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A case study of shallow and eutrophic lakes in China

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Abstract — The majority of lakes in the eastern part of China are shallow and in various stages of decaying. Chaohu Lake is a typical example and was chosen as a case study in the Cooperative Ecological Research Project (CERP). Through various observations and sample analyses, the environmental impact of heavy nutrient load was assessed, and a multi-dimensional picture of the eutrophication state was obtained. Chaohu Lake is in hypertrophic state and has many typical symptoms: high concentrations of phosphorus and nitrogen, frequent algal bloom, dominance of bluegreen algae, high content of chlorophyll-a, low Secchi Disk depth and abnormal siltation of the lake. The lake pollution is still developing and in recent years has affected the city water supply and the regional economy.

Keywords: lake pollution; eutrophication; shallow lakes; China.

INTRODUCTION

Eutrophication represents the natural "aging" process of lakes. A lake receives inflows of water from its surrounding drainage basin and from the atmosphere. Over time, the lake will be filled with solid materials with nutrients and become shallow. Nutrient concentrations in both water and sediment layers will become high and more suitable for the growth of phytoplankton and other aquatic plants. The high productivity of the biological accelerates the "aging" process, causing the lake ecosystem to advance from oligotrophic to mesotrophic and eutrophic state, and becoming marsh and, ultimately, a terrestrial system. This process, under natural conditions, is usually irreversible and takes many thousands of years to complete.

The development of society and civilization has provided human with great power so that sometimes the landscapes of drainage basins changed resulting in the natural and biological cycles being disrupted. In the recent modernization process, rapid development of industries, expansion of towns, heavy application of chemical fertilizer and severe soil erosion has resulted in an imbalance of nutrient elements. Many receiving waters are forced to take nutrients and solid material in such a large quantity that their environmental quality shows great degradation. This process is often very rapid and it is refered as "cultural eutrophication" (Ryding, 1989).

Cultural eutrophication greatly reduces the resources value of water bodies for human use and has significant ecological impact. Thus since 1970, many countries have studied this problem and tried to develop a proper management strategy for its control (Vollenweidar, 1982).

EUTROPHICATION OF CHINESE LAKES

China is a country with a long history. The civilization of more than 4000 years has speeded the process of water eutrophication. The majority of lakes in the eastern part of China are now shallow lakes with average depth of less than 6 meters.

The shallowness could be explained by insubstantial glacial movement in the land of east China, but another important reason is the long term silting process caused by in the drainage basins.

Reduction of depth changes the morphology of lakes and it can be considered as the first stage in the process of eutrophication. Stable stratification usually does not exist in those areas where the depth is less than 10 meters for large lakes. Under such conditions, the wind can easily disturb the density stratification of the whole lake and mix it homogeneously. Without stratification, which acts as a barrier for nutrients and other chemical components to move up, the nutrient release from the sediments is much quicker. This changes many physical and chemical processes in lacustrine environments and is typical for Chinese lakes.

Also because of the shallowness, the wind can often stir up the sediment, causing the high turbidity. In many lakes, the reduction of Secchi Disk depth is not mainly caused by the biomass of phytoplankton but by the high content of suspended mineral particulates. Because there is usually extensive soil erosion in upstream catchment areas resulting in heavy loads of suspended solids, many lakes suffer greatly from the problems of siltation. This process reduces the lake depth and finally the surface area. Some lakes become swamps or seasonally fall dry. Famous lakes such as Nansi Lake (area 1270 km^2, Shandong Province) and Baiyangdian Lake (area 210 km^2, Hebei Province) have no water or little water in some dry years. Many lakes have disppeared permanently with the lake basins being turned into farm lands.

Natural lake ecosystems can no longer tolerate when human interference through increasing use of chemical fertilizers and the massive municipal and industrial wastewater discharges either directly into lakes or into upstream rivers. It was found that many lakes accepted large quantities of untreated wastewater and pollution caused by oxygen consuming organics was recognized as a major problem for aquatic environments. Researches show that the water quality of the major Chinese lakes has declined since 1970s and will continue to decline to the end of the century (Shu, 1987).

Up to 1970, most people in China did not consider eutrophication as a problem of the environment. On the contrary, they gave higher grades to eutrophic waters because such waters benefitted fishery production (Rao, 1958). Even now, many farmers by Chaohu Lake consider algal bloom as gift from the heaven, and when it has accumulated into a thick layer by the lake shore, the farmers alike to collect, ferment and use it as fertilizer for their rice fields.

After the Stockholm Declaration in 1972, environmental protection attracted attention in China. Environmental monitor stations were set up in the province capitals and some other cities and by major rivers in the 1970s.

Eutrophication developed rapidly in many lakes and reservoirs. Chinese scientists started to measure the parameters of lake eutrophication in some lakes in the early 80s. These lakes are mostly small urban lakes such as East Lake in Wuhan, West Lake in Hangzhou, Xuanwu Lake in Nanjing, Yuqiao Reservior in Tianjin and so on. Chaohu Lake in Anhui Province and Dianchi in Yunnan Province are the only two big lakes monitored. With very limited information, the eutrophication problem in Chinese lakes was unknown before 1986. Table 1 shows some environmental parameters related to eutrophicationof several Chinese lakes.

Table 1 The environmental parameters of some lakes (annual mean, 1984)

Name of lakes	COD, mg/L	Total N, mg N/L	Total P, mg P/L
Chaohu Lake	4.0	1.31	0.12
Dianchi	6.1	1.86	0.11
East Lake	4.25	1.27	0.16
West Lake	6.90	2.20	0.10
Xuanwu Lake	6.1	2.18	0.17
Yuqiao Reservoir	4.5	–	0.08

CERP C-3 — A CASE STUDY OF EUTROPHICATION AND ORGANIC POLLUTION IN A CHINESE LAKE

In 1986, a national eutrophication research program started and Chaohu Lake was chosen as a case study for more detailed research. Nanjing Institute of Geography and Limnology, Research Center for EcoEnvironmental Sciences, Chinese Academy of Sciences; Anhui Institute of Environmental Sciences and Hefei Environmental Monitor Station took part in this research project. Part of the research task was expanded into an international cooperative ecological research project (CERP C3) between Chinese and German scientists. The purpose of the joint project was to answer the following unsolved questions: The time and spatial distribution of algal bloom in Chaohu Lake; the effect of eutrophication and organic pollution on the water supply plant of Hefei; the mechanism of eutrophication; the pollution sources; the method of controlling the overgrowth of bluegreen algae ; the lake management which is very shallow and already eutrophic; the development proper methods for the research project .

This research has the following topics which compose a interrelated network to fulfill the general objectives (Fig. 1).

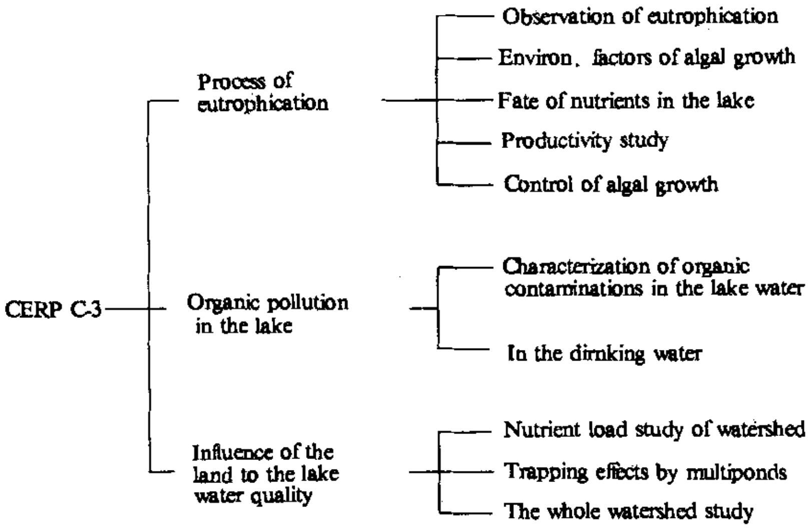

Fig. 1 The fremework of UNESCO CERP C-3 subproject

Chaohu Lake is located in central Anhui Province of East China away from the province capital city — Hefei. It lies at N 31 °, E117 °. It is one of the five largest freshwater lakes in China. It is on one of the tributaries of the Yangtze River (Fig. 2). The lake was originated by subsidence of the earth's crust (Table 2).

Chaohu Lake watershed is under the influence of a substropical monsoon climate which

Table 2 Characteristics of Chaohu Lake

Surface area	760 km^2
Surface elevation above sea level	8.3 m (average)
Average variation of water level	2.5 m
Volume at 8.3 m level	1960×10^6 m^3
Mean depth	2.6 m
Maximum depth	3.6 m
Catchment area	9200 km^2
Average water retention time	3.2 months
Mixing characteristic	no stratification in all seasons.

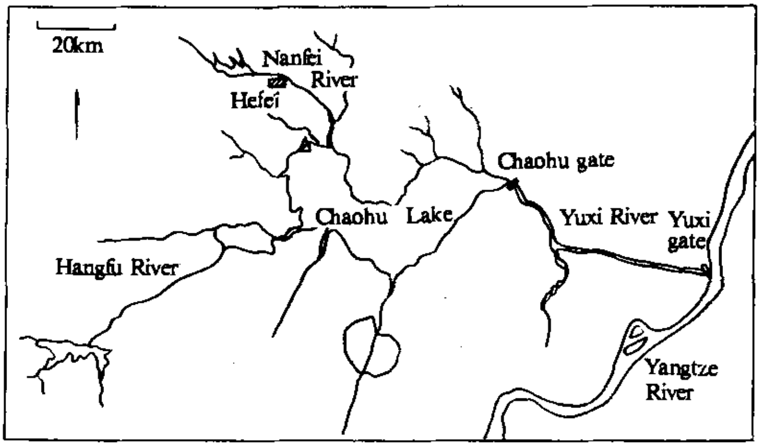

Fig. 2 The geographical location of Chaohu Lake basin

transits from subtropical to temperate zone with a mean annual temperature of 15 − 16 ℃ and the precipitation of 1100 mm. The whole watershed has low mountains in the southwest with an elevation of 400-500 meters, hills in the southeast of 200-300 m, hillock and mound in the west of 50 − 100 m and alluvial plain downstream of several meters.

There exist five soil groups in the watershed. Burozen is found at higher elevation in the mountain area. Yellow-brown earth in hills and mounds, paddy in the alluvial plain or between two mounds. Because of the soil erosion or the influence of soil parent material, two types of lithological soils appear in the watershed. According to the soil survey, the parent material of yellow-brown earth is one of loess. Its topsoil contains about 1% organic matter, 0.1% total N and 5 − 7 ppm bioavailable P. Paddy soil has total N 0.17% and bioavailable P 3 − 6 ppm.

Because of long history agriculture, the original natural vegetation has disappeared and there only exists some artificial and secondary forest. The forest land is about 17.6% of the whole watershed area. The coverage of vegetation is about 6.77%. Due to lack of the protection from vegetation, soil erosion and bare land can be seen on many mountains and hills.

About 62.1% of the watershed is used for agricultural land, mostly rice fields. Non-rice farm land is only 10.1% of the agricultural land. About 4000 km^2 of rice field depend on the irrigation network. There are 150 reservoirs and several canals in the whold watershed. Chaohu Lake Gate and Yuqi Water Gate were built 30 years ago. They control the water flow between the Yangtze River and Chaohu Lake.

Chaohu Lake is vitally important to the development of agriculture and industry in Anhui Province. Its functions are as follows:

(1) Water supply to province capital Hefei City and neighboring cities for domestic and industrial use. (2) Aquatic product: the fishery output is 5000 tons per year. (3) Shipping of goods through the province and through out China. (4) Irrigation and recreation are minor functions.

EUTROPHICATION STATE OF CHAOHU LAKE

1. Experimental

One field laboratory station was set by Zhongmiao Village at the lake peninsula. This laboratory was equipped with simple instruments and four to six research fellows worked there for about 100 days per year to observe the lake eutrophication phenomenon, to monitor environmental factors and to carrying out subcatchment investigations and water enclosure experiments. Pretreatment and simple analysis of samples was accomplished in the field laboratory station. More detailed studies were carried out at the Hefei Environmental Monitor Station and The Research Center for Eco-Environmental Sciences (RCEES). CERP C-3 project shares some data with the Chaohu Lake project of the national eutrophication program in which the RCEES cooperates with Nanjing Institute of Geography and Limnology, Anhui Institute of Environmental Sciences and Hefei Environmental Monitor Station. Some analyses were finished at laboratories of Germany with the aids of German scientists and technicians.

The experimental subwatershed is located at the north side of Chaohu Lake and has a name Liuchahe watershed where our field laboratory is located. Water samples were collected once a month in the major tributaries, output river and one sampling point near the field laboratory and once every three months in the other sampling points in the lake. Water sample was collected by a device similar to the Kemmerer water sampler at the depth of 0.3–0.5 m below the water surface. Water temperature, dissolved oxygen (DO), transparency and pH was measured in the field with a thermometer, DO meter, Secchi Disk and pH meter. Enclosure experiments were carried out in the lake around the major sampling point near the experimental station. In this sampling site, frequent sampling, which was once every four days or a week, took place during the season of algal bloom.

Samples were pretreated within two hours with filtration, abstraction, drying or digestion. The total nitrogen (TN) and total phosphorus (TP) were measured by digestion with a persulphate ($K_2S_2O_8$) solution (Ebina, 1983) and spectrometric analysis. All the parameters which are not mentioned specially in the text were analyzed with the standard methods (American Public Health Association, 1985).

Nutrient concentrations (TN and TP) were measured monthly for the tributary samples with additional measurements for the estimation of storm effects. The nutrient load is calculated with the concentration and the flow quantity of that month. Every three months, additional analyses were done for tributary samples to measure the nutrient composition into the lake. Since the water gauges do not measure the flow rate well for the tributaries into the lake, the flow quantities were calculated based on the gauge data in the upstream, the amount of precipitation and the catchment runoff coefficient.

Phytoplankton community was investigated for lake samples with a microscope. Chlorophyll-a content was the main measurement for the phytoplanktonic biomass in the lake water. Besides the extraction standard method, a visual observation was carried out daily along a ship line of 40 km across the lake for three years. In order to obtain a macroscopic view of the lake eutrophication and an average of chlorophyll-a content of the whole lake, TM images from the Landsat-V satellite in combination with the field data were analyzed. These observations could provide a multi-dimensional picture of eutrophication in Chaohu Lake.

RESULTS

Daily observation revealed a very frequent distribution of algal bloom in Chaohu Lake. In 1988, algal bloom was observed on 80% of the days from June 1 to November 30. Fig. 3

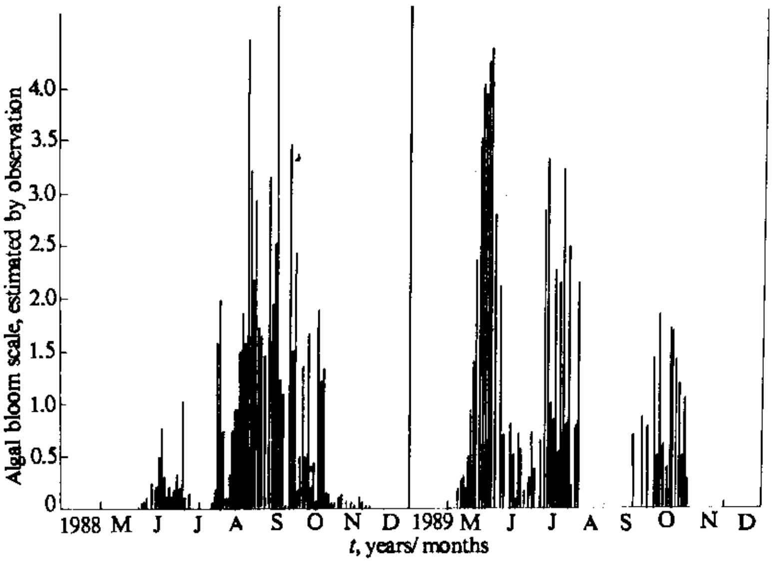

Fig. 3 Daily variation of algal bloom scale in the lake
(In about one month from mid August 1989 there was no observation because of the strong wind)

shows the relative scale of algal bloom in 1988 and 1989. The algal bloom scale is estimated according to the severeness using an arbitary scale of bloom saturation and each vertical bar represents the average of ten scales which is for two days on five parts on the lake. One can see there are two peaks of bloom appearance in the years of 1988 and 1989. The first peak showed in May or June. The second peak started in August and was high in September and October.

In our observation , blooms in autumn have always been more heavier than the spring bloom and the water plant suffers more seriously from the autumn bloom .

The bloom scale varies great from one day to another and varies from one place to another. The latter can be interpreted as the wind drifting on the lake surface. The TM image from the Landsat-V satellite on August 11, 1987 shows a vivid view of bloom distribution on the lake (Cheng, 1992).

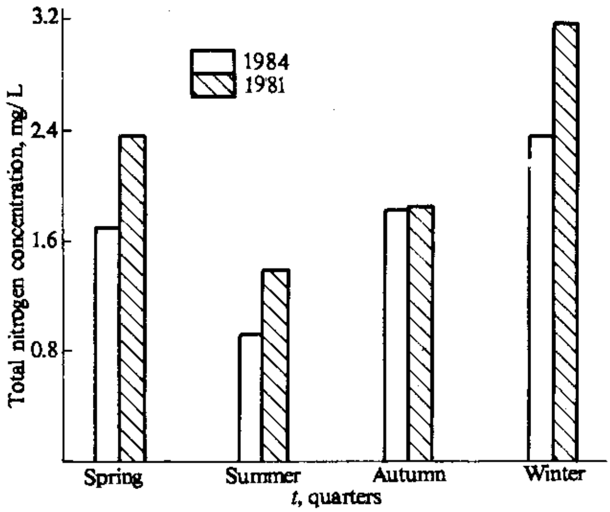

Fig. 4 The average total phosphorus concentrations in February, May, August and November samples of Chaohu Lake in 1984 and 1987

The heavy and frequent algal bloom could be interpreted as a consequence of a high concentration of nutrients in the lake water. Fig. 4 and Fig. 5 show the average phosphorous and nitrogen concentrations of more than 30 samples collected over the lake in 1987. In a comparison of the data in 1984 (Anhui Institute of Environmental Sciences, 1986), the total nitrogen concentrations of the lake water in 1987 was higher than that in 1984 for all seasons . For phosphorus, the summer and autumn concentration in 1987 were higher than these in 1984, but spring and winter concentrations in 1987 were a little less, although the annual average concentration of the four seasons was higher than 1984. This evidence suggests that the eutrophication in Chaohu Lake in still getting worse.

Unlike the nutrient concentration, chlorophyll-a content showed a very uneven distribution because of the accumulation caused by wind drifting (Fig. 6). In the over-lake monitoring periods, the August samples had the highest chlorophyll-a concentrations (Tu, 1990) . The northern sampling sites and the central eastern sites both showed heavier algal bloom. It was the consequence of wind drifting.

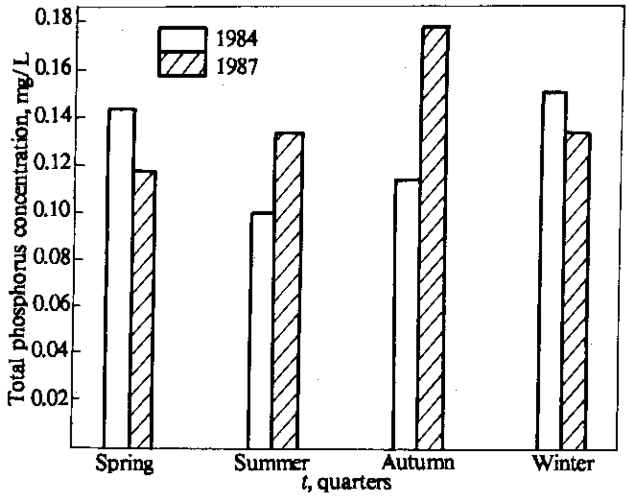

Fig. 5 The average total nitrogen concentrations in February, May, August and November samples of Chaohu Lake in 1984 and 1987

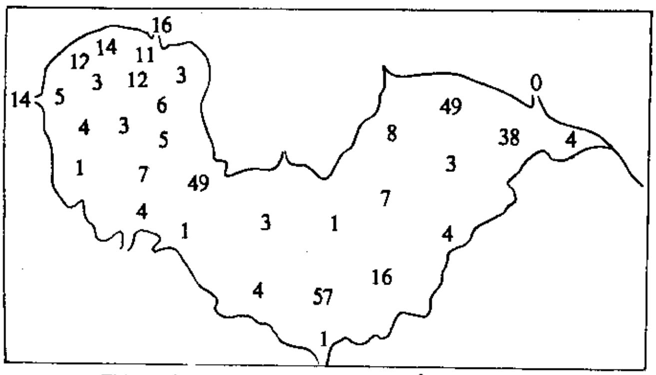

Fig. 6 The chlorophyll-a concentrations show a great variation in Chaohu Lake water in August, 1987

In most of the months, *Microcystis* was found the dominant species. In winter, there were more diatoms than other algae. In April, although the bluegreens were dominant, the *Anabaena* had more biomass compared with *Microcystis*. In summer and autumn when the lake showed the worst algal bloom, *Microcystis* was always found the dominant species and contributed more than 90% of total biomass. When there was an algal bloom and a mild wind, the bloom often shifted to form a thick layer in the lake. Sometimes the shifted layer would accumulate at the lakeside to form a layer ranging from several centimeter to more than one meter thick. The farmers in local villages, have a custom to collect the thick blooming algae and ferment it to make organic fertilizer. The fertilizer was mostly used on the rice fields and it helps to raise the yields and at meanwhile to recycle nutrients to the terrestrial ecosystem. The blooming algae often decomposed rapidly, releasing unpleasent odors into the atmosphere. Unfortunately, because of the increased labor cost and the widespread use of chemical fertilizers, the collection and utilization of algal fertilizer has decreased in recent years.

Evidence suggests that Chaohu Lake is in the eutrophic state. But it is still necessary to give some kind of assessment, so that its trophic state can be compared with other lakes in the world and its development be evaluated over the time period. Of the numerous assessment standards in the literature the OECD (the Organization for Economic Cooperation and Development) criteria is now still the most widely used for eutrophication assessment and Table 3 shows the specific boundary values of the most important parameters (Vollenweider, 1982).

Table 3 OECD boundary values for fixed trophic classification system (modified from Vollenweider and Kereke, 1982)

Trophic category	TP	Mean Chl	Maximum Chl	Mean Secchi	Minimum Secchi
Ultraoligotrophic	< 4.0	< 1.0	< 2.5	> 12.0	> 6.0
Oligotrophic	< 10.0	< 2.5	< 8.0	> 6.0	> 3.0
Mesotrophic	10 – 35	2.5 – 8	8 – 25	6 – 3	3 – 1.5
Eutrophic	35 – 100	8 – 25	25 – 75	3 – 1.5	1.5 – 0.7
Hypertrophic	> 100	> 25	> 75	< 1.5	< 0.7

In a comparison of Chaohu Lake data, all five parameters indicate that Chaohu Lake is in a hypotrophic condition (Table 4).

Table 4 Parameters measured in Chaohu Lake water near Zhongmiao. 1987, 1988

	Dissoloved oxygen, mg/L	Secohidise depth, m	pH	Total N mg/L	Total P mg/L	Dissolved N, mg/L	Dissolved P, mg/L	Chlorophyll-a mg/m³	Dominant algae species
Jan.	–	–	–	–	–	–	–	–	–
Feb.	10.1	–	7.2(1)	3.07(1)	0.158(1)	0.97(1)	0.039(1)	8.2(1)	–
Mar.	–	–	–	–	–	–	–	–	–
Apr.	–	–	–	–	–	–	–	–	*Anabanea, Microcystis*
May	9.3(5)	0.16(2)	7.0(3)	1.83(2)	0.130(2)	1.75(4)	0.048(1)	2.3(6)	*Microcystis, Anabanea*
June	8.0(7)	0.22(7)	7.9(7)	–	–	–	0.051(4)	24.3(6)	*Microcystis,*
July	7.5(1)	0.18(1)	8.5(1)	–	–	–	0.047(1)	662.6(1)	*Microcystis;*
Aug.	7.0(1)	0.18(2)	8.1(4)	2.00(1)	0.135(1)	0.73(1)	0.018(1)	27.4(2)	*Microcystis*

Table 4 (Continued)

	Dissoloved oxygen, mg/L	Secohidise depth, m	pH	Total N mg/L	Total P mg/L	Dissolved N, mg/L	Dissolved P, mg/L	Chlorophyll-a mg/m³	Dominant algae species
Sept.	7.5(8)	0.24(11)	8.0(17)	0.88(3)	0.112(4)	0.63(3)	0.025(2)	14.1(15)	*Microcystis*
Oct.	9.6(2)	0.4(4)	8.6(5)	1.64(1)	0.075(3)	0.36(1)	0.032(1)	6.2(5)	*Microcystis*
Nov.	10.1(1)	–	7.5(1)	1.64(1)	0.176(1)	1.11(1)	0.076(1)	0.6(1)	*Microcystis*
Dec.	–	–	–	–	–	–	–	–	
Average	8.3	0.25	8.0	1.63	0.117	1.10	0.043	30.5	
Max.	12.0	0.58	9.7	3.07	0.176	2.65	0.076	662.6	
Min.	6.1	0.14	6.0	0.57	0.049	0.36	0.018	0.5	

DISCUSSION

Chaohu Lake is an eutrophic lake with dominance biomass of buoyant bluegreen algae *Microsystis* and *Anabaena*. The very uneven distribution of bloom over daily time and space because of wind drifting and other meteorological factors makes it difficult to get presentative samples and interpret the results on sole chemical analysis. Eutrophication assessment is much improved with the combination of chemical analysis and observation, which is carried out by visual view and TM satellite image. Thus a multi-dimensional picture over time, space, scale and absolute value on the lake eutrophication is obtained.

Because of the limit of fund, the frequency of chemical analysis over the whole lake was still too low. Much more samples were taken and analyzed at the point near the Zhongmiao experimental station and this does help to understand the system.

In order to compare Chaohu Lake with other lakes in the world and to compare the present state with the past and the future, the OECD boundary criteria and phosphorus loading model are employed for assessment. But it has to be mentioned that the OECD model is based on the data of 140 water bodies most in Europe and North America, which are mostly deep lakes with stable stratification in the summer and winter and trophic states are on a phosphorus limiting conditions. Chaohu Lake is not in such conditions. Another alternative is to put Chaohu Lake data in the model derived in OECD SLR (Shallow Lakes and Reservoirs) version (Clasen, 1980). Still there is the problem because the diagram is mostly developed for the cases of reservoirs which are deep and is the condition of phosphorus limiting and there are not statistically enough data for shallow lakes. Chaohu Lake water contains a large quantity of silt and the solar light can only penetrate a thin layer. This helps to reduce its primary productivity. This will be further discussed in another paper of this issue (Yin, 1992).

CONCLUSIONS

This research project is a case study for Chinese lakes which are mostly shallow and eutrophic. Chaohu Lake is typically such a lake: it is shallow, the nutrient concentrations in lake water are high, the appearance of algal bloom is frequent, the scale of bloom varies greatly in time and space, the dominant in the algal community is *Microsystis* and *Anabaena* for most seasons, the lake water has high content of chlorophyll-a, the water has very low Secchi Disk depth, the high turbidity is mainly caused by large amount of suspended mineral particles. The lake is in a hypotrophic state.

Chaohu Lake is a lake with several important functions. Its deteriorated eutrophication state has greatly impaired the economic value as well as the ecological balance. This has threatened the regional economy and people's lives. Thus, this problem has to be solved as soon as possible.

The objective of the project is to understand in more detail, the mechanism of its eutrophication, estimate nutrient flux in the ecosystem, develop related research methods, identify and assess organic contaminants, find out nutrients sources and raise suggestion proposals based on our research results. The research results for the above objectives are summarized in the following articles in this composite report, which reflects the common effort of the cooperation of Chinese and German scientists.

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