ISSN 1070-3632, Russian Journal of General Chemistry, 2012, Vol. 82, No. 13, pp. 2210–2215. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © G.T. Frumin, Zhan-Zhan Khuan, 2012, published in Ekologicheskaya Khimiya, 2012, Vol. 21, No. 2, pp. 74–80.

Dynamics of Nutrient Concentrations in Lake Taihu

G. T. Frumin and Zhan-Zhan Khuan

Russian State Hydrometeorological University, Malookhtinskii pr. 98, St. Petersburg, 195196 Russia
e-mail: gfrumin@mail.ru

Received May 11, 2012

Abstract—Variation of the concentrations of chlorophyll *a* and nutrients (total nitrogen, total phosphorus, inorganic phosphorus, and silicon) in Lake Taihu from 1985 to 2011 was analyzed. Considerable trends to increase were revealed for the total nitrogen and silicon concentrations and insignificant trends to increase of total and mineral phosphorus, as well as of chlorophyll *a*, concentrations were revealed. Phosphorus was found to limit primary production in the lake. Probability assessment of the trophic status of the lake over the examined period was performed.

DOI: 10.1134/S1070363212130063

Lake Taihu is a large lake in the Yangtze delta, at the boundary between Jiangsu and Zhejiang provinces (China). Its geographical coordinates are 31°10′00″ N and 120°09′00″ E (Fig. 1). Lake Taihu is linked to the renowned Grand Canal and is the origin of a number of rivers, including Suzhou Creek. The lake is renowned for its unique limestone formations. These Chinese rocks are often used by Chinese artisans as a decorating material for the traditional Chinese gardens in that region. Lake Taihu houses about 90 islands, some of which are quite tiny (a few meters in length), while some other extend over several kilometers. Lake Taihu ranks third among Chinese fresh-water lakes after Poang Lake (volume 25.2 km^3, average depth 8.4 m) and Lake Dongting (volume 17.8 km^3, average depth 6.7 m) (Table 1). The lake is also known for its productive fishing industry (~13 696 ton per annum), navigation, and tourism [1].

The water temperature in the lake changes over a wide range from the minimal value 2.5°C in January to the maximal value 30.2°C in August. The population density at the drainage area is about 877 per km^2, which corresponds to a population of 30 million people.

The lake basin is located near the Yangtze delta, in the area occupied by the industrially developed maritime Jiangsu and Zhejiang provinces. Yixing, Suzhou, Wuxi, Jiaxing, and Huzhou cities constitute the main industrial and agricultural zones surrounding Lake Taihu. Industrial waste waters entering the lake contain chemical substances from textile, pharmaceutical, metallurgy, food, and pulp-and-paper industries. In addition, nitrogen and phosphorus compounds are supplied from domestic sewage and agricultural wastewater. Therefore, the lake water accumulates considerable amounts of pollutants and biogenic compounds. Thus the main ecological problems of Lake Taihu are its toxification and eutrophication [2, 3].

The goal of the present study was to analyze variation of the concentration of total nitrogen (TN), total phosphorus (TP), inorganic phosphorus (IP),

Table 1. Physical and geographical parameters of Lake Taihu

Parameter	Value	Parameter	Value
Area, km^2	2427.8	Maximal depth, m	2.6
Volume, km^3	4.3	Average depth, m	1.9
Length, km	~60	Residence time, year	0.79
Width, km	~ 45	Drainage area, km^2	34207.7

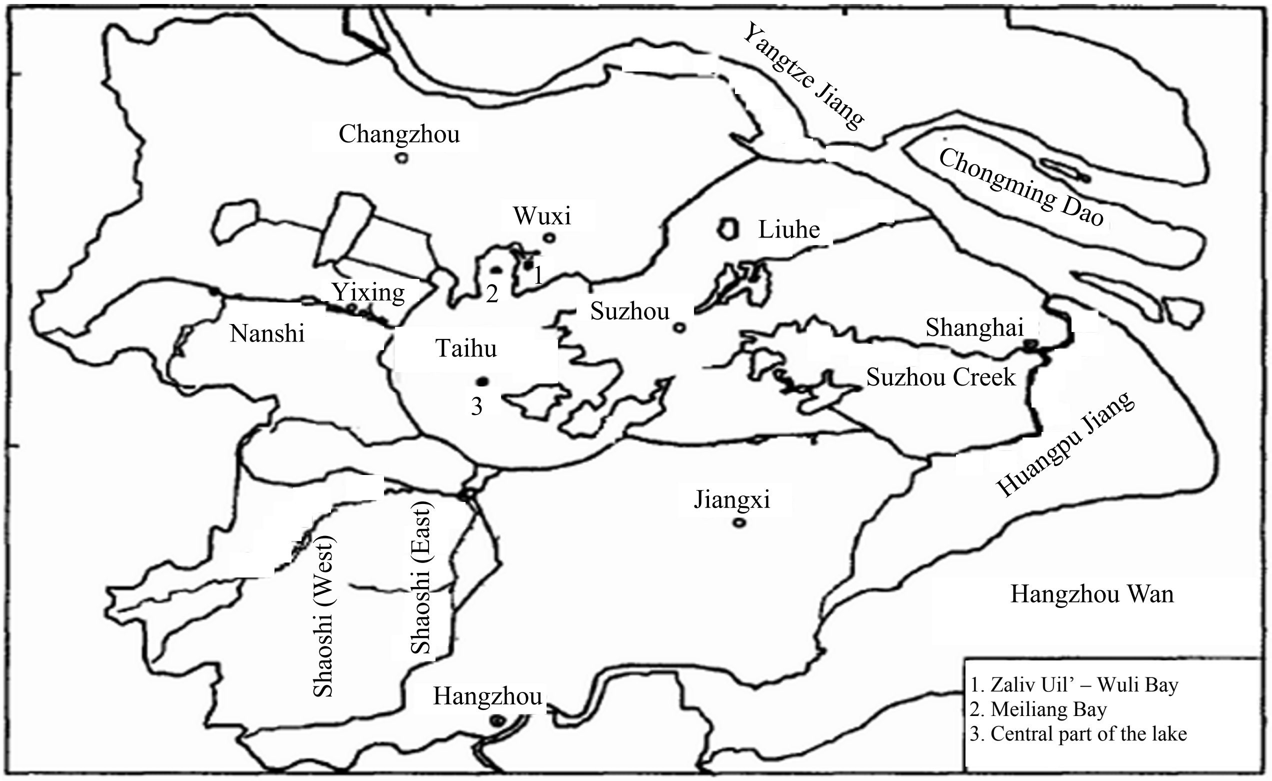

Fig. 1. Map of Lake Taihu and its basin.

silicon (Si), and chlorophyll *a* (Chl *a*) over a period since 1990 till 2011. The initial data were taken from different literature sources, mainly from the Hydrological Monitoring Center in Wuxi (Table 2). These data were statistically processed, and the results are presented in Figs. 2–6 and Table 3.

As follows from the determination coefficients R^2 (Figs. 3–6), the total nitrogen and silicon contents showed considerable trends to increase over a period from 1985 to 2011, while the concentrations of total and inorganic phosphorus tend to increase insignificantly. The concentration of chlorophyll *a* also increased over the examined period. According to [4, 5], the ratio of inorganic nitrogen (N_{in}) and phosphorus (P_{in}) may be used to estimate their limiting effect on the growth of algae. If $N_{in}:P_{in} < 10$, the primary production in the lake is limited by nitrogen. If $10 = N_{in}:P_{in} < 17$, nitrogen and phosphorus simultaneously determine biosynthesis, and phosphorus supply

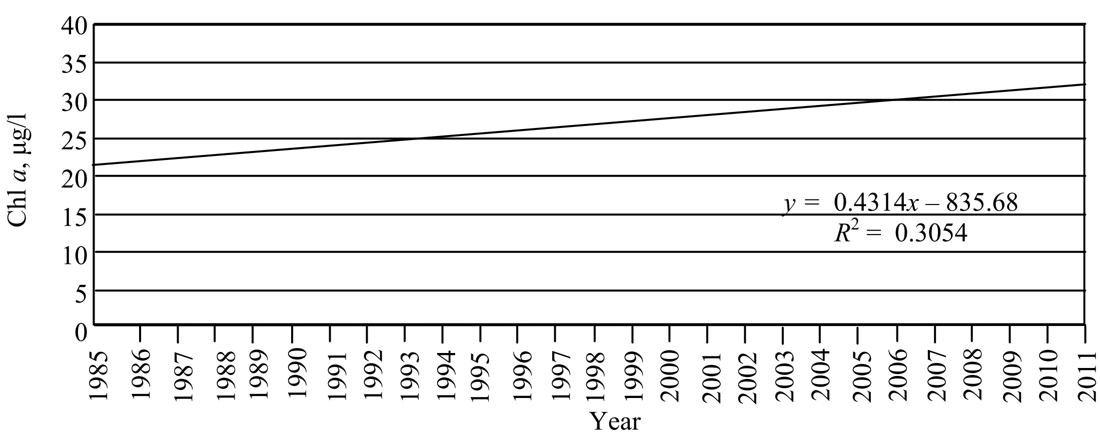

Fig. 2. Inter-year dynamics of chlorophyll *a* concentration in Lake Taihu.

Table 2. Inter-year dynamics of biogenic element concentrations in Lake Taihu

Year	Chl *a*, μg/l	TN, μg/l	TP, μg/l	Si, μg/l	IP, μg/l
1985	19.5	653	26	499	19
1986	19.0	898	31	354	24
1987	22.6	1574	29	627	22
1988	23.5	1106	44	514	29
1989	20.0	1340	47	554	33
1990	34.1	2419	62	617	45
1991	18.2	1406	70	561	74
1992	19.6	1658	71	444	54
1993	23.5	1963	117	372	78
1994	29.6	2257	62	573	41
1995	20.4	2438	82	452	61
1996	24.1	2796	92	589	68
1997	23.7	2953	107	961	80
1998	27.2	2387	101	952	143
1999	22.6	2193	86	1081	95
2000	35.6	2699	123	986	101
2001	31.7	2471	105	955	71
2002	24.8	2733	79	1097	59
2003	19.9	2947	73	1514	55
2004	29.9	3008	82	2065	62
2005	21.3	3964	79	1214	57
2006	37.7	4980	95	1521	72
2007	36.7	5229	150	1927	114
2008	36.0	3692	74	1568	56
2009	33.3	3312	57	1539	45
2010	28.7	2856	44	1181	32
2011	24.6	2204	50	967	33

becomes the main factor determining algae growth when $N_{in}:P_{in} \geq 17$.

Taking into account the above stated, sampling analysis of the $N_{in}:P_{in}$ ratio showed that phosphorus supply is responsible for the primary production in Lake Taihu. In all the examined cases, the ratio of the inorganic nitrogen and inorganic phosphorus contents exceeded 17 (Fig. 7).

The trophic status of Lake Taihu was estimated on the basis of the average chlorophyll *a* content over a period from 1985 to 2011 (26.2 μg/l). Chlorophyll *a* concentration was selected as reference parameter for the following reasons. Chlorophyll *a* is the main photosynthetic pigment, so that its concentration measured in a water sample reflects the amount of algae biomass. Chlorophyll *a* concentration is a useful and precise measure of eutrophication; therefore, it is

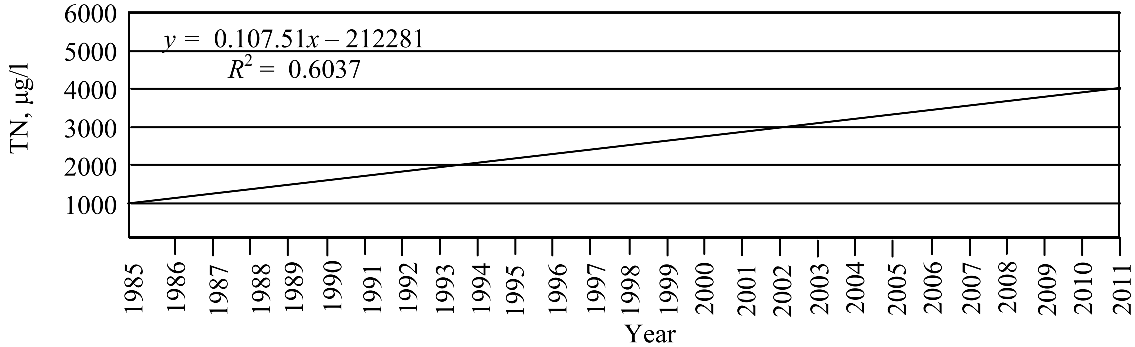

Fig. 3. Inter-year dynamics of total nitrogen concentration in Lake Taihu.

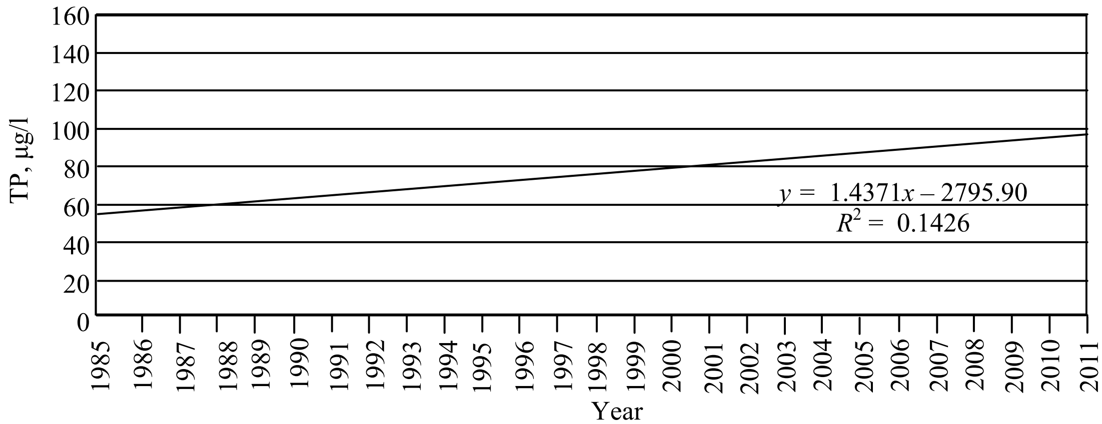

Fig. 4. Inter-year dynamics of total phosphorus concentration in Lake Taihu.

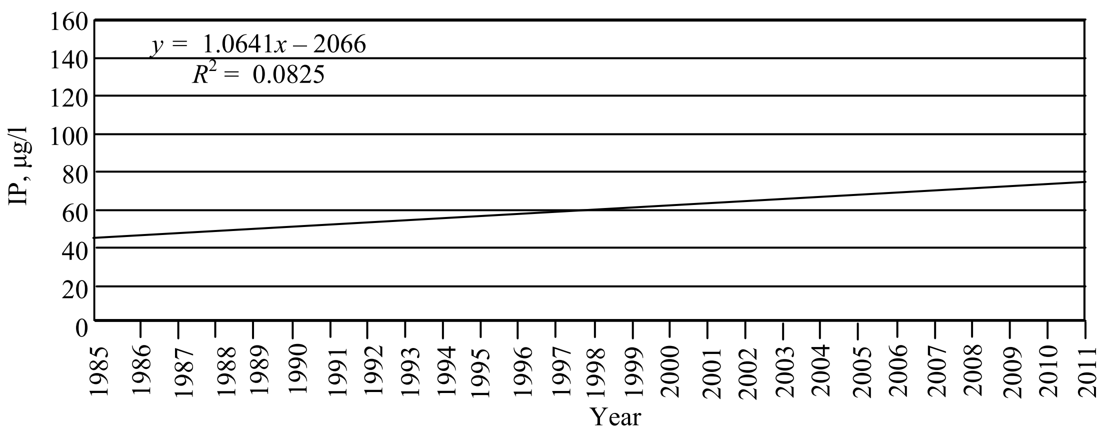

Fig. 5. Inter-year dynamics of inorganic phosphorus concentration in Lake Taihu.

widely used to describe the response of water reservoirs for biogenic load with a view of their recreation [6].

In this study, the trophic status of Lake Taihu was assessed in terms of the probability approach developed previously by OECD, which is based on the chlorophyll *a* content in bulk water. The trophic status was evaluated with respect to five probability levels, namely ultraoligotrophic (μ_{UO}), oligotrophic (μ_O), mesotrophic (μ_M), eutrophic (μ_E), and hypertrophic (μ_{HT}). The probability curves given in [6] were approximated by analytical expressions (Table 4). The results are presented in Table 5. These data indicate that Lake Taihu may be characterized as mesotrophic

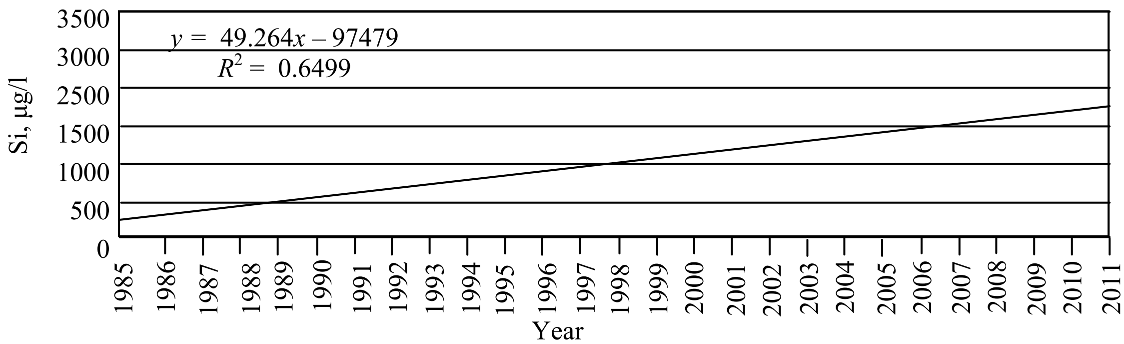

Fig. 6. Inter-year dynamics of silicon concentration in Lake Taihu.

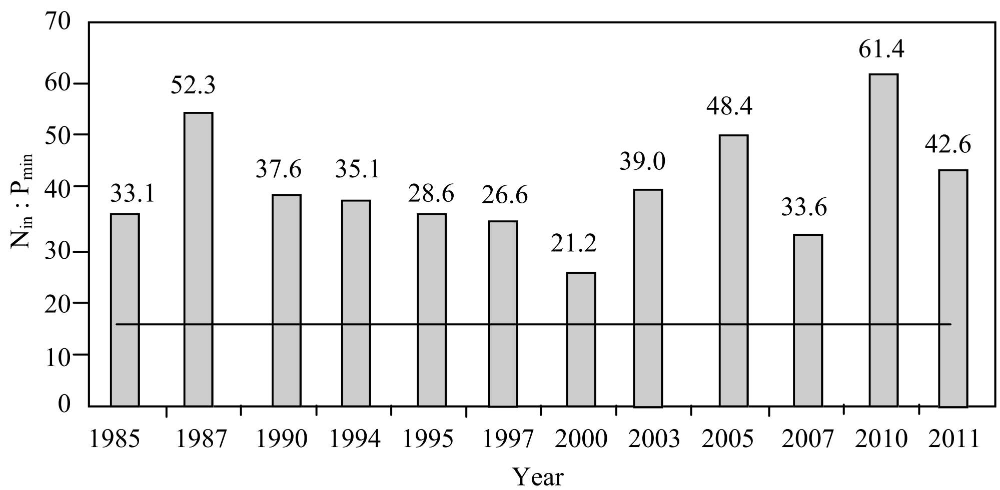

Fig. 7. Ratio of inorganic nitrogen and phosphorus in Lake Taihu.

by 4%, as eutrophic by 47%, and as hypertrophic by 49%.

De-eutrophication of Lake Taihu to reverse it to oligotrophic state requires considerable reduction of anthropogenic phosphorus load. According to [7], the phosphorus input should not exceed 89 tons per annum.

Strong increase in the blue–green algae biomass in Lake Taihu since April 2007 induced mass fish mortality and impaired drinking water quality. Local authorities tried to repair this situation, in particular, by closing near-shore enterprises and increasing the population of fish in the lake. Since 2009 near-shore Suzhou, Wuxi, Changzhou, and Huzhou cities jointly initiated Lake Taihu Fish Festival. More than 20 million hutchlings of various sorts were planned to put in Lake Taihu to reduce green–blue algae which have made it critically endangered. The authorities started to use fish with a view to clean up the lake. They placed and 10 million grass and silver carps in

Table 3. Average concentrations of chlorophyll *a* and nutrients in Lake Taihu over a period from 1985 to 2011

Parameter	Average concentration (confidence interval), μg/l
Chlorophyll *a* (Chl *a*)	26.2(23.7–28.7)
Total nitrogen (TN)	2524(2089–2959)
Total phosphorus (TP)	75(63–87)
Inorganic phosphorus (IP)	60(48–72)
Silicon (Si)	951(759–1143)

Table 4. Formulas for the calculation of trophic state probability

Trophic state	Analytical expression
Ultraoligotrophic	$\mu(x) = 1 - e^{-e^{\frac{[-x^{0.9} + (0.7)^{0.9}]}{(0.4)^{0.9}}}}$
Oligotrophic	$\mu(x) = 0.62 - e^{-\left(\frac{\ln x - \ln 1.5}{\ln 1.5 - \ln 43}\right)^2}$
Mesotrophic	$\mu(x) = 0.62 - e^{-\left(\frac{\ln x - \ln 4.7}{\ln 4.5 - \ln 15}\right)^2}$
Eutrophic	$\mu(x) = 0.62 - e^{-\left(\frac{\ln x - \ln 15}{\ln 15 - \ln 43}\right)^2}$
Hypertrophici	$\mu(x) = - e^{-e^{\frac{[-x^{0.5} + (21)^{0.5}]}{(2.4)^{0.5}}}}$

Table 5. Probability assessment of the trophic state of Lake Taihu by the average chlorophyll *a* concentration over a period from 1985 to 2011

Trophic state	Probability, %
Mesotrophic	4
Eutrophic	47
Hypertrophic	49

the lake after millions of local people have been stripped of drinking water. Lake Taihu Fishery Management Council declared the next step to house 20 million algae-eating fishes in the lake. The total cost of this campaign funded by the Government and social offerings amounts to 8.6 million yuan (1.3 million dollars). Silver carp during its life is capable of taking up to 50 kg of algae and other plankton, thus gaining only 1 kg in weight. Millions algae-eating fishes have already been used to clean up Lake Taihu and other lakes, which led to improvements in fishing industry despite some people's concern with eating fish that was fed with toxic products.

REFERENCES

1. *Lakes in China. Research of Their Environment*, Xiangcan, J., Ed., Beijing: China Ocean, 1995.
2. Khuan, Zh.-Zh. and Frumin, G.T., *Uch. Zap. Ross. Gos. Gidrometeorol. Univ*., 2011, no.19, p. 14.
3. Frumin, G.T. and Khuan, Zh.-Zh., *Uch. Zap. Ross. Gos. Gidrometeorol. Univ*., 2011, no. 21, p. 32.
4. Forsberg, C., *Z. Wasser- und Abwasser Forsch*., 1979, vol. 2, no. 2.
5. Dmitriev, V.V., *Diagnostika i modelirovanie vodnykh ekosistem* (Diagnostics and Modeling of Aqueous Ecosystems), St. Petersburg: Sankt-Peterb. Gos. Univ., 1995.
6. Henderson-Sellers, B. and Markland, H.R., *Decaying Lakes: The Origins and Control of Cultural Eutrophication*, Chichester: Wiley, 1987. Translated under the title *Umirayushchie ozera. Prichiny i kontrol' antropogennogo evtrofirovaniya*, Leningrad: Gidrometeoizdat, 1990.
7. Frumin, G.T. and Khuan, Zh.-Zh., *Russ. J. Gen. Chem*., 2011, vol. 81, no. 13, p. 2653 (*Ekol. Khim*., 2011, vol. 20, no. 1, p. 11).