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Soil erosion and lake eutrophication— The case of Chaohu Lake

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Abstract— Several hypothesis of nonpoint pollution mechanisms, with emphasis of soil erosion, are discussed. The multistepped landscape with multipond systems makes it difficult to apply existing soil erosion models based on universal soil loss equation (USLE) to simulate nonpoint pollution in Chaohu Lake catchment. The subrecent sediments in the lower reaches of some tributaries of the lake are suggested the most important and decisive natural nutrient pool to the eutrophication of the lake.

Keywords: soil erosion; nonpoint pollution; lake eutrophication.

INTRODUCTION

Lake eutrophication is one of the biggest environmental problems of our time and it is highly caused by an intensified input of nutrients, especially of phosphorous and nitrogen, into water bodies. The sources of these nutrients are widespread. It can be sewage produced by the industry and every single household, overfertilization in agriculture, the feces of animals, the decomposition products of plants and animals in general. Above all, eroded soil particles play an important role in the dramatic increase of the level of nutrients in rivers, lakes and - finally of the sea.

This has also been one of the principal problems of Chaohu Lake, Peoples Republic of China, which has been investigated with the help of UNESCO during the last years. This highly eutrophic lake is situated approximately 400 kilometers west of Shanghai and 50 kilometers west of the Yangtze River. It has a surface area of about 760 km^2 which makes it the fifth largest freshwater lake of China. The lake is very shallow, barely 2.6 m on the average . Millions of people get their drinking water from this lake, among them the one million residents of the capital of Anhui Province, the city of Hefei.

The catchment area of the lake (Fig. 1) is about 9250 km^2 and is formed in mostly metamorphic crystalline rocks, with some scattered volcanic rocks. However, this geological basis only appears in the hilly areas of the catchment, especially in a mountain chain in the southwest, reaching about 1500 m in height. Otherwise this basement is covered by a two to five meters thick layer of loess and loessial deposits The relief outside the mountain chain in the southwest consists of one or more slightly undulating peneplains, siddled by a dense network of small and some medium-sized valleys together with some rivers flowing in broad alluvial plains (Hangfu, Nanfei River and so on).

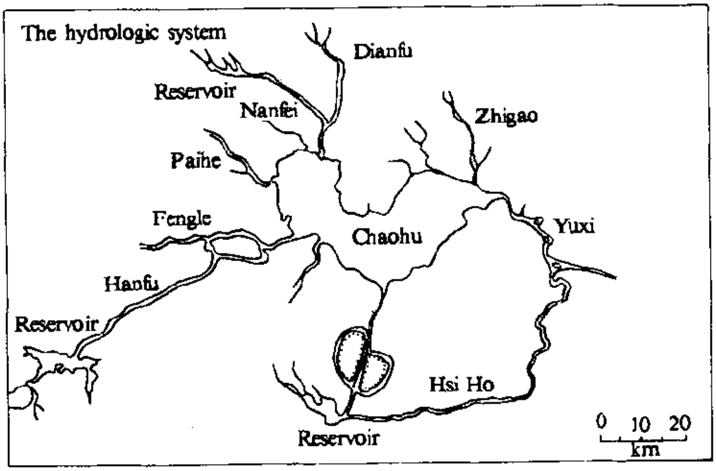

Fig. 1 The hydrologic system around Chaohu Lake

In this area a highly developed agricultural landscape has been set up except for the steep and wooded mountains in the Southwest. More than half of the area consists of irrigated rice terraces, which produce three crops during the agricultural year: carly and late rice, and additionally a winter crop like rapeseed or winter wheat. A large number of ponds, aligned along the valleys of the smaller rivers and rivulets, are used for the entire storage of the irrigation water for this unique multiple stepped multipond agrarian landscape. Every square meter of arable land that can be irrigated is incorporated in this system. The water for irrigation comes from rainfall, from damming of the smaller rivers (ponds), from irrigation canals, which get their water from two big reservoirs. Additional water is supplied from the Yangtze River via a canal.

Above the multipond multistepped rice terrace-system lies a second, more or less extended belt of non-irrigated farmland used for the production of different crops such as wheat, beans, or rape-seed. In a third belt we finally find the forests and meadows taking up the highest relief.

The cities and trade settlements are located along the rivers. The agricultural villages lie mostly on flat hills and on local divides, very often just at the boundary between irrigated and non-irrigated land.

Within the entire catchment of Chaohu Lake there is no sewage treatment plant and there are few simple treatment facilities for the industry. Among the latter eight fertilizer factories are especially remarkable. Additionally a very large number of small livestock like chicken, ducks and geese, buffalos, and pigs add much phosphorous and nitrogen to the water, and as one would suppose further effluents reaching the lake from the intensive fertilized fields. As a matter of fact, all the daily organic garbage and the feces of humans and animals are very carefully collected in a lot of pits and then spread onto the fields, especially during the transplantation of the seedlings of early rice in spring time.

Under these circumstances it seems inevitable that Chaohu Lake is highly contaminated, despite of its partial exchange of water with the Yangtze River, and in spite of its seemingly short residence time, which according to the information available ranges from somewhere in between 110 and 150 days.

According to the previous research data (Anhui Institute of Environmental Protection, 1986), the lake water has an average content of nutrients in the range of 0.127 g/m^3 for total phosphorous (TP) and 1.68 g/m^3 for total nitrogen (TN).

Combined with other conditions favoring eutrophication, such as the combination of a very large surface area with a very low depth, the high water temperature in summer and the intensive illumination on the lake, this leads to an immense biomass produciton, especially in the hot and humid summer months, with blue green algae (especially *Microcystis*) vastly dominant.

This situation raises a number of question: the methods that prevent this pollution, plug or reduce all these sources of nitrogen and phosphorous and revert this lake to a quasi natural (resp. mesotrophic) condition.

NONPOINT LOAD OF THE NUTRIENTS BY SOIL EROSION

Therefore considerable uncertainty remains just with respect to the most important factor: the ratio of the input of nutrients resulting from nonpoint to point sources. According to Wei *et al.* (Wei, this issue) almost two thirds of the input of nutrients should come from the agricultural side, namely 59.9% of TN and 63.2% of TP. But there are also other estimations, attributing to the nonpoint sources a range of only 50% of the total input of pollutants.

Hitherto there are no really concrete figures existing on the processes and there is also little hope of getting such data with the help of a soil erosion model. Such models seem useless here, because under the conditions of a multistepped, multipond rice terrace landscape we are dealing with, there are neither definable slopes, nor is there an unidirectional surface runoff depending on natural conditions, but both informaiton are necessary for each of the existing soil erosion models, such as the world wide used USLE (Universal Soil Loss Equation) by Wischmeier *et al.* (1958). All we find in the study area is a multistepped system of flat, closed basins, some of them a little bit deeper and filled with water-the ponds-and the rest very shallow and "filled" with partly water-covered rice plants at different stages of development. Nowhere water continuously flows through the system, everywhere it stagnates in these basins or is even being recycled in different ways, in different spans of time and in different quantities. This means that we have a highly developed water and sediment recycling system of rice fields and ponds. Similar conditions also prevail in most of the non-irrigated farmland. Because almost all the water and solid matter coming form these fields, which are situated above the rice terraces, have to pass through the rice-pond-terrace system. In this way it is getting incorporated in the recycling system.

Expect to emanate from such a system, these are very important questions which have been investigated with the help of a small (760 ha) subwatershed of Chaohu Lake during the last years. The Liuchahe-watershed, that has been selected, drains directly into the lake. It is largely a micro-version of the whole catchment of Chaohu Lake, and in its natural conditions as well as in its pattern of land use and the type and distribution of human settlements (Jin, this issue), it may be regarded as representative for the whole watershed of this lake.

Even if the data from this smalll catchment stem from only one year of observation (Jin, 1990) they are just as remarkable as symptomatic, because they show that there is almost no input to the main drainage channel (in this case the lake itself), and that in every respect: very little water, very little sediment and therefore also very few nutrients reach the lake, and this in spite of an additional supply of 117900 m^3 of water pumped from the lake into the catchment during that year. Indeed, during the rainy season of 1989, only about 0.55% of the total rainfall of this period, which was 676 mm, drained from the catchment via its main drainage channel, and this water had only 0.475 mg/L of TN and 0.053 mg/L of TP. This amounts are much less than that of the lake water.

On the other hand these figures can be easily explained, because in an agrarian system such as the multistepped, multipond rice terraces water and matter do not reach any main drainage line in the direct way, but only after manifold use and repeated recycling. In this way water and fertilizers are largely consumed within the system itself and are not injected into the rivers draining such systems.

To a certain degree this can be even applied to the additional input of water and substances coming from the non irrigated fields located above these terraces and also for additional water pumped into such systems of rice terraces.

Certainly, and for different reasons (soil type, higher slope inclination, lower soil cover, less time of cover during the year) soil erosion in the non-irrigated fields and in pasture land is much higher than in the rice fields, and surely part of the input of soil erosion particles and nutrients reaching the rivers and the lake come from these areas. But as most of the non-irrigated fields and pastures are situated above the rice terraces, they have to be drained through them, which means that water and matter coming from them normally get incorporated to the geoecological recycling system of the rice terraces. Only in those subwatersheds with an unbalanced ratio between non-irrigated higher land and irrigated rice terraces, the latter may not be able to "digest" this additional input of water and pollutants from the upper storey, which may then find passages to the main drainage lines below and give rise to heavy pollution there.

This is surely not enough however, to account for as much as 40 – 50% or even two third of the nutrients of the lake which are supposed to originate in the agricultural land.

Indeed, there is intensive soil-erosion in the area, which can be seen everywhere on the slopes, especially where the forest has been destroyed by the cutting of trees for wood, for agriculture and grazing. The effects of this erosion are also evident along the main drainage lines located in the foreland of these mountains. Wide river beds filled with gravel and sand, which in some cases have almost blocked the passages underneath the bridges, indicate heavy transport and sedimentation there. A big dammed reservoir, constructed about 30 years ago, is one of the reasons for the heavy sedimentation in this area. At the same time erosion on the mountain slopes was increased, because most of the inhabitants of the area of the reservoir which had to leave their land because most of their earlier villages by the new reservoir were given a new home in just that mountain chain. By clearing the forests and by their settlement activities they gave a huge impulse to the progress of erosion in these mountains.

All the eroded material from the mountains is disposed of in the reservoirs, from where it does not enter at all the middle and lower course of the Hangfu River. The same is true for another reservoir build at about the same time on the Nanfei River, the most polluted one of all the rivers draining into Chaohu Lake. Water from these reservoirs can in no way be held responsible for pollution of the lake, as all their water, instead of entering the lower reaches of both rivers, is used up for other purposes, partly for drinking water but mostly for irrigation. Huge and long channels taking the water and bring it to the rice terraces of the watershed. This means that even this water and the material transported with it gets incorporated into the recycling system of the rice terraces and is thus appropriately and ecologically used. Thus, even this potential source of nutrients can not be the one delivering huge quantities of pollutants to the lake.

There is another source which nobody had thought of before. Based on my research, this source appears to be the most important and decisive natural nutrient pool . These are the subrecent sediments in the lower reaches of some bigger rivers flowing into Chaohu Lakes, especially the sediments along the two rivers Nanfei and Hangfu, where the reservoirs were built about 30 years ago (Fig. 1). These young river sediments, which in Europe we would call "Auelehm" (alluvial loam), were accumulated along all the rivers draining into the Chaohu Lake in historical time, as can be derived from the fact, that the lake was formerly much larger than today. The construction of both big dams (completion forward the end of the 1950s) did not only cause erosion in the mountainous upper reaches of these rivers and accumulation just upstream of the reservoirs, but also triggered heavy erosion below the dams in the former middle and lower reaches of the Hangfu and Nanfei rivers. This type of erosion, following the construction of dams, is well-known to science, as it has happened in the same way in Europe before: after the construction of the dams the dynamic equilibrium of flow and transport was disturbed in both of these river-systems and had to be adjusted by accumulation upstream and by incision downstream of the dams. Both rivers, the Hangfu and the Nanfei, had to change their runoff-behavior in order to arrive at a new "steady state" - equilibrium. This new "steady state" may already have been reached, which is not known, but certainly the new longitudinal profiles of both rivers markedly differ from their predecessors from before the construction of the dams. Upstream of the dams the rivers have broadened their beds significantly and have deposited huge quantities of gravelly and sandy sediment; downstream of the dams they have remarkably incised their beds. This can be seen everywhere along the rivers. Those parts flowing today at a level near or even above the surrounding land can be kept in their beds only by giant artificial dikes constructed upstream of the reservoirs. On thc other hand downstream of the dams, especially along the Hangfu River system, one can find deeply incised valley-bottoms, lying 6 to 8 meters and more below the old flows. This incision is also evident at almost all bridges, because their foundations have been washed out and most of them have to be renewed these days. Furthermore numerous slides on the banks of these rivers and also the specific shape of their low-water beds give proof of the ongoing process of incision. Maximum deepening is reached in the new "upper" courses of both rivers, i. e. in the upper third of the "new" rivers regenerating today below the dams with the water of their tributaries. Obviously even these tributaries have been affected by the young incision, because a deepening of the local base level of erosion by 6 to 8 m or even 10 meters has naturally caused a headward erosion impulse within the tributaries, especially in the Fengle-system. Erosion therefore is highest near the river mouths and gets weaker upstream.

In this way a large quantity of material has been removed from the relatively narrow strips of alluvial loam along the Hangfu (erosion width about 30 to 50 m) and Nanfei River (eroded strip roughly 20 to 30 m) and its tributaries during the last thirty years. As the eroded material was transported downstream, it was either prograding deposited as overbank sediment in the lowest reaches of these rivers, as a delta-sediment prograding into the lake, or as a bottom-sediment in the lake itself. A certain amount of this material was also transported through the lake to the connecting channel leading to the Yangtze and thus into that river. Based upon a rough estimate of the volume of this recently eroded material (length of the incised river reaches × transverse erosion profile) the total quantity of material which has been processed during the last thirty years in this way , should be approximately 30 to 50 million m^3. According to existing sources approximately 10 million m^3 of this matcrial have been deposited in the lake itself during this period . This quantity seems to be well sufficient to accumulate an immense pool of phosphorus in the lake , being an important source of its eutrophication .

This is due to the fact that these sediments are especially rich in nutrients because of their specific geomorphodynamic and anthropogenic history . Two important facts of this history have to be noted : first , that the materials under consideration is nothing else than older river bank sediment , eroded from the farmlands and deposited along the rivers in historical times (roughly) during the last few hundred centuries, and , secondly , that this sediment had been disposited there prior to its reerosion at a time of maximum population pressure alonge the rivers. This means that these materials are finer grained than the normal antochthonous soils (higher clay content) and that they are heavily charged with nutrients because of their age old function as toilets for man and livestock and as dumps for every type of refuse produced by these population. Furthermore , just on top of these river bank sediments people did their laundry and thereby soaked these sediments with every kind of detergent they used. These are the reasons why just these strictly absorbent (high clay content) historic river bank sediments were nearly saturated with nutrients, which afterwards with their reerosion were transported into the lake and deposited on its bottom and shores. Of course this mostly happened in the western half of Chaohu Lake. The present day distribution of clay on the lake bottom (Fig. 2) and the areal pattern of fertility of lake sediments (Fig. 3) clearly

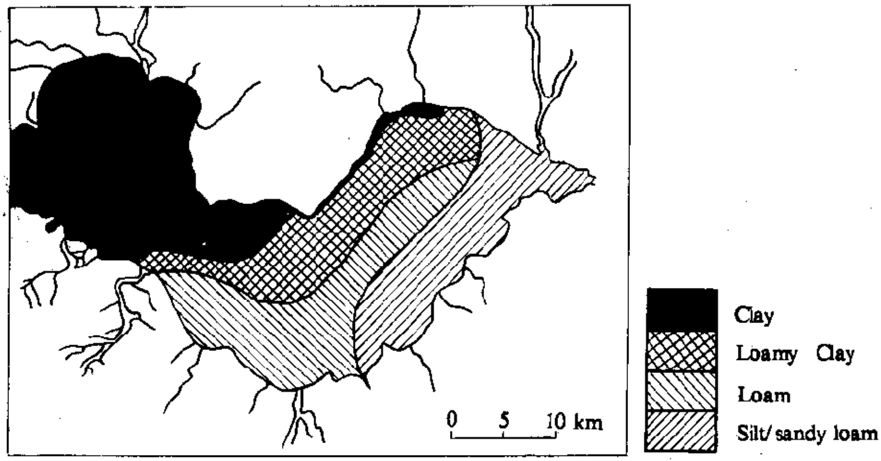

Fig. 2 Chaohu-granulometry of sediments, modified from Anhui Institute of Environmental Protection, 1986

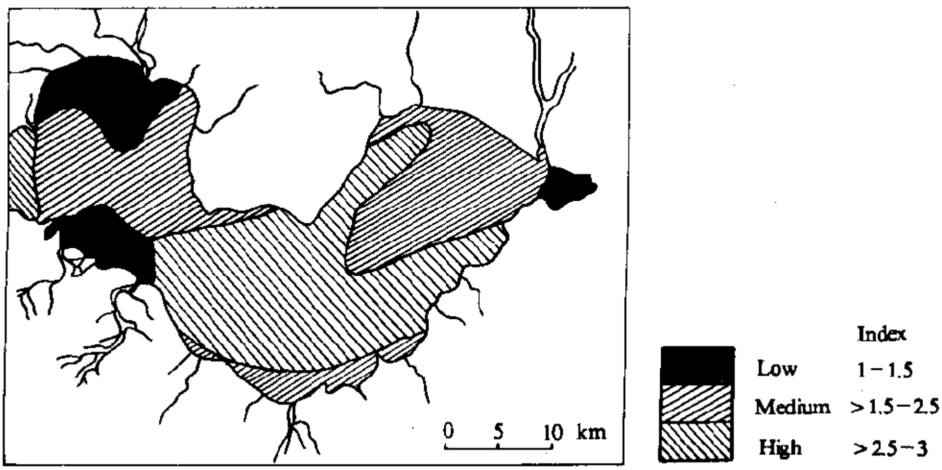

Fig. 3 Chaohu-fertility of sediments, modified from Anhui Institute of Environmental Protection, 1986

demonstrates the dominant role that is being played by the western half of the lake for its eutrophication.

It is very important that the nutrient depot in the lake resulting from the young, man-induced erosion phase is almost exclusively located in the western part of the lake. This has been another most important impulse for the intensive eutrophication and the massive algal growth just in this half of the lake.

CONCLUSIONS

The causes leading to the present ecological condition can be summed up as follows:

(1) Maximum input of nutrients from point sources, easily available to aquatic plants (especially NH_3-N and dissolved phosphorus), transported into the lake mainly by the Nanfei and Shiwuli rivers;

(2) A soil sediment at the lake bottom that is extremely saturated with phosphorous;

(3) An especially low lake depth in the western Chaohu Lake because of the higher deposition rate there of the sediments originating from man- induced erosion over the last thirty years;

(4) An especially high water temperature in the western part of Chaohu Lake due to the lower water depth there and the higher input of sewage;

(5) An especially strong mixing of the water in this western part of the lake, which has the longest possible fetch during the very persistent southeasterly monsoon during summer. Therefore, during this hot period of the year there is a particularly intensive mixing which reaches down to the shallow bottom and constantly whirls up new sediment particles into the water layers close to the surface, where, in spite of the high turbidity of the water in this part of the lake, there is still sufficient sunlight for an intensive assimilation of aquatic plants.

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