Journal of Geographical Sciences 14, 4 (2004) 456–464 ISSN: 1009–637X www.geog.cn

The environment evolution of Wuliangsuhai wetland

YU Ruihong[1], *LI Changyou*[2], *LIU Tingxi*[2], *XU Youpeng*[1]
(1. Department of Urban and Resources Sciences, Nanjing University, Nanjing 210093, China;
2. College of Hydraulic and Civil Architecture Engineering, Inner Mongolia Agricultural University, Huhhot 010018, China)

Abstract: The environment evolution of Wuliangsuhai wetland since 1986 is analyzed based on the remote sensing principle. The total water area of Wuliangsuhai lake has been increased during the past 17 years. The open water area had an increasing trend before 1987, and the trend was decreasing up to 1996, then the trend has increased again since 2000; the variation of the water area with dense aquatic weed is basically contradictory to the variation of open water area. The natural reed area had been decreased before 1987, and then it has been increased. The areas of shallow water and swamp have been slightly increased, in fact, the variations are quite steady. The artificial reed area has been increased since the reed plantation was started in 1988. The relationships of the water environment, the climate, hydrology and different types of areas are discussed, and then the technological measures for sustainable development and utilization of Wuliangsuhai lake water environment are proposed.
Key words: Wuliangsuhai lake; wetland environment; remote sensing; evolution

1 Introduction

With the improvement of people's living standard and economic development, the demands for high quality water resources have been growing, meanwhile, water pollution has become increasingly. According to the survey, most of the rivers, lakes and reservoirs are threatened by the pollution and eutrophication. To solve the problems, and to control the deterioration of water environment of lakes of Dongting, Boyang, Qinghai, and to find the best reclamation measures, experts on lake and water environment have studied the relationships of the pollution and hydraulics of the lakes such as volumes, water quantity, water level etc. (Jin and Jiang, 2001; Bai and Lu, 1994; Liu, 2001; Zhu *et al.*, 2001). However, the pollution and eutrophication of the lakes are a dynamical change process, it is not only influenced by hydraulic characteristics and the carrying capacity of the lakes, but also controlled by economic development scale, hence, the relationships of the evolution of different types of areas of a lake to the hydroclimatic and water environmental factors have to be studied systematically so as to find out the main factors that cause pollution and eutrophication of a lake, and then to find out the theoretical bases and technological measures as well as the related engineering and non-engineering measures to solve lake eutrophication problems. The Inner Mongolia Autonomous Region is located in the arid and semi-arid areas of mesothermal zone. The lakes are mostly distributed in the hilly areas or desert areas due to the typical climate and topographical conditions, such as Juyan lake, Wuliangsuhai lake, Hasu lake, Daihai lake, Huangqihai lake, Chagan lake, Anguli lake, Dalinuo lake, Horqin wetland, Hulun lake natural reserve. The lakes receive irrigation return, groundwater, surface runoff, sewage and industrial wastewater, which cause constant accumulation of the organic matter and nutrition matter, i.e. cause water pollution and eutrophication, and some of the lakes have even lost their basic function (EMGS, 1999-2002). In this paper Wuliangsuhai lake is taken

Received: 2004-04-03 **Accepted:** 2004-07-20
Foundation: National Natural Science Foundation of China, No.50269001; No.50169002; Natural Science Foundation of Inner Mongolia, No.200208020512; The Key Scientific and Technologic Project of the 10th Five-Year Plan of Inner Mongolia, No.20010103
Author: Yu Ruihong (1978-), Ph.D., specialized in water environment analysis and water pollution control in the dry land area. E-mail: rhyul@hotmail.com

as the study area, and the remote sensing principle is used to interpret the variation of different types of areas of the lake in recent 17 years; the corresponding relationships of the main correlation factors and the dynamical evolution of different types of areas of grass type lake in the arid and semi-arid areas of mesothermal zone are studied.

2 Basic conditions of the study area

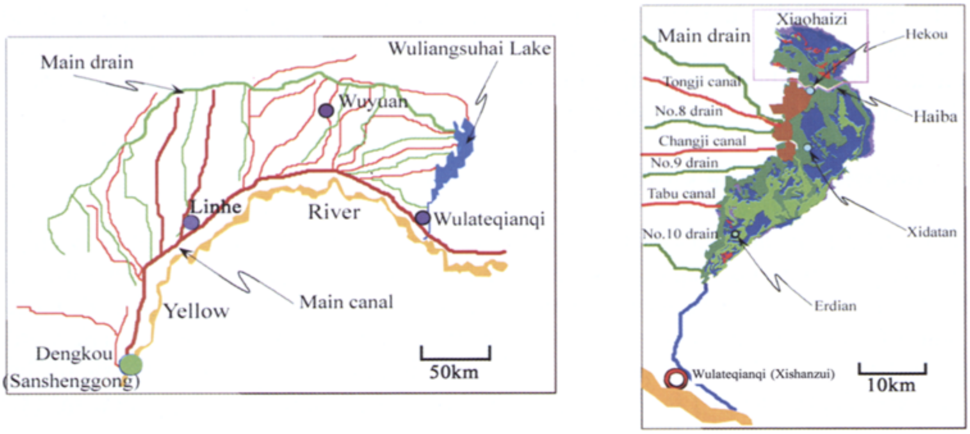
Wuliangsuhai lake is located in Urad Front Banner (Wulateqian Banner) of Linhe Municipality, Inner Mongolia Autonomous Region, and it is the largest lake of the Yellow River reach in Inner Mongolia (Figure 1). It lies between 40°36'-41°03'N and 108°43'-108°57'E. The distance from north to south is about 40 km, and the distance from east to west is about 8 km. The water level of the lake is 1018.5 m, and the depth of water ranges from 0.5 m to 3 m, and 80% of the water area has a water depth of 0.8-1.0 m. The water volume is about 250-300 million m^3 (Wang *et al.*, 1993).

The climate of Wuliangsuhai lake belongs to the typical continental temperate monsoon climatic zone. The average annual precipitation is 215 mm, 73% of which is concentrated from July to September; average annual evaporation of a 20-cm-long diameter pan is 2200 mm, and 50% of evaporation is from May to July; average annual temperature is 6.6°C, the highest temperature is in July and average annual temperature is 24.6°C, the lowest temperature is in January and average annual temperature is -10.2°C; the average monthly temperature from November to February next year is below 0°C, hence, the surface of the lake freezes with the frozen layer being about 80 cm.

The water area of Wuliangsuhai lake is 333.48 km^2 (2002), which is one of the ten largest fresh water lakes in China, and is also the large wetland biodiversity protection area listed in the Asian wetland convention organization. The main recharge of the lake is from irrigation return (Figure 1) and then sewage and industrial wastewater. There are the main drain, Tongji canal, No.8 drain, Changji canal, No.9 drain, Tabu canal and No.10 drain connecting with Wuliangsuhai lake from north to south. The average recharge volume to the lake from 1984 to 2002 is 561 million m^3. The evaporation and transpiration are the main discharge, and average annual evaporation and transpiration is 360 million m^3; the rest water of the lake is discharged through the discharge gate in the south of the lake to the Main drain, then to the Yellow River, and the average discharged volume is about 194 million m^3. The fertilizer applied in 1978 was about 70,000 ton, and the fertilizer applied in 2002 was about 520,000 ton, but the utilization rate of fertilizers was only about 30%. The lost fertilizer was discharged into the lake with irrigation return, which caused the total nutrition salts ranging from 560,000 ton to 1.1 million ton. The eutrophication and swamping are enhanced. Now, Wuliangsuhai lake has become a typical heavy eutrophication grass type lake. According to the measurement, the total production capacity of large type water weed is up to 3.6 million t/a, and water weed is spreading throughout the lake. The production quantity of water weed was only 23,000 ton in 1975, 66,000 ton in 1996, however, it was 120,000 ton in 2002. The accumulated depth of the deposit of remains of reed and water weeds has reached 360 mm since the 1950s, now ulcer water weed depositing rate ranges from 9 mm to 13 mm (Shang *et al.*, 2003), and Wuliangsuhai lake has become one of the lakes with the highest eutrophication and swamping rate in the world.

3 The selection and analysis of typical satellite images

According to the characteristics of the water body, Wuliangsuhai lake can be classified into open water area, reed area, dense water weed area, swamp area, shallow water area and artificial reed area. The time interval selected for the satellite images is August (sometimes September if the quality of satellite image is not good in August) when reed and water weed are growing well, i.e., the satellite images of Landsat TM and ETM in August between 1986 and 2002 were



a Map of Hetao irrigated area   b Magnification map of Wuliangsuhai

Figure 1 Geographical location of Wuliangsuhai lake

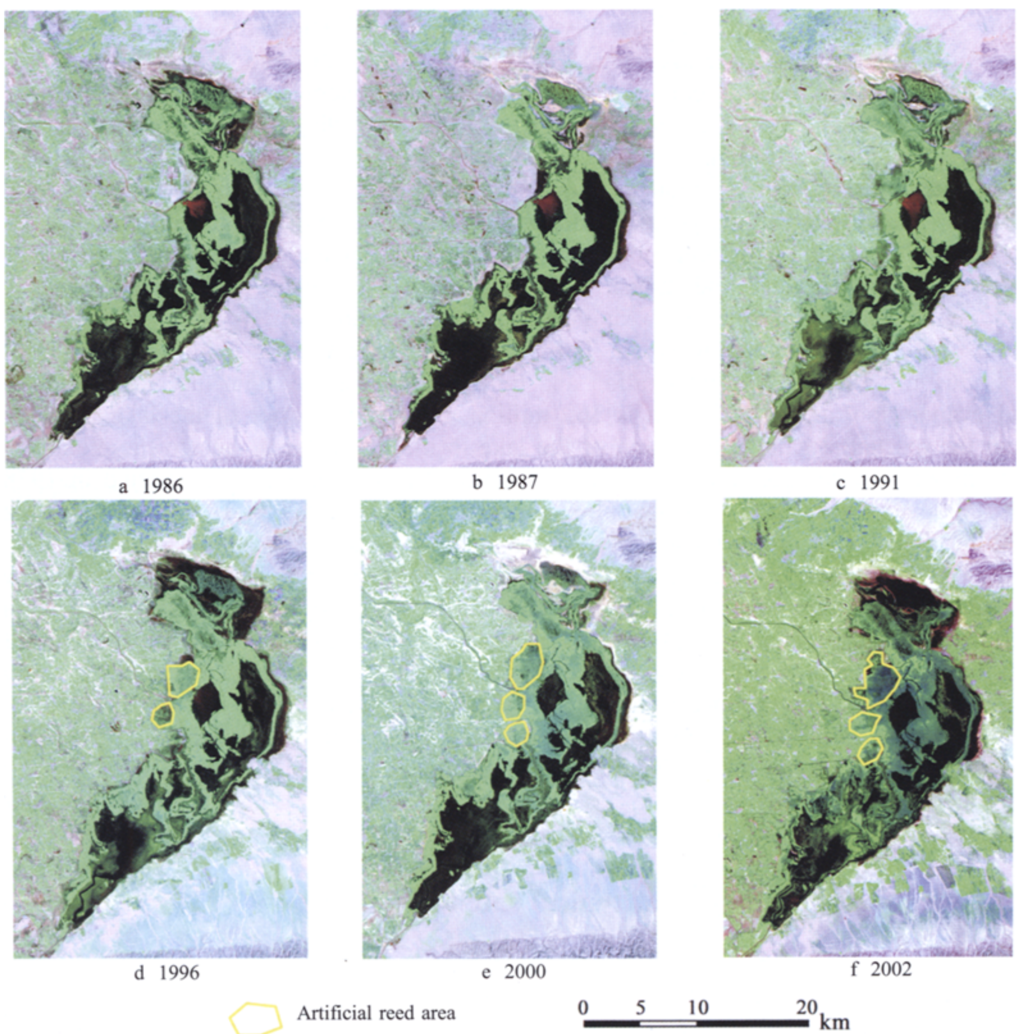


Figure 2 The composite satellite images of Landsat TM4, TM3 and TM2 of Wuliangsuhai lake in 6 typical years

selected for the analysis. The different types of areas of Wuliangsuhai lake in the 17 years are compared and the reasons to cause the variations are analyzed.

According to the survey in 2002 and the historical records before 1986 and the satellite images at the same time, the total water area of the lake was reduced in 1987 compared with that of 1986, especially Xiaohaizi in the northern part of the Wuliangsuhai lake was reduced significantly. Artificial reeds have been planted since 1988, however, the satellite images in August and September from 1988 to 1990 were shaded by cloud, so we have to select 1991 for the study. The total water area was steady from 1991 to 1995, but in the early 1996 water in the south of Haiba was diverted to the west field of Xiaohaizi in the north of Haiba, which caused natural reed growing, and the total water area seemed to increase. From 1996 to 2000 the total water area had been decreased, and it has been increased significantly since 2000, which is a turning point of 2000. On these grounds, 1986, 1987, 1991, 1996, 2000 and 2002 have been selected as the typical years for in-depth analyses. The composite images of TM4, TM3 and TM2 of the 6 typical years are shown in Figure 2.

Figure 2 shows that in 1986 Wuliangsuhai lake looks spacious with large open water area (continuous black), few water weed (light black colour mixed with green around margins of the balck area), luxuriant reed (bright green), especially, the area of Xiaohaizi is larger; the decreased area of Xiaohaizi leads to the decrease of the total area in 1987, and the open water area increases compared with that of 1986; the artificial area is seen clearly in 1991, and the dense water weed area is larger than in 1986 and 1987 in the south of Haiba; the open water area of Wuliangsuhai lake further reduces in 1996, dense water weed is seen not only in the south of Haiba, but also in the north of Haiba, and the artificial reed area further increases and the shallow water area in the north expands (the surrounding dark red area). The open water area increases significantly in 2000 compared with that of 1996, and the growth of water weed in north of the lake Xiaohaizi is retarded, the area of artificial reed area continues to increase, and the shallow water area reduces slightly. The open water area in the south of Haiba reduces till 2002 compared with that of 2000, water weeds seriously deposit in the lake bottom, and the area of shallow water and dense water weed present an increasing trend.

4 The abstraction and analysis of different types of areas in the 6 typical years

The composite satellite images of TM4, TM3 and TM2 in the 6 typical years are selected analyse Wuliangsuhai lake using ENVI software. The images of TM and ETM were all selected in August (or September), and the comparison of the satellite images with the field survey showed that the reed area of the lake is bright green on the composite images, dense water weed area is light black with green, the open water area is deep black, shallow water area is dark red, swamp area is pink white, hence, it is easy to abstract the areas of different types. The results of different types of areas in the 6 typical years are shown in Figure 3.

4.1 The varying characteristics of different types of areas

As the north of Haiba is maintained for its eco-environmental functional area by diverting water from the south of Haiba, this functional area is affected by the water quantity of the south of Haiba and human activities. The yearly variations are analyzed based on the abstracted results in Figure 3 of different types of areas of Wuliangsuhai lake, the south and north of the lake; the yearly variations of different types of areas in the above three regions are shown in Figure 4; the yearly variations in percentage of the above three regions of the lake are shown in Figure 5. The conclusions of Figures 4 and 5 are described below.

(1) The swamp area of the whole lake increases slightly. The swamp area in the south of Haiba increases in the 6 typical years with the drop of the water level, for instance, the water level of the lake in 1996 is higher than that of 2000, the swamp area in 2000 is larger than that of 1996. The variation in the north of Haiba is not clear. Besides, as the swamp area is mainly distributed in the north of Haiba, which causes the swamp area of the whole lake not to vary as

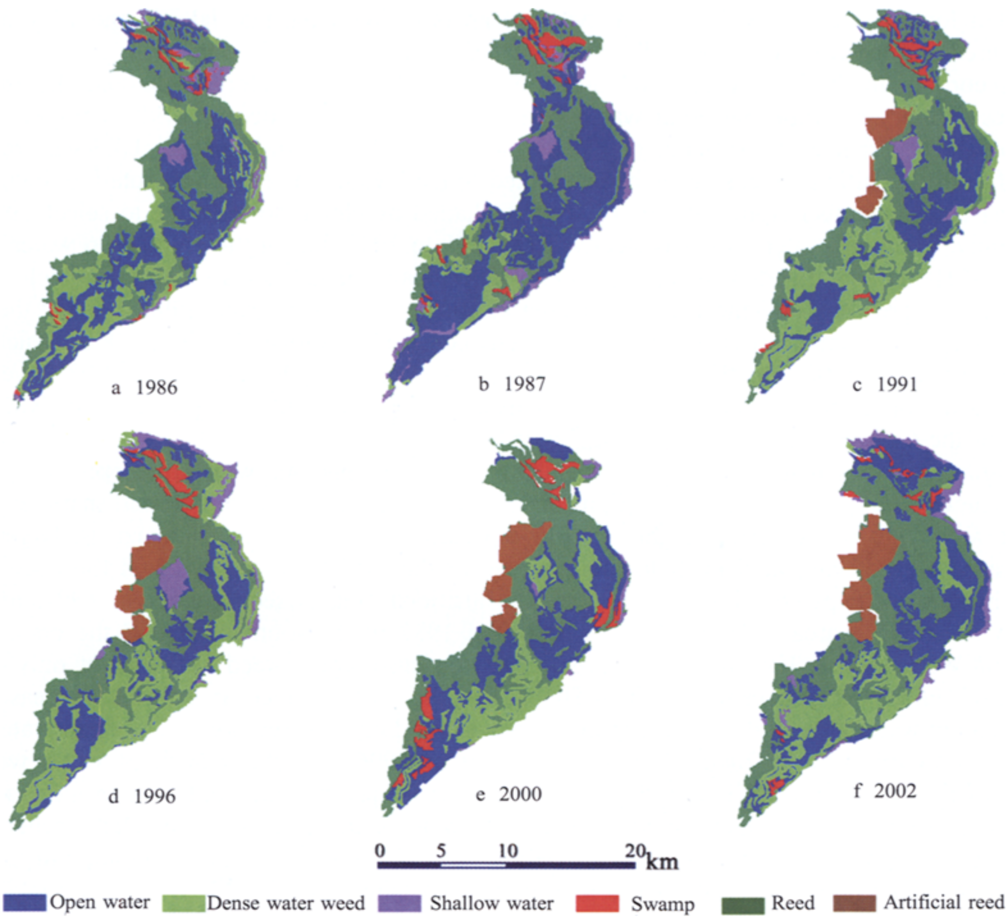


Figure 3 Different types of areas from satellite images of Wuliangsuhai lake in 6 typical years

the way mentioned above between the typical years (such as between 1996 and 2000).

(2) The shallow water area of the whole lake decreases slightly. The reed area expands 4 m to 6 m every year, and the shallow water area is gradually replaced by reed. For example, the increased shallow area of the northern Xiaohaizi in 1996 resulting from rise of the water level of the lake has been changed to reed bed in 2000.

(3) The natural reed area of the whole lake is predominant, and increases every year. The natural reed area in the south of Haiba in 1986 is 116.85 km^2, and it increases to 134.20 km^2 in 2002, hence, an annual increase of 1.02 km^2. The natural reed area in the north of Haiba decreases generally.

(4) The artificial reed area has been increasing since the reed plantation started in 1986. The artificial reed area reached 14.46 km^2 in 1991, although the increasing trend slowed down gently, the reed area had been increased to 28.12 km^2 in 2002.

(5) The dense water weed areas between the typical years vary with the water level of the lake in the southern Haiba, while the open water area varies just opposite to the water level of the lake. The open water area of the lake in 1987 is the largest, an increase of 42.38 km^2 compared with that of 1986, and the dense water reed area is the least. The open water area of the lake decreases significantly from 1987 to 1996, and decreases from 120.89 km^2 to 59.64 km^2, a deduction of 61.25 km^2, the increased rate is great during the period 1987-1991, and the dense water weed area increased rapidly; the open water area increases in 2002 compared with that of 1996 (Figure 4b). The general trend of the water level increases from 1986 to 2002, and the percentage of the water reed area increases, and percentage of open water area decreases, while

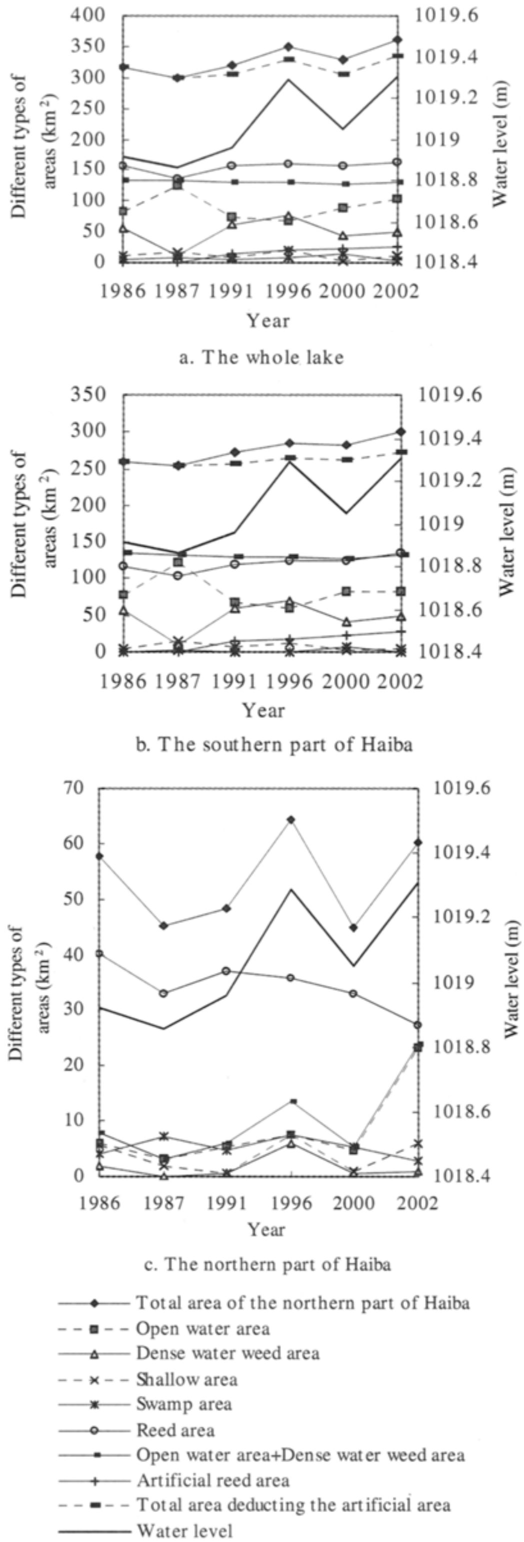


Figure 4 The yearly variations of different types of areas of Wuliangsuhai lake

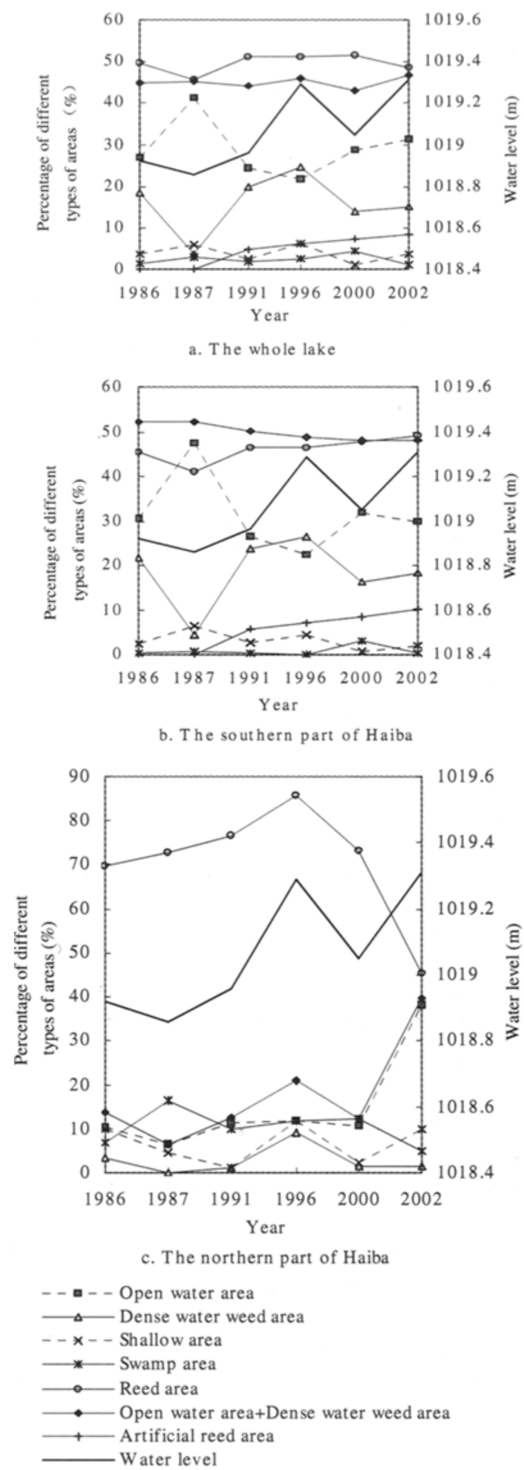


Figure 5 The yearly variations of the area percentage of different types of areas of Wuliangsuhai lake

the summation of the two was decreased (Figure 5b). Two problems are shown: 1) the residues of water weed are deposited at the bottom of the lake, and the bed of the bottom is elevated; and 2) a large quantity of the nutrition salts are drained and deposited into the lake, which enhances the growth of water weed and reed as well as the biological materials filling and the lake leveling. While in the northern part of Haiba, the open water area varies with that of water level, the variation of the dense water weed area is not clear with that of water level in the southern part of Haiba. For the whole lake, the variation characteristics of the open water area and the dense water weed area are similar to the variation of the southern part of Haiba. The constant increase of eutrophication degree of Wuliangsuhai lake will bound to cause gradual change of wetland environment, and loss of function of the water body.

4.2 The relationships of different types of areas with the climatic factors

In order to analyze the relationships of different types of areas with the climatic factors, Figure 6 shows the variations of water quantity discharged into the lake, water quantity discharged out of the lake, the net water quantity recharged to the lake, evaporation of the open water area, precipitation, net evaporation of open water area, the rainfall variation in the flood season before obtaining the satellite images. It can be seen clearly from the combination of Figure 6 with Figures 4b and 5b that: the variations of the net recharged water quantity of the lake and net evaporation of the open water area are basically the same, and are balanced more or less. The rainfall in the flood season before obtaining the satellite images varies similarly with that of the water level of the lake, this is because the flood and groundwater flowing into the lake (no observations, hence substituted with the rainfall in the flood season before obtaining the satellite images) account for the variations of the water level of the lake in summer and mutual transformation of different types of areas. The open water area of the lake increases with the increase of the recharged water into the lake, net evaporation of the open water area and the decrease of rainfall in the flood season, while the dense water weed area decreases basically with the net recharged quantity, the increase of net evaporation of open water area and the decrease of rainfall in the flood season. The summation of open water area and dense water weed varies with the quantity of the water recharging into the lake, the quantity of water discharging out of the lake, rainfall, evaporation of open water area, water level and water depth etc. The percentage of the summation of the two items to the total area decreases continuously (Figure 5b). Because of constant filling up of the lake, the depth of water decreases even with the same water level, hence the open water area decreases, and the area of dense water weed increases. As time goes by, the open water area will continue to decrease.

4.3 The relationships of different types of areas with the water environmental factors

Because of the block by Haiba, all the intakes of the drains to the lake are in the southern part of Haiba, there is no influence on the water area in the northern Haiba, hence, the water environment indexes of southern Haiba are of even more representative and can reflect the eutrophication degree of the whole lake. In view of this, the south water area of the lake is taken as the study area in order to reveal the relationships between different types of areas and the water environmental factors. Figure 7

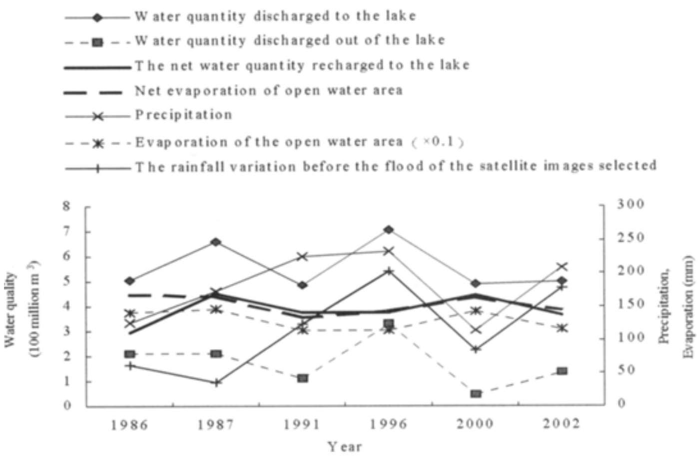


Figure 6 Yearly variations of the climatic factors in Wuliangsuhai lake

shows the yearly variations of the main water environmental factors (DO, BOD, transparent, total dissolved salts, total phosphate and total nitrate). The variation relationships of different types of areas with the water environmental factors combined with the results of Figure 4b from 1986 to 1996 to 2002 are shown in Table 1. The conclusions are: no matter from 1986 to 2002 or from 1996 to 2002, BOD, the total dissolved salts, total phosphate and total nitrate are increasing, while DO and transparent are decreasing, all of which show that the environment of Wuliangsuhai lake is deteriorating and the eutrophication of the lake is aggravating.

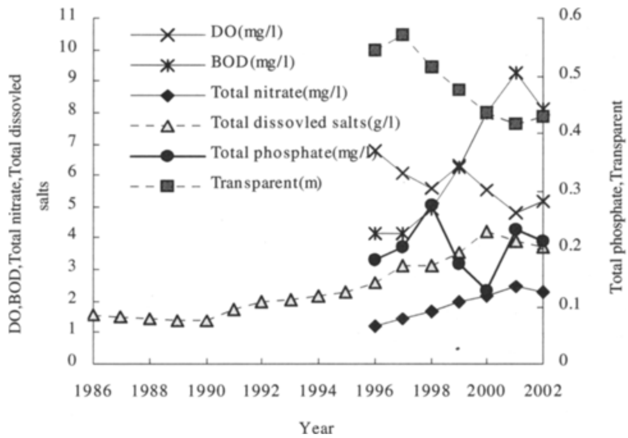


Figure 7 Yearly variations of the main water environmental factors in Wuliangsuhai lake

With the expansion of the whole lake area, the areas of reed, artificial reed, swamp and open water are increasing; the areas of dense water weed and shallow water are decreasing. Both the open water area and dense water weed area belong to the submerged water weed growing area, and the two changed from each other with rising and falling of the water level. The percentage of the summation of the open water area and dense water weed area decreases from 52.0% in 1986 to 48.3% in 2002 (Figure 5b), which shows that the open water area is transforming into water weed area, dense water weed area and shallow water area are changing into reed area, and some shallow water area and reed area are changing into swamp area with the aggravation of lake eutrophication in the case keeps water level unchanged. On the other hand, with the increase of biomass in water weed, reed area and swamp area, all kinds of nutrition salts in the lake are taken by water plants, which enhances the self-purification ability of the water body. Meanwhile the decaying of the stems, leaves and roots of the water plants accelerates the

Table 1 The relationships of different types of areas of Wuliangsuhai lake with its water environmental factors

Item	Different types of areas (km^2)						
	Open water area	Dense water weed area	Shallow water area	Swamp area	Natural reed area	Artificial reed area	Area in southern parts of Haiba
1986	78.505	55.817	6.014	0.935	116.847	0	258.118
1996	59.641	70.186	11.912	0.339	123.178	19.264	284.520
2002	81.695	50.081	5.865	1.237	134.197	28.115	301.19
Variation between 1986-2002	3.190	-5.736	-0.149	0.302	17.350	28.115	43.072
Variation between 1996-2002	22.054	-20.105	-6.047	0.898	11.019	8.851	16.670

Item	Water environmental factors					
	Total dissolved salts (g/l)	BOD (mg/l)	Total phosphate (mg/l)	Total nitrate (mg/l)	DO (mg/l)	Transparent (m)
1986	1.521					
1996	2.601	4.128	0.181	1.197	6.790	0.543
2002	3.700	8.090	0.212	2.257	5.167	0.430
Variation between 1986-2002	2.139					
Variation between 1996-2002	1.099	3.962	0.032	1.060	-1.623	-0.113

biological filling up function, and the nutrition salts released will cause the secondary pollution of the lake.

Besides, the reed area is expanding at an annual rate of 4-6 m without considering the death of reeds due to the lake level rise in the spring time (March to May). If it is not controlled, the reed areas in different parts of the lake will be definitely connected with each other, the function of Wuliangsuhai lake as a lake and its drainage ability in the irrigated area will be lost eventually, then the Wuliangsuhai lake will become a swamp or saline and alkaline lowland within 30 years according to the biological filling up rate of 10 mm/year.

5 Conclusions

The evolution of different types of areas of Wuliangsuhai lake relative to the water level, hydroclimatic factors and environmental factors includes the following aspects.

(1) The total water area of Wuliangsuhai lake is increasing in general although the area variation is affected by many factors, and the total area of the lake was reduced in the periods of 1986 to 1987 and 1996 to 2000.

(2) The natural reed area occupies a predominant position in the total area of Wuliangsuhai lake, which accounts for about 45.8%-51.5% of the total lake area, and the area of natural reed is increasing every year; the open water area and dense water weed area come the second, the summation of the two accounts for about 42.9%-46.7% of the total lake area. The water area in the south of Haiba is affected by the water quantity flowing into the lake, water quantity out of the lake, rainfall, evaporation of open water area, the areas of open water and dense water weed changing with each other, but the percentage of the area summation to the total lake area has been decreasing every year.

(3) With the increase of the total area of the lake, the areas of reed, artificial reed, swamp and open water are increasing, the areas of dense water weed and shallow water are decreasing. The open water area is changing into the dense water weed area, the dense water area and shallow water area are changing into swamp with the same water level because of the accumulation of the nutrition salts in the lake. The increase of biomass aggravates the self-purification of the lake, meanwhile, the result accelerated biological filling up function of the lake also causes the secondary pollution of the lake.

(4) The water environment was increasingly deteriorated, and the eutrophication became more and more serious in the period 1986-2002. The water level of the lake can be controlled by diverting water into the lake during slack farming season, then BOD, total phosphate, total nitrate and total salts of the lake can be reduced, the DO and transparent of the lake can be increased.

References

Bai Xue, Lu Nanjun, 1994. Study of the spatial and time variation of the water quality parameters of Boyang lake. *Water Resources Science and Technology of Jiangxi*, 20(2): 181-188. (in Chinese)

Environment Monitoring General Station of Inner Mongolia Autonomous Region. The Report of Environment States of IMAR in 1999 to 2002, 1999 to 2002. (in Chinese)

Jin Shengao, Jiang Shirong, 2001. Hydrological characteristics of Dongting Lake outlet. *Water Resources and Hydropower Express*, 22(18): 23-26. (in Chinese)

Liu Xiaoyuan, 2001.The analysis of the water level of Qinghai Lake. *Arid Zone Research*, 18(3): 58-62. (in Chinese)

Shang Shiyou, Du Jianmin, Li Xuying, 2003. Study on the management of eutrophication in Wuliangsuhai. *Journal of Inner Mongolia Agriculture University*, 24(4): 6-12. (in Chinese)

Wang Lunping, Chen Yaxin, Zeng Guofang, 1993. Irrigation and Drainage, the Saline and Alkaline Control of Hetao Irrigation Area of IMAR. Beijing: Water Resources and Hydropower Publisher. (in Chinese)

Zhu Yan, Cui Guangbo, 2001. Causes of shrinking and drying up of Qinghai Lake, trend of development and its impact on ecological environment. *Journal of Hehai University*, 29(4): 104-108. (in Chinese)