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Effects of land use on water quality of two high-altitude lakes and catchments in Yunnan Province, China

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SUMMARY

Reclaiming farmland from lakes in China in the 1950s damaged the water quality of many lakes. Tremendous efforts have been made since the late 1990s to restore vegetation around the damaged lakes. This paper examines water quality of Fuxian and Qilu Lakes and land-use characteristics within the two catchments in the high-altitude area of Yunnan Province, China. Landsat TM data acquired in 1989, 1994, 1999 and 2005 were used to extract land use and land cover (LULC) information. Measurements of five water quality indices (WQIs), BOD, COD, pH, TN and TP, for the same period of time were examined. The results showed that the area of residential and forest/shrub increased, whereas that of cropland and barren land decreased from 1989 to 2005 in both catchments. Qilu Lake was much more polluted than Fuxian Lake, and pollution worsened over time for both lakes. The differences in water quality between the two lakes were caused by differences in LULC composition and continued degradation in water quality was caused by intensive farming and urban sprawl. Unless the landscape is converted back to its pre-1950 composition and structure, water quality in both lakes cannot be significantly improved and will continue to threaten sustainable development in the region.

INTRODUCTION

Lakes are important ecosystems and are critical 'storage tanks', which contain more than 90% of all available liquid surface freshwater on Earth. Freshwater area makes up only 0.8% of the Earth's surface but supports almost 6% of all described species (Dudgeon *et al.* 2006). However, the quality

of freshwater has been degraded by a wide variety of natural and human influences. The most important factors among the natural influences are geological, hydrological and climatic conditions; the most important effects of human activities come from both point sources, such as wastewater discharge

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with high nutrient loads, and non-point sources such as run-off from livestock feedlots or agricultural land fertilised with organic and inorganic fertilisers. All these factors are altering the health of lake ecosystems, but vary greatly between developing and developed countries. In developing countries, intestinal disease is a major problem, while organic load and eutrophication may be of greater concern in developed countries (Meybeck *et al.* 1996). Studies also suggest that water quality and sediment chemistry of lakes are influenced by their geographic location, vegetation and land use in the catchment area (Müller *et al.* 1998), as well as by atmospheric deposition of pollutants (Mosello *et al.* 2002).

China is a huge country with many freshwater lakes, over 2,300 of which are over 1 km² (Jin and Zhang 1995). The total area of all the lakes accounts for less than 1% of the total area of the country but lakes are the most important freshwater source for the 1.3 billion inhabitants. Unfortunately, lakes in China have been misused during the past five decades. The major misuse was the countrywide reclamation of farmland from lakes in the 1950s. As a result, big lakes shrank and small lakes disappeared, reducing the total lake area by at least 1 million ha. Many lakes in China are suffering from severe pollution caused by urban sprawl, intensive farming and industrialisation. Non-point source pollution is a major contributing factor to water pollution in many parts of China. There have been major cleaning efforts in several large lakes where eutrophication is severe (Ongley 2004). Falkenmark (2005) warns that continued degradation in water usability is directly threatening public health, local ecosystems and sustainable development of the economy and society. The sustainable management of water resources implies the indefinite continuation of physically and biologically stable systems (Ioris *et al.* 2006).

China has four major lake districts: Qinghai-Tibet Plateau, the Eastern Plains, Yunnan-Guizhou Plateau and the Northeastern Plains, which account for 45.8, 31.5, 12.7 and 8.3% of China's total freshwater storage, respectively (Ministry of Water Resources 1992). Lakes in Yunnan Province have an average elevation of around 2,000 m and many of them are surrounded by subtropical forest. These high-altitude lakes support some of the most diverse freshwater ecosystems. More than half of freshwater fish species in China are found in

Yunnan Province (SEPA 1998). A number of fish species, such as *Anabarilius grahami*, *Cyprinus pellegrini*, *Schizothorax taliensis* and *Sinocyclocheilus grahami grahami*, are found only in the high-altitude lakes in Yunnan. Sket (2000) reported a new species of amphipod from Fuxian Lake in Yunnan. Unfortunately, lakes in Yunnan have varying degrees of pollution as a result of deforestation and destruction of habitat, silt and fertiliser runoff from intensive rice farming, human and industrial waste disposal, aquaculture and fisheries. For example, in Dianchi Lake, outside Kunming, Yunnan's capital city, the total number of fish species has declined from 68 to about 30 due to water hyacinth infestation of the lake (Ding *et al.* 1995). The pollution problem of Dianchi Lake has received major attention since the 1980s. Billions of Chinese yuan have been invested in cleaning the water but without obvious positive effects. Studies suggest that surface runoff and soil erosion have contributed to water quality degradation in lakes in Yunnan (Whitmore *et al.* 1994, 1997; Luo *et al.* 2004; Gao *et al.* 2005). Since the 1990s, systematic efforts have been made to protect and restore natural vegetation near water bodies in China through two national forestry programmes: Natural Forest Conservation Programme (NFCP) (Zhang *et al.* 2000) and Returning Forest/Grassland to Cropland or Grain-for-Green Programme (Li 2004). The purpose of this paper is to: (1) investigate changes in land use and lake water quality over time within two catchments, Fuxian catchment and Qilu catchment in Yunnan Province; (2) examine how land-use change within the catchments affects water quality in both lakes by comparing the two catchments/lakes; and (3) find effective solutions to improve water quality in lakes with different water pollution backgrounds in Yunnan.

METHODS

Study area

From the largest seven lakes in Yunnan Province, Chenghai, Dianchi, Erhai, Fuxian, Lugu, Qilu, and Xingyun Lakes (Figure 1), Fuxian Lake and Qilu Lake were selected for this study because they are geographically close and represent different water pollution problems. Fuxian Lake is slightly polluted whereas Qilu Lake is severely polluted. The maximum water depth of Fuxian Lake is 158.9 m, with a

Figure 1 Locations of major lakes and rivers in Yunnan Province, China

surface area of 216.6 km² and water storage capacity of 20.6 billion m³. Qilu Lake is much shallower (6.8 m) and smaller (37.3 km²), storing only 0.17 billion m³ of water (YAE 1999). The average air temperature is 16.1°C for Fuxian catchment and 15.6°C for Qilu catchment. Both lakes are surrounded by farmland, villages/towns and hills with slopes ranging from 10–30°. Fertiliser use increased by 0.7% per year in Chenghong, Huaning and Jiangchuan Counties, where Fuxian Lake is located, and by 4.3% in Tonghai County, where Qilu Lake is located, between 1990 and 2005 (YDG 1991, 2006). The annual population growth rate is less than 1% in the counties containing the two lakes, slightly lower than the national average (1.2%). Wastewater from local villages is not treated.

Data sources and methods

Cloud-free Landsat TM satellite imagery acquired for 3/1/1989, 2/11/1994, 2/25/1999 and 2/25/2005 was used to derive land-use features in the study area. The 2005 satellite image dataset was converted into UTM coordinates by referring to 17 GPS ground control points. The average root-mean square error for the rectification was below 13 m. The resulting image dataset was used to rectify the other three TM datasets. Digital elevation models (DEM) with a 20-m resolution were used to derive watershed boundaries for the two catchments. A total of 300 points were randomly

selected within the two catchments. The features of land use and land cover (LULC) types were recorded on the ground in spring 2005. These ground survey data were partially used to train classifications and assess the classifications of the 2005 TM data. After balancing between classification details and accuracy levels, the final acceptable classification scheme included five LULC types: forest/shrub, barren, water, cropland (including vegetables) and residential area. Unsupervised classifications (Jensen 2005) with six TM bands (except for band 6) were used for discriminating the five LULC types. The overall classification accuracy was 92.3% for the 2005 TM data. The same classification strategy was used to classify the other three TM datasets. LULC composition for the catchments and a 200-m buffer zone (200BZ) around each lake were computed using geospatial operations. The definition of the 200-m buffer zone was referred to the minimum riparian width in China's forest management system (Lin 1999).

Water quality records came from local county offices. The data were available at 5-year intervals between 1990 and 2005 for both lakes. The water quality indices (WQI) were biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, total nitrogen (TN) and total phosphorus (TP). The data contained measurements at four random locations within a lake and these measurements were repeated in rainy (September), normal (June) and drought (March) seasons. The coefficient of variation (CV), defined as the ratio of the standard deviation to the mean, was computed by lake, year and season to compare the degree of variation among location (lake), year and season data series. The Bonferroni *t*-test in SAS (Cody and Smith 1997) was performed to examine differences in WQI means between two sites, among 4 years, among four locations within each lake, and among three seasons within a year. The combined analysis of CV computations and Bonferroni *t*-test was used to resolve the limiting factor(s) of water quality for the two catchments studied.

RESULTS

LULC variations and transitions

Except for water, the other four LULC types either gained or lost area over time within both catchments (Figures 2, 3). The area of residential and

forest/shrub increased whereas that of cropland and barren decreased from 1989 to 2005 at the catchment level. Similar trends were found within 200BZ around both lakes for all the LULC types except residential, whose area decreased for the Qilu catchment

The area of Fuxian catchment (617.9 km²) was about 50% higher than that of Qilu catchment (403.1 km²); water surface area of Fuxian Lake (216.6 km²) was almost six-times larger than that of Qilu Lake (37.1 km²) in 2005 (Figure 2). Fuxian catchment top two LULC types were water and forest/shrub but Qilu catchment top two LULC types were cropland and forest/shrub in 1989–2005. By averaging the observations for the four time periods, the percentage land area for barren or forest/shrub is nearly the same in the catchments; Qilu catchment land area for residential or cropland was more than twice that of Fuxian catchment; Fuxian catchment land area for water or water catchment (W/C) area ratio was nearly four-times higher than in Qilu catchment (Figures 2, 3).

Between 1989 and 2005, Fuxian catchment residential area increased from 2.0 to 3.5% (3.6% per year) of its total area, and Qilu catchment residential area increased from 4.7 to 7.9% (3.3% per year); cropland area decreased from 9.9 to 7.3% of the total catchment area for Fuxian catchment, and from 24.8 to 21.4% for Qilu catchment; and forest/shrub and residential increased while barren and cropland decreased in area for both catchments over time.

Neither the LULC proportions at a given time nor the magnitudes of changes over time were the same for the catchments and 200BZ. For Fuxian catchment, residential area increased over 200% within 200BZ compared to a 77% increase within the catchment; cropland area decreased about 70% within 200BZ compared to a 35% decrease within the catchment; forest/shrub increased 52% within 200BZ compared to a 39% increase within the catchment from 1990 to 2005. For Qilu catchment, residential area decreased by 21% for 200BZ compared to a 70% increase for the catchment; forest/shrub area increased more than seven times for 200BZ compared to a 23% increase for the catchment between 1989 and 2005.

Changes in LULC over time, such as the new residential area along the water edge of Fuxian Lake and new shrubs along the water edge of Qilu Lake,

Figure 2 A comparison of LULC between Fuxian catchment and Qilu catchment, 1989 and 2005

are clearly visible from the LULC maps (Figure 2). Residential area was spatially mixed, containing crops, and the total area of the residential–crop mosaic (RCM) seemed not to change over time for either catchment. RCM in Fuxian catchment covered only part of the water edge of the lake; RCM in Qilu catchment basically surrounded the entire perimeter of the lake. Local documents and DEM data indicate that most of RCM was reclaimed from the lakes in the 1950s. The levees and natural rocky banks around the lakes helped keep the water area unchanged for both lakes between 1989 and 2005.

Water quality variations

Except for pH, the values of the other four WQIs were different between the two lakes (Figure 4). Based on China's national standards for surface water quality (Table 1), water quality of Fuxian Lake was Grade I (best) according to BOD, COD, TN and TP; while water quality of Qilu Lake was Grade III for BOD, Grade I/II for COD and Grade V for TN or TP from 1990–2005 (Figure 4).

The CV of each WQI within a lake was much smaller than that within a year or a season. The yearly average CV was close to the seasonal average CV for each WQI. The *t*-test suggested that there

Figure 3 The dynamics of LULC proportions within Fuxian and Qilu catchments and 200-m buffer zones around the two lakes

Figure 4 Mean values of five indices of water quality for Fuxian and Qilu Lakes, 1990–2005, and water quality grade (Roman numbers on the right axis; Grade I is the best and Grade V is the worst, see Table 1)

were significant differences ($P < 0.0001$) in all WQI values between the two lakes or among the 4 years. The seasonal differences varied with WQI. There was no significant difference in TN among the three seasons. The combined results indicate that the variations in water quality between the two lakes were much greater than those among the 4 years or three seasons. The mean BOD, COD, TN or TP for Fuxian Lake and those for Qilu Lake were not the same order of magnitude (Figure 5): Qilu Lake

BOD was nearly five-times higher, COD was nine-times higher, TN was 17-times higher and TP was 12-times higher than Fuxian Lake. Qilu Lake pH was significantly higher than Fuxian Lake ($P < 0.0001$) although the difference in mean values was $< 4\%$.

The t -test for Fuxian Lake data alone showed overall increases in BOD and COD, almost no change in pH and TN, and a sharp decrease in TP over time (Figure 5). Similar analysis for Qilu Lake

Table 1 Environmental quality standards for surface water (SEPA 2002)

Index	Quality Grade (I best and V worst)				
	I	II	III	IV	V
BOD (mg/L)	≤ 3		3–4	4–6	> 6
COD (mg/L)	≤ 15		15–20	20–30	> 30
pH			6–9		
TN (mg/L)	≤ 0.2	0.2–0.5	0.5–1.0	1.0–1.5	> 1.5
TP (mg/L)	≤ 0.01	0.01–0.025	0.025–0.05	0.05–0.1	> 0.1

Figure 5 The t-test of 4-year water quality measures for each lake studied. The categorization, A, B, C and D, was determined at 95% confidence level

data also showed increases in BOD and COD over time. However, Qilu Lake pH seemed to decrease but TN and TP increased. The five water quality indices had consistent responses to seasonal change between the two lakes: every WQI experienced steady increases from rainy to drought seasons.

DISCUSSION

Effects of land use on water quality

The differences in LULC or water quality between the two catchments or lakes were much greater than those over time for each catchment or lake. Fuxian Lake was clean whereas Qilu Lake was severely polluted. The differences in LULC between the two catchments reflected the differences in human land-use activities; differences in WQI between the two lakes were the direct or

indirect consequences of historical land-use activities. By comparing a clean lake such as Fuxian Lake with a polluted lake such as Qilu Lake, insights could be obtained into what land-use activities have important impacts on lake water quality.

Based on the results above, it was obvious that the proportions of residential, crop, and water LULC types within a catchment, particularly within a buffer zone around a lake, were important indicators for lake water quality. Another effective indicator was the W/C area: Fuxian catchment W/C area was nearly four-times higher than Qilu catchment. The average water storage of Fuxian Lake (20.6 billion m³) was much higher than that of Qilu Lake (0.17 billion m³). When water volume is used for water surface area in computing the W/C, Fuxian catchment W/C (20.6/617.9) will be 79-times higher than Qilu catchment W/C (0.17/403.1), indicating that Fuxian Lake had advantages over Qilu Lake in terms of absorbing the load of pollutants within the catchment.

The farmland reclaimed around lakes in the 1950s expanded agricultural land within the catchments. The new agricultural land provided additional food sources for growth in human population around the lakes and also expanded pollution sources for remaining, smaller water bodies. This was particularly true for Qilu catchment. The relative increase in fertiliser use in Qilu catchment was much greater than that in Fuxian catchment (YDG 1991, 2006). Despite steady declines in cropland area in both catchments, fertiliser overuse caused agriculture to continue to have negative effects on water quality of both lakes. Compared to Fuxian catchment, Qilu catchment area of cropland was still relatively larger in 2005 and agricultural activities around Qilu Lake still overwhelmed vegetation restoration efforts made on its hills and around the lake. The high concentrations of TN and TP and their increase over time in Qilu Lake

could be the direct consequences of fertiliser overuse.

The increase in residential area for both catchments was 12% to 14% per decade from 1989 to 2005, similar to the national average (Shen 2006). This means that no special measures were taken to restrict development around the lakes. Although such a land-use practice was ecologically unfriendly for both catchments, the farmland reclaimed from Fuxian Lake was small relative to the water surface and did not cause obvious pollution in Fuxian Lake. In contrast, such expanded farming activities overwhelmingly contaminated Qilu Lake. It is difficult, or even impossible, to improve water quality without eliminating agriculture land around Qilu Lake.

Visible efforts and invisible effects

The sharp increase in forest/shrub, steep decrease in barren and steady decrease in cropland in both catchments indicate that tremendous vegetation restoration efforts have been made by local people. This was particularly true along the lake banks, as forest/shrub area had a greater increase around the lakes than within the whole catchments; the decrease in residential area within 200BZ of Qilu Lake was in sharp contrast compared to the increase in residential area for the entire Qilu catchment. These positive land-use efforts may have increased in 1998–2000, when the NFCP (Zhang *et al.* 2000) and Grain-for-Green Programme (Li 2004) were implemented. However, the vegetation restoration efforts on the hills did not have direct impacts on the quality of lake water, and the increase in riparian vegetation was not significant enough to stop pollutants from flowing into the lakes. As a result, there were still negative trends in lake water quality over time. For example, both BOD and COD in Fuxian Lake were increasing, and four of five WQIs (except pH) in Qilu Lake were increasing, over time. This shows the complexities and difficulties in reversing escalating water pollution, which have previously been severely underestimated (Falkenmark 2000). There was a greater increase in BOD in Fuxian Lake than that in Qilu Lake, which may be because residential within the 200-m buffer around Fuxian Lake has increased but that within the 200-m buffer around Qilu Lake has declined (Yang *et al.* 2007).

If intensive farming and urbanisation are not controlled, vegetation restoration efforts on the

hills cannot be effective enough to improve lake water quality. Computer simulations suggest that reducing agricultural phosphorus surplus is an effective way to maintain water quality of lakes (Van de Schippers *et al.* 2006). The sharp decline in TP in Fuxian Lake may result from an improvement in fertiliser application methods. Zhang *et al.* (2004) suggest that no fertilisation before rain and no irrigation immediately after fertilisation would reduce phosphorus runoff. Regulating the water level to increase flushing during sediment release periods and decrease flushing during uptake periods has the potential to significantly enhance the recovery of shallow lakes and reservoirs following historic nutrient loading (Spears *et al.* 2007).

A sustainability perspective

Forest vegetation restoration and farmland reduction in both catchments did not significantly improve water quality of the lakes between 1990 and 2005 because there was still too much cropland and an increasing residential area around the lakes. Because water quality is an important indicator for the assessment of water sustainability (Ioris *et al.* 2006), any factors that contribute to continued degradation of water quality in the lakes threaten sustainable development in the region. Lake water quality is the result of long-term land-use history in the catchments if there are no imported sources of pollutants (Yang *et al.* 2007). The continued degradation of water quality in both Fuxian and Qilu Lakes suggests that the water resources and land-use practices in both catchments are not sustainable, although there were positive trends in land use for 1989–2005.

Sustainability involves meeting the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland 1987). A critical component of sustainability science focuses on observing and monitoring land-use and land-cover change (LUCC) and assessing the impacts of LUCC on ecosystem processes (Wu 2006). Because the impacts of LUCC are scale-dependent, the LUCC within the two catchments between 1989 and 2005 cannot represent the trend of LUCC in the same region during the 1950s, when much farmland was reclaimed around lakes. The same scale issue is applicable to the in lake water quality during past decades. Approaches to sustainable water resource management can

utilise and build on insights from physical geography to apply the principles and practice of hydrology at the catchment scale (Ioris *et al.* 2006). Due to differences in land use and water quality between the two catchments, sustainable management plans, including land-use planning and water management strategies, need to be developed differently for the two catchments (Chen and Tung 2007).

Lessons have been learned from attempts to clean Dianchi Lake near Kunming, where a huge investment in cleaning water resulted in no improvement in water quality in the long term. For the purpose of sustainability, it is essential to maintain water quality in Fuxian Lake and improve water quality in Qilu Lake in the future. Such fundamental goals cannot be easily realised unless the

landscape is converted back to its pre-1950s composition and structure. Because of strict farmland protection policy from China's central government, we cannot expect complete or near-complete elimination of farmland around the lakes in the near future. Under these circumstances, more efforts are needed to develop effective riparian vegetation zones around both lakes. Wastewater from the villages needs to be treated before entering the lakes.

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REFERENCES

- Brundtland GH (ed.). *Our common future*. World Commission on Environment and Development. Oxford: Oxford University Press; 1987
- Chen YJ and Tung CP. New criteria for sustainable water quality management. *Journal of the American Water Resources Association* 2007;43:372–83
- Cody RP and Smith JK. *Applied Statistics and the SAS Programming Language* (4th ed.). New Jersey: Prentice-Hall; 1997
- Ding JQ, Wang R and Fan ZN. Distribution and infestation of water hyacinth and the control strategy in China. *Journal of Weed Science* 1995;9:49–51
- Dudgeon D, Arthington AH, Gessner MO and Kawabata ZI. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Review* 2006;81:163–82
- Falkenmark M. Semiarid crop production from a hydrological perspective: gap between potential and actual yields. *Critical Reviews in Plant Sciences* 2000;19:319–46
- Falkenmark M. Water usability degradation – Economist wisdom or societal madness? *Water International* 2005;30:136–46
- Gao L, Zhou JM, Yang H and Chen J. Phosphorus fractions in sediment profiles and their potential contributions to eutrophication in Dianchi lake. *Environmental Geology* 2005;48:835–44
- Ioris AAR, Hunter C and Walker S. A framework of indicators to assess the sustainability of freshwater systems. *Physical Geography* 2006;27:396–410
- Jensen JR. *Introductory Digital Image Processing: A Remote Sensing Perspective* (3rd ed.). New Jersey: Prentice Hall; 2005
- Jin XC and Zhang ZS. *Lakes in China: Research on Their Environment*. Beijing: Ocean Press; 1995:19–26
- Li WH. Degradation and restoration of forest ecosystems in China. *Forest Ecology and Management* 2004;201:33–41
- Lin J. Studies on technical criteria and index system for classifying public benefit forest and commercial forest. *Scientia Silvae Sinicae* 1999;4:23–8
- Luo J, Yin JF, Cai L, Zhang KQ and Hyde KD. Freshwater fungi in Lake Dianchi, a heavily polluted lake in Yunnan, China. *Fungal Diversity* 2004;16:93–112
- Meybeck M, Kuusisto E, Mäkelä E and Mäkki E. Water quality. In Bartram J and Balance R (eds), *Water Quality Monitoring – A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*. New York: UNEP and WHO; 1996
- Ministry of Water Resources. *Water Resources Assessment for China*. Beijing: China Waterpower Press; 1992
- Mosello R, Lami A, Marchetto A, Rogora M, Wathne B and Lien L. Trends in the water chemistry of high altitude lakes in Europe. *Water Air & Soil Pollution: Focus* 2002;2:75–89
- Müller B, Lotter AF, Sturm M and Ammann A. Influence of catchment quality and altitude on the water and sediment composition of 68 small lakes in central Europe. *Aquatic Sciences* 1998;60:316–37

- Ongley ED. Non-point source water pollution in China: Current status and future prospects, *Water International* 2004;29:299–306
- Shen JF. Estimating urbanization levels in Chinese provinces in 1982–2000, *International Statistical Review* 2006;74:89–107
- Sket B. *Fuxiana yangi* g.n., sp.n. (Crustacea: Amphipoda), a “baikaloid” amphipod from the depths of Fuxian Hu, an ancient lake in the karst of Yunnan, China. *Archiv fur Hydrobiologie* 2000;147:241–55
- Spears BM, Carvalho L and Paterson DM. Phosphorus partitioning in a shallow lake: implications for water quality management. *Water and Environment Journal* 2007;21:47–53
- State Environmental Protection Administration (SEPA). Species Number in China and the World. In *China's Biodiversity: A Country Study*. Beijing: Chinese Environmental Science Press; 1998
- State Environmental Protection Administration (SEPA) and General Administration of Quality Supervision, Inspection and Quarantine of China (GAQIQC). *Environmental Quality Standards for Surface Water*. Beijing: Governmental Document GB 3838-2002; 2002
- Van de Schippers P, Weerd H, de Klein J, de Jong B and Scheffer M. Impacts of agricultural phosphorus use in catchments on shallow lake water quality: About buffers, time delays and equilibria. *Science of the Total Environment* 2006;369: 280–94
- Whitmore TJ, Brenner M, Engstrom DR and Song XL. Accelerated soil erosion in watersheds of Yunnan province, China. *Journal of Soil And Water Conservation* 1994;49:67–72
- Whitmore TJ, Brenner M, Jiang Z, Curtis JH, Moore AM, Engstrom DR and Wu Y. Water quality and sediment geochemistry in lakes of Yunnan province, southern China. *Environmental Geology* 1997; 32:45–55
- Wu JG. Landscape ecology, cross-disciplinarity, and sustainability science. *Landscape Ecology* 2006; 21:1–4
- Yang L, Ma KM, Zhao JZ, Bai X and Guo QH. The relationships of urbanization to surface water quality in four lakes of Hanyang, China. *International Journal of Sustainable Development and World Ecology* 2007;14:317–27
- Yuxi District Government (YDG). *Yuxi District Statistical Yearbook 1990*. Yuxi: Yunnan People Press; 1991
- Yuxi District Government (YDG). *Yuxi District Statistical Yearbook 2005*. Yuxi: Yunnan People Press; 2006
- Yunnan Academy of Environment (YAE). *Overall Planning for Environmental Treatment of South Yunnan Lakes* (internal document); 1999
- Zhang NM, Yu Y, Hong B, Chen JJ and Zhang YJ. Factors influencing runoff losses from farmlands of the Dianchi Lake watershed in Yunnan, China. *Pedosphere* 2004;14:259–62
- Zhang P, Shao G, Zhao G, LeMaster DC, Parker GR, Dunning JB and Li Q. Ecology: China's forest policy for the 21st century. *Science* 2000;288:2135–6