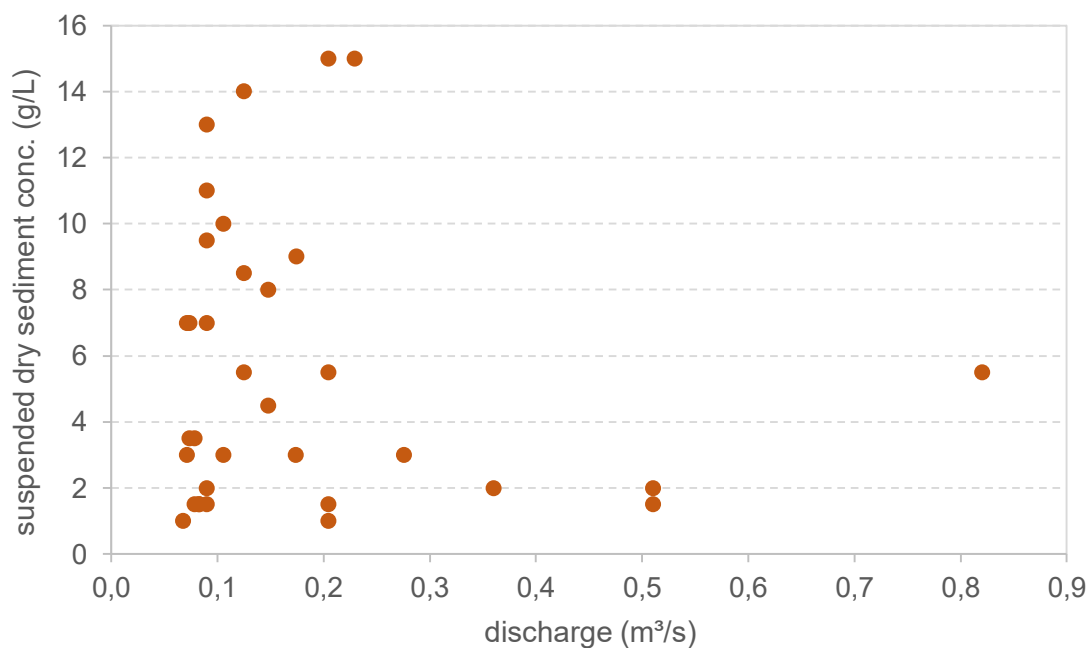


Fig. 18: Relationship between suspended dry sediment concentration and discharge in Hkaung Tung Hka Chaung in Mine Naung for the period between September 2017 and May 2018

5.2.2.2 *Estimation of the suspended sediment load*

From the data of the discharge and the suspended sediment concentration in the water from the reference date sampling, a load of 2.3 to 2,900 t dry mass per day was calculated for Hkaung Tung Hka Chaung for the sampling site at the bridge in the Mine Naung (Fig. 19); the mean value was 359 t/d.

Naturally, the highest amount of suspended sediments was transported at times of high discharge during the rainy season between May/June and September. During the dry season within the remaining eight months of the year, the absolute quantity was much lower (Fig. 20, Fig. 21). This is a clear indication that, on the one hand, there is a significant amount of soil erosion from the areas deforested by mining. On the other hand, a large amount of sediment deposited in the stream bed during periods of low discharge is likely to be remobilised and transported downstream into the lake during periods of high discharge.

The annual load of suspended sediments transported into Indawgyi Lake can be estimated at approximately 133,000 t. Assuming a dry bulk density of the sediment in the lake of about 0.5 g/cm³ (dry sediment mass per m³ of fresh substance), the lake loses about 0.26 to 0.4 million m³ of water volume per year. The complete filling of the lake basin would take between 3,600 and 5,400 years, if the sediment load would stay constant.

However, according to the methods applied in the monitoring programme, this can only be a rough estimation of the actual values, but it shows the great challenges in dealing with this environmental problem.

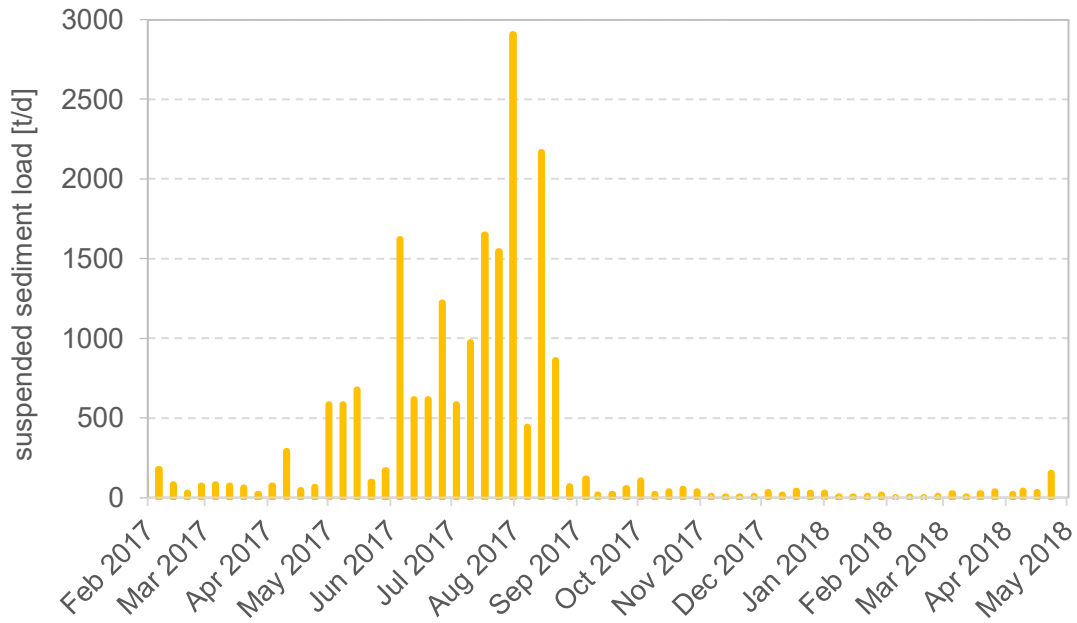


Fig. 19: Daily dry weight of suspended sediment transported downstream in Hkaung Tung Hka Chaung at the stream gauge in Mine Naung on weekly reference sampling dates

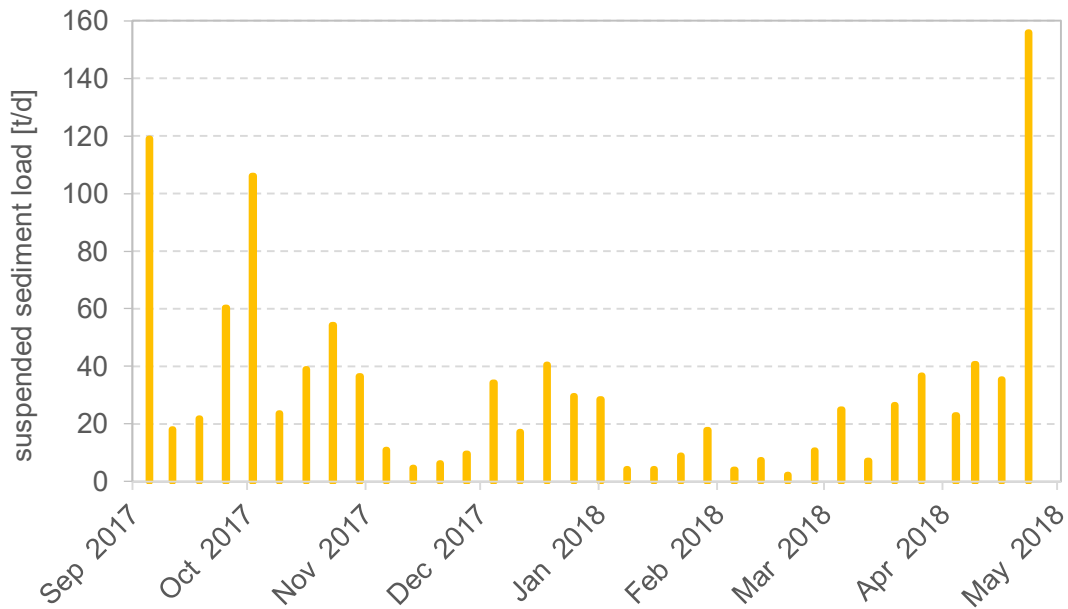


Fig. 20: Daily dry weight of suspended sediment load based on weekly reference date measurements during the dry period from the middle of September 2017 until the middle of May 2018 in Hkaung Tung Hka Chaung at the stream gauge in Mine Naung

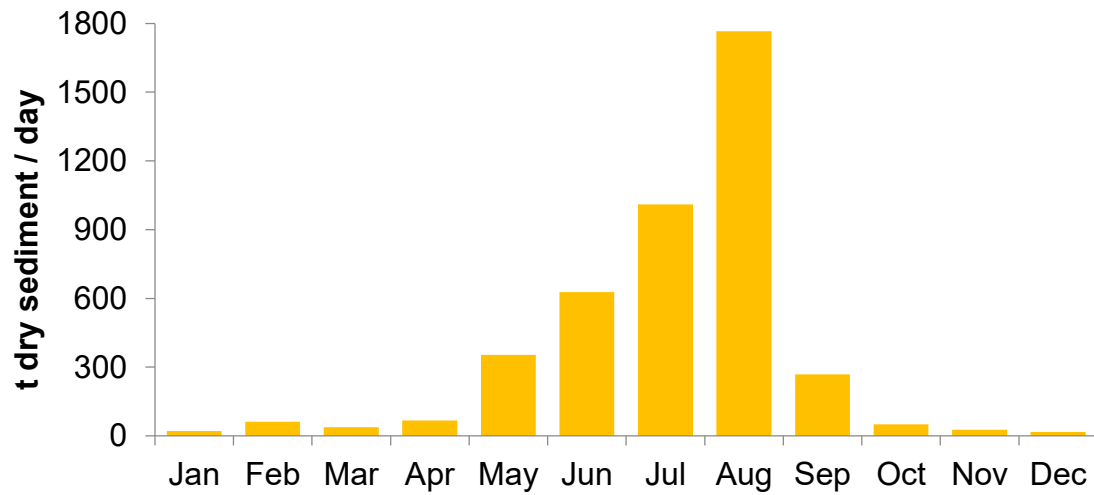


Fig. 21: Monthly average of the daily suspended sediment load as dry weight based on weekly reference date measurements in Hkaung Tung Hka Chaung at the stream gauge in Mine Naung

6 Overview of measures for sediment retention in running waters

6.1 General measures for sediment retention

There are various measures available for reducing the sediment transport in water bodies. The primary principle of all measures is to create flow-calmed areas where sedimentation can take place. Depending on the settling behaviour of the suspended matter and the grain size composition of the sediment, a certain residence time in such retention areas is required.

As examples of suspended matter retention in the Lusatian mining district, reference may be given to sedimentation ponds, as they have successfully been used at Eichower Fließ and Vetschauer Mühlenfließ to reduce the iron hydroxide load (Fig. 22, Fig. 23). A water retention time of several days and an iron load reduction of more than 80 % have been achieved there (Uhlmann & Hiekel 2017).

In other streams, the main challenge is the retention of the total sediment transport from erosion processes. Increased sediment inputs are often due to soil erosion from arable land and from deforestation (Wantzen & Mol 2013). In addition to dam structures that create reservoirs in the longitudinal course of water bodies, the widening and a meandering structure of the stream bed are used to reduce flow velocity and thus the sediment transport potential (Fig. 24, Fig. 25).

Also, sediment traps like groynes in the bank areas can serve for sediment retention. In general, it will always be necessary to implement a series of measures in combination with one another in order to achieve an improvement in the ecological status of the affected stream.

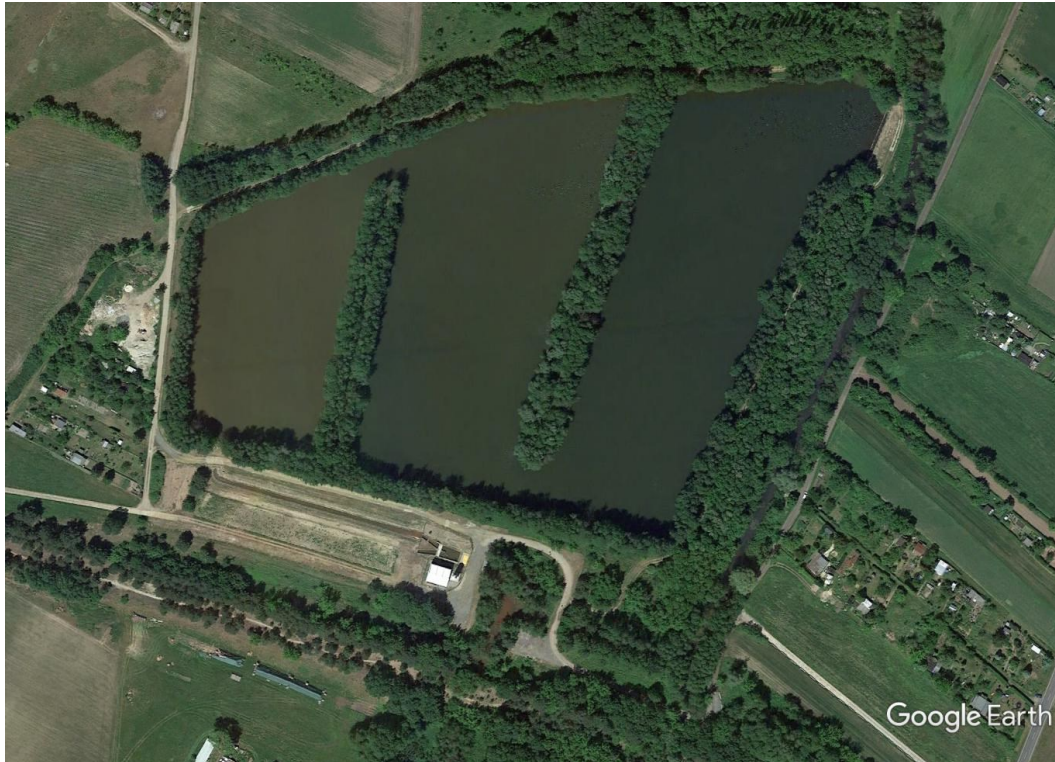


Fig. 22: The water treatment pond system Vetschau for the abatement of the iron contamination of Vetschauer Mühlenfließ



Fig. 23: Oxidation and sedimentation ponds of the water treatment system at Eichower Fließ



Fig. 24: Sediment trap at Lungwitzbach/Saxony (source: LTV Saxony)



Fig. 25: Sediment trap at a brook in Bavaria/Germany (source: Bavarian Ministry of Nutrition, Agriculture and Forests)

6.2 Potential measures at Hkaung Tung Hka Chaung

The great challenge at Hkaung Tung Hka Chaung is the enormous dimension of the sediment input into the stream. This makes measures at the source of the sediment input indispensable. Unless artisanal gold mining can be stopped, adequately dimensioned sedimentation basins would have to be constructed to ensure a water residence time of at least eight to ten hours to effectively retain the coarser particles. This would require settling ponds with a volume of up to 234,000 m³ to ensure the required retention at a maximum discharge of 6.5 m³/s during the rainy season. With a depth of 2 meters this would mean a necessary area of about 12 hectares. However, it can be assumed that significantly higher flows of up to about 40 m³/s can occur, which were not recorded during the monitoring, but which were reported by locals (Kreber, pers. comm.).

Additionally, the retention of fine particles is ecologically highly important, since the negative effects on plants and animals mainly emanate from the fine particles of the clay fraction. Also the transport of heavy metals is coupled to fine particles. Considering the results of the sedimentation experiment, the retention of the suspended fine particles in the water seems to be possible only with a significantly longer water residence time in settling ponds of several weeks. Assuming a two weeks water residence time, ponds with a size of 400 ha would be necessary. Ponds of this size would not be procedurally manageable.

In addition, a frequent dredging of the basins would be necessary to counteract the continuous reduction of the residence time by the loss of storage volume. The extracted material would have to be dried and dumped, taking care that it cannot be flushed back into the streambed during heavy rainfall. Also the increased heavy metal concentrations must be taken into account when choosing appropriate landfill areas in order to prevent further environmental damage.

Above all, measures are necessary directly at the source of the turbidity. These include, in the first place, the cessation or at least the control of artisanal small-scale gold mining with stringent environmental regulations, which must include obligations to build several successive sedimentation basins for water before discharged into the stream. In addition, there is an urgent need for immediate reforestation after clearance of the area used by gold mining to prevent soil erosion which is likely to be the most important source of the suspended solids in the stream in the rainy season.

In addition to immediate measures at the sources of the sediment load, or where retention measures cannot be implemented in these areas, the option of building sedimentation basins in the lower course of Hkaung Tung Hka Chaung can be considered, through which at times of lower discharge the water can be directed before entering Indawgyi Lake. For this purpose, the areas of the flood plain south of Mine

Naung, which are already severely disturbed by gold mining, could be taken into consideration (Fig. 26).

Also a series of small barrages could be built in the stream bed to reduce flow velocity and thus contributing to sediment retention. Again, a frequent dredging at short intervals will be necessary.

However, the reduction in suspended sediment load that can be achieved by these measures can only lead to a reduction of the sediment load in Hkaung Tung Hka Chaung of about 15 to 25 % since the main impact would remain during the rainy season if no measures will be undertaken at the source of the sediment input.



Fig. 26: Potential sites for sedimentation ponds at Hkaung Tung Hka Chaung south of the village of Mine Naung

7 Summary and recommendations

Indawgyi Lake is one of the largest lakes in East Asia. Due to its habitat diversity and its importance for international bird migration, it got the status of an UNESCO Biosphere Reserve. Efforts to protect the lake must address a range of adverse anthropogenic impacts on the lake. Increasing population in the catchment area, overfishing and intensification of agriculture and forestry contribute to the anthropogenic pressure on the lake just as the impacts from artisanal small-scale gold mining at the southern tributaries of the lake.

The main mining impact on Indawgyi Lake originates from Hkaung Tung Hka Chaung with its uncontrolled gold mining operations. The stream water shows extremely high turbidity due to the washing of floodplain sediments to extract the gold and the direct discharge into the stream. The artisanal gold mining is associated with a destruction of the floodplain and of forest areas, resulting in soil erosion which is most likely to become the most important source of suspended sediment load together with the remobilisation of sediments from the stream bed during times of high precipitation and high discharge.

The high input of suspended sediments from Hkaung Tung Hka Chaung has significantly shifted the southern shoreline of the lake within a few years and has led to mighty deposits of stream sediments in the southern lake basin as well as to a high turbidity of the water in front of the delta of Hkaung Tung Hka Chaung.

Based on a first short investigation programme as well as on a one-year monitoring, the extent of suspended matter transport from Hkaung Tung Hka Chaung into Indawgyi Lake was estimated and data on the heavy metal pollution of the suspended sediments could be gained to enable the proposal of measures to reduce the mining impacts on the lake.

As part of the initial investigations, both suspended matter from Hkaung Tung Hka Chaung and lake sediments along a transect from the stream delta to the north were sampled and analysed. Within the monitoring programme a weekly data collection of the water levels of Hkaung Tung Hka Chaung and Indawgyi Lake and a stream water sampling were established.

The results of these initial investigations revealed that the stream sediment can be optically and geochemically detected up to several kilometres into the lake from the delta of Hkaung Tung Hka Chaung.

A sedimentation experiment showed that even after 50 hours the river water has a high turbidity due to the finely suspended material. In contrast, material in sand grain size already completely settled after about 10 hours. The clay fraction of the suspended

sediment was associated with high contents of a range of heavy metals including cadmium, copper, nickel, chromium and lead.

As part of the monitoring programme from February 2017 to May 2018, the stream discharge was measured at weekly intervals on reference date samplings at the Mine Naung gauge of Hkaung Tung Hka Chaung to determine the suspended sediment load. During the four-month rainy season, a strong increase in the discharge occurred, while the discharge during the dry season was well below 1 m³/s, with a minimum of 0.04 m³/s.

No correlation between discharge and suspended sediment content could be found. The average dry sediment concentration of 9.6 g/L (dry weight of suspended solids per water volume) was very high. Based on the suspended sediment concentrations and the discharge, a suspended dry sediment load between 2.3 and 2,900 t/d was calculated for Hkaung Tung Hka Chaung at Mine Naung. The mean load was 359 t/d. By far the highest amount was transported by the stream during the rainy season at times of high discharge, which supports the thesis that, in addition to direct inputs from mining activities, high sediment inputs from soil erosion as well as remobilisation from stream sediments occurs.

The estimated annual input into Indawgyi Lake may total to about 133,000 t, which corresponds to a fresh material volume of 0.26 to 0.4 million m³. Thus, it would take between 3,600 and 5,400 years to fill up the lake basin with the suspended sediments from Hkaung Tung Hka Chaung.

The primary goal for reducing the suspended sediment load and the heavy metal pollution from the artisanal gold mining for the protection of the biosphere reserve must be to drastically reduce the suspended sediment introduction into the surface waters at the pollution source. This is the only way to sustainably improve the ecological state of Hkaung Tung Hka Chaung and of the southern area of Indawgyi Lake. The abatement of the sediment load of Hkaung Tung Hka Chaung can be achieved by two fundamental measures:

- A stop of the artisanal small-scale gold mining or at least a control by state authorities with strict environmental regulations is necessary. At each mine site the miners must be responsible to prevent suspended solids from entering the stream. This must be achieved by retaining particles in settling basins.
- Areas used by mining must immediately be recultivated (reforested) after use to stop erosion processes. This applies in particular to destroyed areas of the flood plain and the stream banks.

From the monitoring data it became obvious that an “end of pipe” cleaning of the whole stream in artificial settling ponds is almost impossible due to the dimension of the sediment load. Especially the retention of the ecologically important fine particles is not achievable.

If only measures for a limited protection of Indawgyi Lake from sediment input can be implemented, the construction of several sedimentation basins in the devastated floodplain south of Mine Naung may enable at least the retention of coarser particles at times of low discharge during most months of the year. The dimensioning should lead to a residence time of the water of about 8 to 10 hours. As a result, however, hardly more than 20 % of the suspended sediments can be retained. Regular dredging would be necessary at short intervals.

Overall, there is an urgent need to significantly reduce the suspended sediment transport from Hkaung Tung Hka Chaung into Indawgyi Lake to protect the ecosystems of the biosphere reserve.

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