Acknowledgements

First of all, I sincerely thank all the people I met in Lisbon that helped me to finish this Master thesis. Foremost I am deeply grateful to my supervisor --- Prof. Ana Estela Barbosa from LNEC, for her life caring, and academic guidance for me. This paper will be completed under her guidance that helped me in all the time of research and writing of the paper, also. Her profound knowledge, rigorous attitude, high sense of responsibility and patience benefited me a lot in my life.

Second of all, I'd like to thank my Chinese promoter professor Xu Wenbin, for his encouragement and concern with me. Without his consent, I could not have this opportunity to study abroad.

My sincere thanks also goes to Prof. João Alfredo Santos for his giving me some Portuguese skill, and teacher Miss Susana for her settling me down and providing me a beautiful campus to live and study, and giving me a lot of supports such as helping me to successfully complete my visa prolonging.

Many thanks go to my new friends in Lisbon, for patiently answering all of my questions and helping me to solve different kinds of difficulties in the study and life. The list is not ranked and they include: Angola Angolano, Garson Wong, Kai Lee, David Rajnoch, Catarina Paulo, Gonçalo Oliveira, Ondra Dohnálek, Lu Ye, Le Bo, Valentino Ho, Chancy Chen, André Maia, Takuma Sato, Eric Won, Paulo Henrique Zanin, João Pestana and so on.

This thesis is dedicated to my parents who have given me the opportunity of studying abroad and support throughout my life.

Abstract

China is the world's most populous country with over 1.35 billion inhabitants; also in area, China is one of the world's largest countries. However, the distribution of water resources in the whole territory of China is not homogeneous and there are increasingly severe water shortages, particularly in the north-east of the country. Over the past decade, the water quality of lakes and reservoirs in China has degraded due to many causes, especially the large population. Water pollution and destruction of aquatic ecosystems have caused massive damage to the functions and the integrity of water resources. Roughly, 298 million Chinese in rural areas do not have access to safe drinking water, and 40% of China's rivers were, by 2011, polluted by industrial and agricultural waste.

The aim of this study is to identify the most common water quality problems in lakes and reservoirs in China and to analyze the variables that control the water quality, based on research on scientific publications, international journals databases, Google maps, and other available sources of information. After the initial literature research, 58 papers were selected; they described the conditions of 52 water bodies. This information was summarized in a Table with the most relevant characteristics, namely: the identification of the lake/reservoir, the pollution sources, the water quality parameters evaluated and the methodologies used in the study. This analysis provides an overview of the situation of Chinese lakes and reservoirs.

It was observed that nitrogen and phosphorus are the most common pollutants. This suggests Chinese water bodies are suffering from serious eutrophication problems, resulting from agriculture practices. Other diffuse pollution source, mining activities, have been considered by 6 of the 58 selected papers. On the other hand, the most relevant point pollution sources are effluents from industry and public or household facilities.

According to the Chinese Surface Water Quality Standard (GB3838), it is observed that the water quality of most of the 52 lakes and reservoirs are of class 3. Nine of the eleven water bodies regarded as class 1or 2, are reservoirs and two of them are lakes. Fifteen of the eighteen water bodies of class 4, class 5 and lower than class 5 are lakes; the remaining three being reservoirs. Therefore, it seems that in China the water quality of reservoirs is likely to be better than that of lakes.

Six case studies were selected among the 53 water bodies, as representative of lakes and reservoirs in China. The criterium was to have 2 groups of water masses of comparable dimensions (volume of water and catchment area) but placed in regions of different mean annual precipitation. According to these criteria, two groups were set. Group 1 includes Poyang Lake, Dongting Lake and Hulun Lake, with volumes of, respectively, 276 $x10^8m^3$, 170 $x10^8m^3$ and 131 $x10^8m^3$ and mean annual rainfalls of 1639 mm, 1350 mm and 319 mm. The water bodies of Group 2 have smaller sizes; they are Shitoukoumen Reservoir (12.6 $x10^8m^3$; 565 mm), Yuqiao Reservoir (15,6 $x10^8m^3$; 750 mm) and Dianchi Lake (15,7$x10^8m^3$; 1007 mm).

Additional data was gathered to better understand and compare the water quality situation of these 6 case studies; including analyzing the degree of eutrophication of each case. Concerning the comparison of water quality of the two groups, it was found that Poyang Lake although having serious phosphorus pollution is the one with the best water quality (class 4) in Group 1. Dongting Lake and Hulun Lake have problems with nitrogen pollution and are of class 5 and inferior class 5, respectively. In both reservoirs Shitoukoumen and Yuqiao from Group 2 nitrogen pollution is more serious than phosphorus; their water quality is similar (class 3). On the other hand, among Group 2 case studies Dianchi presents a worse water quality having less then class 5.

It China there are different seasons characterized by the amount of precipitation and temperature. It was found that 4 of the 6 water bodies, namely Poyang Lake, Dongting Lake, Yuqiao Reservoir and Dianchi Lake have seasonal water quality changes. Only Hulun Lake and Shitoukoumen Reservoir do not show this phenomenon, probably because both regions have low annual mean rainfall, and therefore relatively stable hydrological characteristics. In both groups there are water bodies showing the following patterns: 1) wet season water quality better than that of the dry season (Poyang and Dianchi Lakes); 2) dry season water quality better than that of the wet season (Dongting Lake and Yuqiao Reservoir); 3) the water quality is similar along the year (Hulun Lake and Shitoukoumen Reservoir). The reason for the first and the second pattern may be related to the fact that the dilution of pollutants in a water body is enhanced in regions with a longer wet season, as well as a higher annual average rainfall, resulting in lower concentration of pollutants in the wet season compared to the dry season.

The observation and analysis of these 6 case studies illustrate how surface water quality is related to several natural characteristics of the catchment, such as climate and geographic conditions. The production of pollutants is trigged by human activities and the ones with higher impacts in lakes and reservoirs in China are: agriculture, application of chemicals, urban and industrial development, irrigation and drainage systems, and tourism.

Water laws or regulations and public involvement in enforcement can play a constructive role in environmental protection. In the near future, in order to protect water from further contamination, China should take actions in order to control the various kinds of diffuse and point pollution that still threatens the water quality, in particular of agriculture and industrial and urban wastewater. Stricter environmental regulations for water quality are required to support protection and management strategies.

Resumo

A China é o país mais populoso do mundo, com mais de 1350 milhões de habitantes, sendo também um dos países do mundo com maior área. Contudo, a distribuição dos recursos hídricos no território não é homogénea havendo cada vez mais problemas graves de escassez de água, especialmente no nordeste do país. Na última década, a qualidade da água dos lagos e albufeiras da China degradou-se devido a várias causas, sendo a mais relevante das quais a grande população do país. A poluição da água e a destruição dos ecossistemas aquáticos tem causado danos enormes nas funções e na integridade dos recursos hídricos. Aproximadamente 298 milhões de chineses que vivem em áreas rurais não têm acesso a água potável e, em 2011, 40% dos rios da China estavam poluídos por resíduos industriais e agrícolas.

O objetivo deste trabalho é identificar os problemas mais comuns que afetam a qualidade da água em lagos e albufeiras da China e analisar as variáveis que controlam a qualidade da água, com base na pesquisa de publicações científicas, bases de dados de artigos científicos, mapas do Google e outras fontes de informação. Da pesquisa inicial foram selecionados 58 artigos científicos que descrevem o estado de 52 massas de água. Esta informação foi sumariada num quadro com as características mais relevantes, nomeadamente a identificação do lago / albufeira, as fontes de poluição, os parâmetros de qualidade da água avaliados e as metodologias utilizadas nos estudos. Esta análise faculta uma visão global da situação nos lagos e albufeiras da China.

Verificou-se que os poluentes mais comuns são o azoto e o fósforo. Isto sugere que as massas de água na China estão com problemas sérios de eutrofização resultantes de práticas agrícolas. Outra fonte de poluição difusa, as atividades de exploração mineira, foram consideradas em 6 dos 58 trabalhos selecionados. Por outro lado, as fontes mais relevantes de poluição pontual são os efluentes de atividades industriais e instalações de uso público ou doméstico.

Atendendo às Normas Chinesas para a Qualidade de Águas Superficiais (GB3838), verifica-se que a qualidade da água na maioria dos 52 lagos e albufeiras é da classe 3. Nove das onze massas de água classificadas como da classe 1 ou 2 são albufeiras e duas delas são lagos. Quinze das dezoito massas de água das classes 4, 5 e acima de 5 são lagos, sendo as três restantes albufeiras. Portanto, parece que na China a qualidade da água em albufeiras tende a ser melhor que em lagos.

De entre aquelas 53 massas de água, selecionaram-se seis casos de estudo como representativos dos lagos e albufeiras da China. O critério foi ter 2 grupos de massas de água de dimensões comparáveis (volume de água e área da bacia hidrográfica) mas colocadas em regiões de precipitação média anual distintas. De acordo com este critério, definiram-se dois grupos. O Grupo 1 inclui os lagos Poyang, Dongting e Hulun cujos volumes são, respetivamente, 276 x108m3, 170 x108m3 e 131 x108m3 e a precipitação média anual de 1639 mm, 1350 mm e 319 mm. As massas de água do Grupo 2 são mais pequenas; são elas as albufeiras de Shitoukoumen (12.6 x108m3; 565 mm) e Yuqiao (15,6 x108m3; 750 mm) e o lago Dianchi (15,7x108m3; 1007 mm).

Foi reunida informação adicional para melhor se entender e comparar o estado da qualidade da água nestes 6 estudos de caso, incluindo-se a análise do grau de eutrofização em cada caso. Comparando a qualidade da água dos dois grupos, verificou-se que o lago Poyang embora tenha graves problemas de poluição por fósforo é o que tem melhor qualidade da água (classe 4) no Grupo 1. Os lagos Dongting e Hulun têm problemas com poluição por azoto sendo da classe 5 e acima da classe 5, respetivamente. Nas albufeiras Shitoukoumen e Yuqiao, do Grupo 2, a poluição por azoto é mais grave que a poluição por fósforo, sendo a qualidade da água similar para ambas (classe 3). Por outro lado, entre os casos de estudo do Grupo 2 o lago Dianchi é o que apresenta a pior qualidade da água, estando acima da classe 5.

Na China existem diferenças sazonais na quantidade de precipitação e na temperatura. Verificou-se que 4 das 6 massas de água, nomeadamente os lagos Poyang, Dongting e Dianchi e a albufeiras Yuqiao têm mudanças sazonais na qualidade da água. Apenas o lago Hulun e a albufeira Shitoukoumen não exibem este fenómeno, provavelmente porque ambas as regiões têm precipitação média anual baixa e, consequentemente, características hidrológicas relativamente estáveis. Em ambos os grupos há massas de água que exibem os seguintes padrões: 1) qualidade da água na estação húmida melhor que na estação sêca (lagos Poyang e Dianchi); 2) qualidade da água na estação sêca melhor que na estação húmida (lago Donting e albufeira Yuqiao); 3) qualidade da água sem variação ao longo do ano (lago Hulun e albufeira Shitoukoumen). O primeiro e o segundo padrão podem dever-se ao fato de a diluição dos poluentes numa massa de água ser reforçada em regiões com estação húmida mais longa. Bem como com precipitação média anual mais elevada, resultando em concentrações de poluentes mais baixas na estação sêca quando comparadas com as da estação húmida.

A observação e análise destes 6 casos de estudo mostram como a qualidade das água superficiais está relacionada com várias características da bacia hidrográfica, nomeadamente com condições climáticas e geográficas. A produção de poluentes é desencadeada por atividades humanas e as que têm maior impacto nos lagos e albufeiras da China são: a agricultura, a aplicação de produtos químicos, o desenvolvimento urbano e industrial, os sistemas de irrigação e drenagem e o turismo.

Leis ou regulamentos de água e o envolvimento público na fiscalização podem desempenhar um papel construtivo na proteção do ambiente. No futuro próximo, para proteger a água de mais contaminação, a China deve tomar medidas para controlar os diversos tipos de poluição difusa e pontual que ainda ameaçam a qualidade da água, em especial nas águas residuais da agricultura, indústria e de usos domésticos. São necessárias normas ambientais mais rigorosas para a qualidade da água para apoiar estratégias de proteção e gestão.

Table of Contents

List of Tables

List of Figures

List of abbreviations

Al	Aluminium
As	Arsenic
BOD_5	5-day biochemical oxygen demand
BPA	Bisphenol A
CA	Cluster analysis
Ca	Calcium
$COD/COD_{Cr}/COD_{Mn}$	Chemical Oxygen Demand/COD based on Cr/COD based on Mn
Cd	Cadmium
CFU	Colony forming units
Chla	Chlorophyll a
Cl^-	Chloride
CN	Cyanide
Cr	Chromium
Cr^{6+}	Hexavalent chromium
Cu	Copper
DA	Discriminant analysis
DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DRP	Dissolved molybdate reactive phosphorus
EA	Econometric analysis
EC	Electrical conductivity
ECM	Export coefficient model
EcoHAT	Ecohydrological Assessment Tool
E. coli	Escherichia coliforms
Eh	Redox Potential
EPA	Environmental Protection Agency
EU	European Union
F/ F^-	Fluoride
FA	Factor analysis
FCA	Fuzzy comprehensive assessment
F. coli	Fecal coliforms
Fe	Iron
HCB	Hexachlorobenzene
I_{geo}	Geoaccumulation index
K	Potassium
MD	Monitoring data
Mg	Magnesium
Mn	Manganese
N	Nitrogen

Na	Sodium
NH_3-N/ NH_4 -N	Ammonia nitrogen
NO_2^-N	Nitrite nitrogen
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_3 -N	Nitrate nitrogen
NPS	Non-point source
NP	Nonylphenol
Ni	Nickel
OCPs	Organochlorine pesticides
orgN	Organical nitrogen
OM	Organic matter
P	Phosphorus
PAEs	Phthalate esters
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
Pb	Lead
PCA	Principal Component analysis
PCBS	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCD/Fs	Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans
PCDFs	Polychlorinated dibenzofurans
PCP	Pentachlorophenol
PFA	Principal Factor analysis
PFOA	Perfluorooctanoic acid
PFCs	Perfluorinated compounds
POM	Particulate organic matter
POPs	Persistent organic pollutants
PS	Point source
PWTLT	Project of Water Transfer from the Luanhe River to Tianjin
QWASI	Quantitative water–air–sediment interaction
S	Sulfur
SNWDP	South-to-North Water Diversion Project
SO_4^{2-}	Sulfate
SPM	Suspended Particulate Matter
Sr	Strontium
SRP	Soluble reactive phosphorus
SS	Suspended Solids
SWAT	Soil and Water Assessment Tool
TCd	Total cadmium
TDS	Total dissolved solids
TEQ	Toxicity Equivalency Quantity
TGR	Three Gorges Reservoir
THg	Total mercury

TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TOC	Total Organic Carbon
TP	Total phosphorus
TPb	Total lead
TS	Total solids
TSS	Total suspended solids
$T\text{–}CN^{-}$	Total cyanide
V-ArOH	Volatile phenol
VOCs	Volatile organic compounds
VP	Volatile phenol
WHO	World Health Organization
WQ	Water Quality
WT	Water transparency
WWTP	Wastewater Treatment Plant
Zn	Zinc
Σ_{15}OCPs	Sum of 15 organochlorine pesticides concentration
ng/L	Nanograms per litre
μg/L	Micrograms per litre

1. Introduction

1.1 The significance of water resources

Water resources are not only the headspring of life, but also vital for national economy. The safety of water resources is closely related to the social stability. Protections of water resources are the inevitable requirement of guaranteeing human living and the social development. At present, Chinese water resources also face with stem situation. Water quality problems have become one of the main restrictive factors that affect human health and the development of Chinese economy.

Water is a renewable natural resources continuously changing its form in the hydrosphere between three states: solid, liquid and gaseous [1]. The significance of water resources can be described in the following aspects:

1) Water is the most important matter to human beings, even all living things. On earth, where there is water, there is life. All life activities are originated in the water. The quantity of water inside the body is about 65% of the body weight [2]. Among them, 75% of the brain is water, 83% of the blood is water, 76% of the muscle is water, even the hard bones also contain 22% of water [2]. Without water, nutrients cannot be absorbed. Once the humans' bodies lack water, the consequence will be serious. We will feel thirsty if there are lack of 1%-2% water in our body; when there is water shortage in 5% in the body, it will make the mouth dry, skin wrinkling, mind unconsciousness, and even visual hallucination; when there is water shortage in 15%, we will suffer more than from hunger [2]. Without food, people can live for two months; Without water, at most for about a week. The view of Figure 1 shows that a girl is drinking a bottle of fresh water, implying that humans need water to survive.

Figure 1: Humans being need water

2) Regulation of the earth's climate. Water is an important component of the atmosphere. The atmosphere contains only one over one million of the world's water. However, the circulation and interaction between air and water determine the earth's water cycle movement and the climate. The water in the atmosphere helps to regulate the global energy balance and energy transfer between different regions is affected by the water cycle.

3) Great amounts of water are used in industry, agriculture and urban areas.
It is estimated that 22% of worldwide water is used in industry [3]. For example, water is used in power generation. Hydroelectricity power comes from water driving a water turbine connected to a generator. Hydroelectricity is a low-cost, non-polluting, renewable energy source. Typically a dam is constructed on a river, creating an artificial lake behind it. This lake is called reservoir. Large amounts of water are needed to produce energy and significant energy is used to treat and transport water to consumers. Water is also used in many industrial processes and machines, such as steam turbines and heat exchangers, and as a chemical solvent. Industry requires pure water for many applications and utilizes a variety of purification techniques both in water supply and discharge. It is estimated that 70% of worldwide water use is for irrigation [3], which is a key component to produce enough food. Irrigation takes up to 90% of water withdrawn in some developing countries and significant proportions in more economically developed countries (E.g. in the USA, 30% of freshwater usage is for irrigation) [4].

It is estimated that 8% of worldwide water use is for household purposes [3]. These include drinking water, bathing, cooking, sanitation, and gardening. Basic household water requirements have been estimated by scientists at around 50 liters per person per day, excluding water for gardens. Drinking water must be of sufficiently quality so that it can be consumed or used without risk of immediate or long term harm. Such water is called potable water. It is not clear how much water intake is needed by healthy people, though most specialists agree that approximately 2 liters (6 to 7 glasses) of water daily is the minimum to maintain proper hydration [5]. In most developed countries, the water supplied to households, commerce and industry is of drinking water standard even though only a very small proportion is actually consumed or used in food preparation. Today, it is estimated that one billion people lack access to clean water. The rapidly increasing demand for water and sanitation is an obvious challenge. In developing countries such as China and India, population growth is often seen as the major problem, whereas in the developed countries such as the United State, the huge overconsumption is more often considered the problem. In the long run, it is necessary that water management strategies and policies take into account both ecological and socioeconomic aspects [6].

1.2 Quantity and quality of water resources

1.2.1 Water Cycle

The water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above and below the surface of the Earth. The mass of water on Earth remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water and atmospheric water is variable, depending on a wide range of climatic variables. The water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere, by the physical processes of evaporation, condensation, precipitation, infiltration, runoff, and subsurface flow. In doing so, water goes through different phases: liquid, solid (ice), and gas (vapor). Figure 2 shows the hydrological cycle.

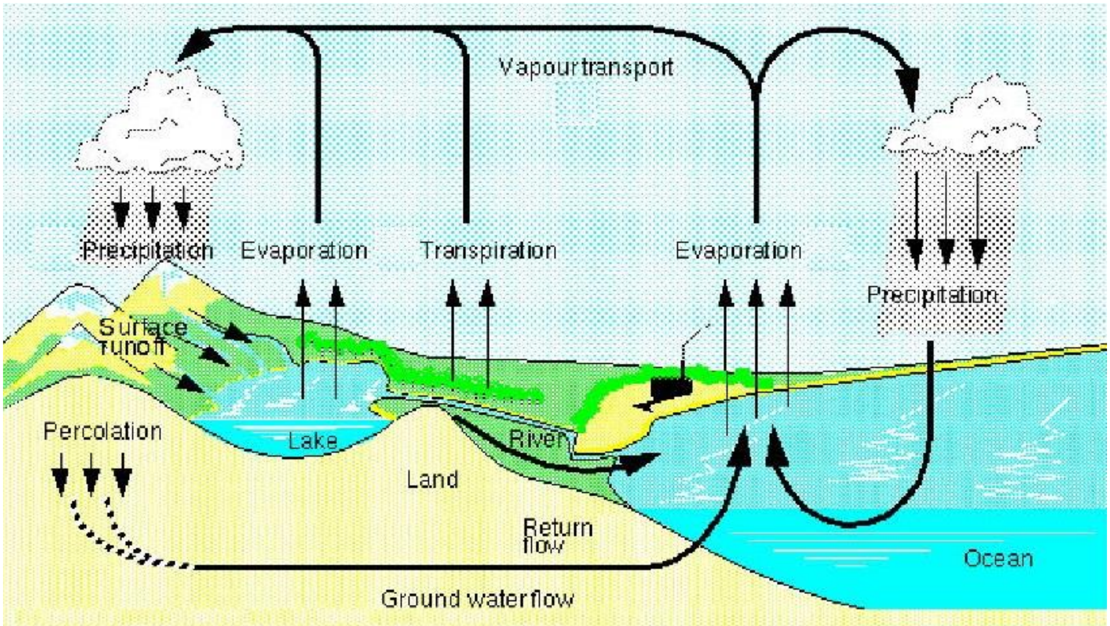


Figure 2: Hydrological Cycle in different water bodies and phases

The Sun, which drives the water cycle, heats water in oceans and seas. Water evaporates as water vapor into the air. Ice, rain and snow can sublimate directly into water vapor. Rising air currents take the vapor up into the atmosphere where cooler temperatures cause it to condense into clouds. Air currents move water vapor around the globe, cloud particles collide, grow and fall out of the upper atmospheric layers as precipitation. Some precipitation falls as snow or hail, sleet and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years. Most water falls back into the oceans or onto land as rain, where the water flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with stream flow moving water towards the oceans. Not all runoff flows into rivers, much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which can store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge.

Some groundwater finds openings in the land surface and comes out as freshwater springs. In river valleys and flood-plains there is often continuous water exchange between surface water and ground water.

Surface water is represented by streams, rivers, lakes, reservoirs, wetlands or the sea and ocean. Groundwater is the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water [7]. There is an ever-increasing need for management of surface and groundwater as they are part of an interrelated system that can be used for water supply.

1.2.2 Catchment as the geographical reference for surface water management

Catchment area, also known as watershed, is an area of land where surface water converges to a single point at a lower level, usually the exit of the basin, where the waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean [8]. A tributary stream of a brook joins a small river, which is the tributary of a larger river, which is thus part of a series of successive drainage basins. The watershed acts as a funnel by collecting all the water within the area covered by the basin and channeling it to a single point. Each drainage basin is separated topographically from adjacent basins by a perimeter, consisting of the most elevated points of the catchment area, as shown in Figure 3. Catchment topography and shape determine the time taken for rain to reach the river, while catchment size, soil type, and land use determine the amount of water that will reach the river [9]. Some details concerning these characteristics of a catchment are presented in Figure 3 below.

1) Topography determines the speed with which the runoff will reach a river. Clearly, rain that falls in steep mountainous areas will reach the primary river in the watershed faster than in the case of flat or lightly sloping areas.

2) Shape will contribute to the speed with which the runoff reaches a river. A long thin catchment will take longer to drain than a circular catchment.

3) Size will help determine the amount of water reaching the river; the larger the catchment the greater the potential for flooding. It is determined based on the length and width of the watershed area.

4) Soil type will help determine how much water reaches the river. Certain soil types such as sandy soils are very free draining and rainfall on sandy soil infiltrates easily in the ground. However, soils containing clay can be almost impermeable and therefore rainfall on clay soils will run off and contribute to surface flow. After prolonged rainfall even free draining soils can become saturated, meaning that any further rainfall will reach the river rather than being absorbed by the ground. If the surface is impermeable the precipitation will create surface

run-off which will lead to higher risk of flooding. If the ground is permeable the precipitation will infiltrate in the soil.

5) Land use can contribute to the volume of water reaching the river, in a similar way to clay soils. For example, rainfall on roofs, pavements, and roads will be collected because urban surfaces are mostly impermeable.

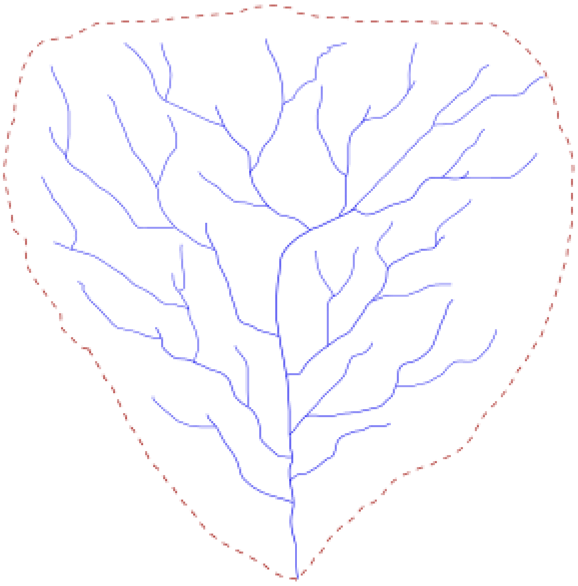


Figure 3: Schematic representation of a catchment area

1.2.3 Water bodies and pollutants

River is a natural watercourse, usually freshwater, flowing towards an ocean, a lake, a sea, or another river. In some rare cases a river can flow into the ground and dry up completely at the end of its course, without reaching another body of water. Small rivers may be called by several other names, including stream, creek, brook, rivulet, and rill.

Lake is an area, localized in a basin, that is surrounded by land, apart from any river or other outlet that serves to feed or drain the lake. Lakes lie on land and are not part of the ocean and therefore are distinct from lagoons, and are also larger and deeper than ponds.

As is mentioned in Chapter 1.1, a reservoir is an artificial lake. Reservoirs may be created in river valleys by the construction of a dam or may be built by excavation in the ground or by conventional construction techniques such as brickwork or cast concrete.

Water pollutants can be categorized as to their source. Numerous classification systems have been devised but the most general approach is to classify pollutants as coming from either a point or a nonpoint source discharge.

i) Point source (PS) pollutants enter the water from a specific point through a sewer pipe, a ditch or a culvert. Common point sources of pollution are discharges from factories and municipal sewage treatment plants [10]. This pollution is relatively easy to collect and treat. However, it needs building up appropriate infrastructures and human resources.

ii) Nonpoint source pollution (NPS), is really a new name for an old problem: runoff and sedimentation. With effective abatement of point sources pollution, contribution from non-point sources, such as agriculture, street runoff, deposition of atmospheric pollutants, mine sites, transportation corridors such as road and railways, etc., have become a major cause of water quality degradation in China [11]. Other sources can be farm fields, animal feedlots or pastures, residential developments and urban parking lots. Sediment, plant nutrients, toxic materials and animal wastes are the major types of NPS pollutants [12]. The diffuse source of these pollutants makes them more difficult to quantify and control than point source pollutants. China is one of the largest producers and consumers of chemical fertilizers in the world and the excessive nutrient loading from agricultural watersheds is considered the principal source of NPS pollution there [11].

NPS and PS pollution always co-exist in the environment [12]. The differentiation between point and nonpoint sources of contamination sometimes may depend on the scale at which the problem is considered.

In this Master Thesis, the main focus is placed on two types of surface water resources: lakes and reservoirs. Both are confined water bodies which may be regarded as almost static systems. On the contrary, rivers are more dynamic. The major problem of confined water bodies is usually the pollution from agriculture, industrial sewage and domestic wastewater.

1.3 Main variables that control the water quality in lakes and reservoirs

Due to the accelerated pace of population growth and climate change, many areas of the world are already experiencing stress on water availability. The situation about water in quantity and quality are expected to get worse. Water quality of freshwater at any point on the catchment basin changes in different periods of the year and has also spatial variations [13]. It reflects the combined effects of local, regional, global differences of many different variables. In the following sub chapter three main influencing factors are described separately, although they are also interconnected.

1.3.1 Climate

Climate and climate change affect the hydrological cycle and the atmospheric water vapor content, thereby changing patterns, intensity of precipitation, thus changing the runoff over watersheds and the stream flow in rivers [14]. To a certain degree, the water quality of rivers, lakes and reservoirs can be directly affected by changes in the amount of precipitation runoff. According to the region of the world, the whole year may have different seasons. Typically, there is a dry season which is a period of low or no rainfall; and a rainy season which is the time of the year when most of a region's average annual rainfall occurs.

In wet seasons, heavy rainfall and floods cause erosion and transport of materials into water bodies. For a given watershed with certain pollution sources, different combinations of pollutants discharges may cause different impacts in the water quality [15]. If there is just small-scale runoff pollution to a given confined water body, the water quality may even improve during the rainy season because the water level rises and dilutes the concentration of contaminants. On the contrary, if runoff pollution is a serious issue, the water quality starts to deteriorate. Meanwhile the structure and the function of plankton population may be affected. It is common to have average concentrations (biochemical oxygen demand loadings, ions and trace metals) of pollutants in the inflow water higher than at confined water bodies [15]. Similarly, the rainstorm will cause river levels to rise sharply and wash out the substances which remained on road or farmlands, and then may cause the deterioration of water quality, particularly the increase in turbidity. Other things being equal, the effects of organic and microbiological pollution should be worse in hot than in cold countries.

In the dry season, due to the low or no rainfall, the quality of lakes and reservoirs can be critical. Confined types of fresh water systems may allow high dilution of pollutants decreasing their possible impacts; even so the volume shortage in the dry season may cause a decrease of the water quality [15]. If there are relevant point sources, such as wastewater from paper mill or other kind of factories, the confined water bodies may get polluted. All these processes are very much dependent on the specific characteristics of the water mass, the presence of pollutant sources at the catchment and the regional climate pattern. Unlike lakes or reservoirs, rivers can wash away some contaminants by keep running through the whole area and moving into another river or the ocean. In spite of that, pollutants attached to particles, may settle and accumulate at the river bed.

Temperature increase brought by climate change may result in significant influence on the water quality of rivers and lakes. Temperature is an important physical property of flowing waters because of its enormous significance for all freshwater organisms. Its influence on other aspects of water quality, such as dissolved oxygen (DO) and suspended sediment concentration [16]. Thus, there is a strong relationship between water temperature and water quality. When the water temperature is about 20 °C, the concentration of DO reaches the peak. When water temperature is higher or less than 20 °C, DO content are reduced; besides, where there is higher temperature, there is higher concentration of minerals. Water temperature affects a variety of microorganisms, algae and protozoa, leading to the occurrence of water bloom phenomenon. What is more, it will result in the local ecological balance to collapse. Changes of temperature can affect nonpoint source pollution, so that it will become more urgent to manage wastewater and water pollution. In many countries, temperature has traditionally received much less attention than other facets of water quality, such as suspended sediment behavior and hydro-chemistry [17]. However, recent years have witnessed a renewed interest in the thermal behavior of water systems, which reflects a number of factors. Recent advances in monitoring and in modeling have facilitated greatly the collection and analysis of information, and an increasing number of field investigations have revealed the complexity of the heat fluxes controlling water temperature.

Water temperature variations tend to lag behind air temperature fluctuations. For larger water bodies, with higher flow volumes and greater thermal capacities, this effect becomes more pronounced. Grant [17] suggested that the maximum water temperature on a given day in the Ngaruroro River, New Zealand should be predicted not only from the maximum air temperature on that day but also from the maximum air temperature on the preceding day. Stefan and Preud'Homme [16] have shown more generally that regression relationships based on daily mean values can be significantly improved by introducing a lag into the data.

1.3.2 Land use of the catchment

Land use kinds is regarded as one of the most important variable that controls water quality. A major potential risk to the water bodies is the wastewater discharged from urban areas, factories and agricultural area. Sources of water pollution are municipal, industrial and agricultural wastewater runoff. The most polluting of them are sewage and industrial waste discharges.

The agricultural development of China uses irrigation systems and this requires the sustainable utilization of water resources [18]. Humans have also engineered many agricultural chemicals, such as pesticides and fertilizers, which are environmental threats to water quality. What's more, fertilizers cause a cumulative increase in Nitrogen compounds and Phosphorus, which results in degradation of water resources [11]. Industrial effluents may contain heavy metals, acids and hydrocarbons. As a result, if the water bodies are located near industrial parks or farmlands, the quality of water can be badly affected. The pollutants can migrate with the water flow, therefore the water quality downstream would be inferior compared to the upstream, and the pollution in small tributaries should be more serious than that in the main channel. In China, the water quality in Southern is superior to Northern and the water bodies in the Central and Western regions compared to Eastern developed regions have a better water quality [19].

1.4 Legislation and regulation. Example from China

In China, since 1980s, modernization efforts have drawn attention to many previously neglected problems like nonpoint source pollution, environmental health and safety [20]. Many laws and public involvement in their enforcement have played a constructive and indispensable role in environmental protection, based on prevention, on the polluter pays principle and on the cooperation principle [21].

With the progress of the times, the Water Law of the People's Republic of China was created as the main law of water in China in 2002. It was enacted for the purposes of rationally developing, utilizing, conserving and protecting water resources, preventing and controlling the flood, bringing about sustainable utilization of water resources, and meeting the need of national economic and social development [22]. This law also defines general and specific objectives related to the protection of different water bodies in China and defines water quality standards and programs and measures that should be implemented in furtherance of the objectives.

Additionally to this main law, some other regulations also play an important role in protecting surface waters in China. There are standards to limit the emissions of pollutants. An example is GB3838 that is concerned with surface water quality. The provision of GB3838 was firstly formulated in 1988 and then updated in 2002 with the water quality evaluation [23]. In it, according to the surface water uses and objects, 5 classes of water protection are defined as follows：

Class 1: applies to waters resource and national nature reserves;

Class 2: applies to Grade-I protective zones* [24] for surface waters that are source of drinking water, habitats for rare aquatic lives, spawning grounds and feeding grounds;

Class 3: applies to Grade-II protective zones* [24] for surface waters that are source of drinking water, wintering grounds and migration channels of fish and shrimp, as well as aquaculture activity and swimming areas;

Class 4: applies to water bodies that supply water to ordinary industrial and recreation areas without people’s direct contact;

Class 5: applies to water bodies that supply water to agricultural irrigation and areas of general requirement.

*According to the Law of the People's Republic of China on Prevention and Control of Water Pollution [24] Grade 1 protective zoom is that: where the agricultural activities, industrial and urban wastes, oil depots and cemeteries are not allow; Grade 2 protective zoom: where the irrigation sewage without purification, industrial activities with serious pollution such as chemical industry, electroplating, leather industry, paper making industry, smelting, radioactive, oil refining are not allow in this area.

Table 1: Standard Limit Values of Basic Items of Surface Water Environmental Quality (GB3838) [23]***. Unit: mg/L***

No.	Items	Class 1	Class 2	Class 3	Class 4	Class 5
1	Temperature (℃)	Range of water temperature change caused by artificial reasons: Average maximum temperature rise each week ≤ 1 ℃ Average maximum temperature drop each week ≤ 2 ℃				
2	pH	6-9				
3	DO ≥	Saturation factor 90%（or 7.5）	6	5	3	2
4	Hypermanganate index ≤	2	4	6	10	15
5	COD ≤	15	15	20	30	40
6	BOD_5 ≤	3	3	4	6	10
7	NH_4-N ≤	0.15	0.5	1.0	1.5	2.0
8	TP ≤	0.02（Lakes natural or man-made 0.01）	0.1（Lakes natural or man-made 0.025）	0.2（Lakes natural or man-made 0.05）	0.3（Lakes natural or man-made 0.1）	0.4（Lakes natural or man-made 0.2）
9	TN ≤	0.2	0.5	1.0	1.5	2.0
10	Cu ≤	0.01	1.0	1.0	1.0	1.0
11	Zn ≤	0.05	1.0	1.0	2.0	2.0
12	Fluoride (as measured by F^-) ≤	1.0	1.0	1.0	1.5	1.5
13	Se ≤	0.01	0.01	0.01	0.02	0.02
14	As ≤	0.05	0.05	0.05	0.1	0.1
15	Hg ≤	0.00005	0.00005	0.0001	0.001	0.001
16	Cd ≤	0.001	0.005	0.005	0.005	0.01
17	Hexavalent chrome ≤	0.01	0.05	0.05	0.05	0.1
18	Pb ≤	0.01	0.01	0.05	0.05	0.1
19	Cyanide ≤	0.005	0.05	0.2	0.2	0.2
20	Volatile hydroxybenzene ≤	0.002	0.002	0.005	0.01	0.1
21	Petroleum ≤	0.05	0.05	0.05	0.5	1.0
22	Anionic surface-active agent ≤	0.2	0.2	0.2	0.3	0.3
23	Sulfide ≤	0.05	0.1	0.05	0.5	1.0
24	Coliform group（CPU/L）≤	200	2000	10000	20000	40000

Different surface waters according to the above-mentioned uses have their corresponding standard values for quality control. The standard value for the control of more demanding uses of water is stricter than that of lower classes. When the water body is of different class uses, the standard value for the highest class shall be the only reference [23]. Table 1 shows the standard limits for basic items of Environmental Quality Standard for Surface Water (GB3838).

Compared to Europe, China is a developing country and safety of drinking water is an urgent subject to be improved. After being purified in the waterworks and reaching the quality standard, the water must go through a long pipeline, and there is the possibility of secondary contamination of the water. This problem occurs more often in the Northwest than that of Southeast. Therefore, people in China are used to boiling the tap water before drinking it.

Being similar to GB3838, standard GB3097 [25] the marine water quality standard, was created in 1982 and then revised in the year of 1997. It provides a very intensive and detailed provision for prevention of pollution of sea water.

Replacing the version of GB8978-1988, standard GB8978-1996 was made in 1996 [26], in order to control water pollution, protect surface water in rivers, lakes, channels, reservoirs and the sea, and to protect the quality of groundwater, safeguard people's health, ensure ecological balance, promote the development of the national economy and rural and urban construction.

Wastewater will eventually discharge to a certain area. GB8978 enforces the maximum allowable discharge concentrations for 69 water pollutants and the maximum allowable discharge volume for certain industries. Additionally, this standard applies to the management of water pollutant discharge of existing units, including the environmental impact assessment of construction projects, design of environmental protection equipment of construction projects, post-construction inspection and management of discharge after commencing production. The technical contents are as follow:

1) Wastewater discharged into a GB3838 [23] Class 3 water body (excluding designated protected areas and swimming areas), and wastewater discharged into a GB3097 [25] Class 2 marine water body, must meet Class 1 standards.

2) Wastewater discharged to a GB3838 [23] Class 4 or 5 water body, and wastewater discharged to a GB3097 [25] Class 3 marine water body, must meet Class 2 standards.

3) Wastewater discharged into city and town sewage systems which have a secondary wastewater treatment plant, must meet Class 3 standards.

4) Wastewater discharged into city and town sewage systems which do not have a secondary wastewater treatment plant, should be subject to provisions 1) or 2) (as shown above) according to the functional requirements of the water bodies which receive effluent from the sewage system.

5) New pollution discharges are forbidden in water bodies of Class 1, 2 and 3, designated protection regions of GB3838 [23]; and in Class 1 marine waters of GB3097 [25]. Mass loading controls should be implemented on existing discharges in accordance with the use of the water body in order to ensure that the water quality of the receiving water conforms with the relevant water quality standard.

2. Objectives and Methods

This Master Thesis has the main objective of understanding the most relevant processes that control water quality in lakes and reservoirs in China. Hydrological and water quality processes are important in this concern everywhere. It is the specific conditions, controlled by climate characteristics, geographic conditions and the presence of pollution sources that represent a natural, social, economic and legislative framework that are targeted in this work.

The main objectives can be divided into three points:

a) To make an overview of the water quality issues in lakes and reservoirs in China.

b) To describe the hydrology and water quality of selected case studies, under different climatic regions and pollution pressures in China, including the characterization of the water body, rainfall pattern and seasonal variation, as well as the water quality processes.

c) To analyze the variables of the selected studies related to water quality, in order to identify the most common water quality problems and the relevant variables that control water quality. Based in this information, to build up guidelines to assess critical conditions for water quality in lakes and reservoirs.

The tasks to be performed may be summarized as follows:

1) Literature revision based on scientific publications.
2) Selection of 2 groups of 3 lakes/reservoirs of comparable dimension (volume and catchment area) and placed in different precipitation regions of China.
3) Characterization of the case studies, based in the literature research.
4) Description of the hydrological and water quality processes in each site.
5) Comparison of the two groups of case studies and discussion of the water quality status for each case, including seasonal changes.
6) Analysis of the most relevant variables that control water quality in lakes and reservoirs
7) Writing of the report containing a description of the work done (Master Thesis).

The methods used to conduct this work are based in scientific publications, searched on international journals databases, Google map, and other available sources of useful information on the case studies. They will be followed by the analysis of the information and the writing of the Master Thesis.

3. Literature research

3.1 Overview of recent studies of lakes and reservoirs in China

The distributions of water resources in the whole territory of Chinese are unequal. There are five areas which contain more abundant water resources than others: the Eastern plain water region, the Northeast mountain lake area, Yunnan-Guizhou plateau area, the Qinghai-Tibet plateau area and the Mongolia-Xinjiang water region [27].

To ensure that the searched data is representative and comprehensive, relevant key words were used to find scientific literature using search engines. Only studies of lakes and reservoirs which were published recently were considered.

Based on key words concerning water quality, 58 references were found; 49 of the papers issued from 2008 to 2014, meaning that almost 84% are quite recent publications; besides, 28 of the cases concern reservoirs and 30 focus on lakes. The water bodies in the selected literature are from different provinces in China, meaning that the sample is representative and comprehensive for accomplishment of the study objectives.

Figure 4 shows the location of the lakes and reservoirs from the literature studies. It shows clearly that different climatic Chinese regions and research backgrounds were covered. It is in line with the pattern that Chinese reservoirs and lakes are mainly distributed in the Eastern monsoon area and there are not monsoon areas in the West that has less lakes and reservoirs. In contrast, water resources in Southern China are more abundant than in the North [27]. Table 2 presents a summary of the 58 studies.

Figure 4: Location of the 58 cases selected for the analysis [28]

Table 2: Summary of the 58 studies used for analyzing the quality issues in lakes and reservoirs

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2013**[29]**	Northern China Reservoirs	SS	NPS, point source	NA	MD, FA	5. 23 /NA*	NA
2011**[30]**	Songtao watershed in Hainan Province	NO_3-N, NH_4-N, and TP	NPS, agriculture pollution	2	Eco-HAT, regression and Scenario analyze,	29 /1496	1896
2011**[11]**	Three Gorges Reservoir Area in Hubei Province	TN, TP	NPS, rural domestic wastes distributed livestock farms, fertilizers, pesticides	2	MD, ECM	393 /1000000	1070-1682
2012**[14]**	Shitoukoumen Reservoir in Jilin Province	Annual NH_4-N and TP	NPS, municipal, industrial, and agricultural sources	3	MD, SWAT model	12.64 /4944	369.9-667.9
2011**[31]**	Dahuofang Reservoir in Liaoning Province	BOD, DO, NH_4, NO_3, TN, TP	NPS, PHYT	2	3-D eutrophication model, Hydrodynamic model, MD	21.87 /5437	840
2011**[32]**	A reservoir in Northern Taiwan	PCDD/Fs	NPS	NA	MD	4.06 /309	2500
2008**[33]**	Yuqiao Reservoir in Tianjin city	COD_{Mn}, TN and TP	Eutrophication: farmland fertilization and fishpond	3	2-D coupled model of hydrodynamics and water quality, MD	15.6 /2060	750
2011**[34]**	Water quality in the SouthWest New Territories and Kowloon	BOD_5, COD, F.coli, E.coli, NH_4-N, TP, NO_3-N	Point source: industrial pollution, and NPS	3	MD, CA, DA, PCA	NA	NA
2010**[35]**	In Chongqing region of Three Gorge Reservoir	Antibiotics	Hospitals, nursery, slaughter house and wastewater treatment plant	2	MD	NA	NA

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2013**[36]**	Shengzhong Reservoir in Sichuan	TN, TP	NPS, agriculture, rural life, livestock breeding, agricultural fertilizers,	3	MD, LA	13.39 / 1756	600—750
2009**[37]**	Baixi Reservoir in Zhejiang Province	E.coli, F, DO	Agricultural sources, domestic pollution source	2	MD, CS	1.684 /254	1840.8
2005**[38]**	The main reservoir in Xinjiang	DO, TP, COD, BOD_5, CN^-, TN, As, Cr, Hg, Cd, Pb, Cu, Zn, F^-, S^{2-}	The long-term human development: NPS and point source	5	MD, FA	NA	NA
2013**[39]**	Twenty reservoirs from Guangdong	TN, TP, DO, TSS, NH_4, NO_2^-, NO_3^-	Agricultural sources, phytoplankton species	NA	CS, MD, biological and chemical analyses	0.017 -0.786 /0. 7 -133	1458-2765
2008**[40]**	Hongfeng Reservoir in Guizhou Province	THg, DHg,	Agricultural, domestic and industrial waste waters, NPS and point source	3	MD, all methods for mercury analysis	6.01 /57.2	1176
2007**[41]**	Wujiangdu Reservoir in Guizhou	THg, DHg	Continuous input of labile allochtonous organic matter: food and Insect larvae, suspended particulate matter and bio-film at the soil-water interface	3	PCA	23 /27800	900-1400
2014**[42]**	Jiangdong Reservoir in Fujian	TP, TN, NH_4-N, NO_3-N, SRP	Algal blooms: phytoplankton, and human activities, NPS, point source	4	CCA, PCA, MD	NA	1771.3

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2012**[43]**	Fenhe Reservoir in Shanxi	PAHs	Coal combustion, emissions of diesel and gasoline	3	CA, MD	7.2 /5268	300-700
2013**[44]**	Fenhe Reservoir in Shanxi	PAHs and PCBs	Industrial sources	3	TEQ, PCA	7.2 /5268	300-700
1998**[45]**	Yantan Reservoir in Guangxi	BOD, DO, CN, VP, Cr^{6+}, TP, TN	Industrial sources, soil erosion, domestic sewage	4	MD	26.1 /106580	1508
2010**[46]**	Changtan Reservoir in Zhejiang	DO, NO_3-N, NH_4-N, BOD, TN, Cl^-, F^-	Point sources, NPS, agricultural, the pollution of lead zinc mine	2	MD	6.91 /441.3	1650.9
2010**[47]**	Water Environment in Xinjiang	DO, TN, TP	Industrial structure, rural agricultural chemical fertilizer, pesticide, organic substance and mass salinity in soil, domestic sewage, household garbage of peasant and herdsman	5	MD, EA	NA	165.5
2008**[48]**	Yuqing Lake reservoir in Shandong	COD, NO_3-N, NH_4-N, TP, TN	Organic pollution discharge	3	MD, Projection pursuit, grey prediction	0.485 / NA	667
1998**[49]**	Muyu Reservoir watershed in Shandong	OM, heavy metals	pesticides and fertilizer	3	MD	1.87 /544	570
2004**[50]**	Manwan Reservoir in Yunnan	OM	Urban pollution, soil erosion, highway and irrigation projects construction	2	MD	9.2 /114500	900-1700

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2007**[51]** 2009**[52]**	Danjiangkou Reservoir in Henan	COD, TN, TP, heavy metals	Mining industry, paper making industry, brewing, pharmaceutical, leather making and other heavy polluting enterprises	2	CA	339.1 /95200	800
2014**[53]**	A drinking water reservoir area in Shanghai	TOC	Environmental estrogens: animal feed operation	2	MD	NA	NA
2011**[54]**	The Beijing Guanting Reservoir	TP, TN, NH_3-N	Excessive nutrients, phytoplankton	4	MD, 3-dimensional eutrophication model	41.6 /43402	426
2012**[55]**	Lake Chaohu in Anhui Province	TOC and TN	Anthropogenic imports, agricultural, eutrophication	≥5	MD, PCA	NA	NA
2010**[56]**	Liuhai Lake in Beijing	COD_{Mn}, TP, TN, NH_3-N	Eutrophication: NPS and point source	4	MD, PCA	NA	NA
2014**[57]**	Lakes Shichahai and the Lakes in Summer Palace	PAEs	Anthropogenic activities: cosmetics, personal care products	4	MD, PCA	NA	NA
2009**[58]**	Luhu, an urban lake in Guangzhou	PAH	Vicinity of urban and industrial areas	4	MD	NA	NA
2011**[59]**	Aha Lake in Guizhou	DOC, EC, DO, Fe, Mn and Al	Acid mining drainages	3	MD, PCA	5.4 /190	1109
2011**[60]**	Hongfeng Lake in Guizhou	Pb	Industrial source	3	MD	NA	NA
2012**[61]**	Baiyangdian Lake in Hebei	EC, DO, BOD, COD_{Mn}, TP NH_4-N, TN, NO_3-N, NO_2-N,	Domestic sewage, industrial wastewater, agricultural sewage, fishery-related pollution	3	Multivariate statistical techniques: PCA, CA	3.3 /31199	560.3

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2013**[62]**	Honghu Lake in Hubei	OCPs	Chemical residues from soils, agricultural source	3	PCA, MD	NA /3000	NA
2007**[63]**	Dongting Lake in Hunan	DO, EC, TN, TP, NH_3-N	Organic pollution, agricultural activities	5	MD, FA	170 /262800	1100-1400
2011**[64]**	Chagan Lake of Jilin	CDOM, TOC, heavy metals	Phytoplankton, mineral, organic matter discharge, non-algal particles	3	MD, PCA	5.98 /35.18	450
2013**[65]**	Hongze Lake in Jiangsu	OCPs	Agricultural source	3	PCA,MD	NA	NA
2001**[66]**	Taihu lake in Jiangsu	TP, TN	Industry and agriculture	⩾5	PCA, MD	NA	NA
2011**[67]** 2012**[68]**	Poyang Lake in Jiangxi	TP, TN, COD	Agricultural and industrial pollution	4	MD	276 /162200	1636
2010**[69]**	Wolong Lake in Liaoning	DO, COD, BOD, oil, NH_4-N, TP, S^{2-}, VP, F^-, CN, As, Hg, Cr	Human development activities: NPS and point source	5	MD, Dynamic Analysis	0.962 /1592.7	542.39
2012**[70]**	Hulun Lake in the inner mongolia	COD_{Mn}, DOM, DO, DOC, EC, OM, TN, TP	Livestock: the high concentration of organic matter	⩾5	PCA, MD, FA	131.3 /153700	319
2008**[71]**	Ulansuhai Lake in the inner mongolia	CN, DO, NH_3-N, TN, TP	Agricultural irrigation	5	CA, pattern recognition	NA	NA
2014**[72]**	Qinghai Lake in Qinghai	TP	NPS	2	MD, Digital Elevation Model	NA	NA
2010**[73]**	Lake in Shandong	PCBs and PCDD/Fs	Pentachlorophenol and sodium pentachlorophenate products	3	WHO-TEQ, MD, Chemical analysis	NA	NA

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2008**[48]**	YuqingLake in Shandong	COD, NH_3-N, TN, TP	Industrial wastewater and domestic sewage	3	MD, PCA, Projection Pursuit, Grey Prediction	NA	NA
2013**[74]**	Dianshan Lake near Shanghai	Chla, SC, WT	NPS: Eutrophication	3	MD, CCA	NA	NA
2011**[75]**	Three Forks Lake in Sichuan	DO, EC, Mn^{6+}, NH_3-N, TP, TN,	Cage breeding of fish and household garbage	3	CA, MD	2.27 /161.25	836.2
2013**[76]**	Sun Moon Lake in central Taiwan	PCDD/Fs	Organochlorine pesticides production, paper making industry	4	PCA, MD	1.72 /15	2281
2008**[77]**	Wulungu Lake in Xinjiang	TOC, TN	NPS, point source	5	MD, DCA, PCA	60.2 /35440	116.5
2005**[38]**	Mainly lake in Xinjiang	COD, DO, F^-, BOD_5, TP, TN, CN^-, As, Cr, Hg, Cd, Pb, Cu, Zn, S^{2-}	The long-term human development: NPS and point source	5	MD, FA	NA	NA
2013**[18]**	Dianchi Lake in Yunnan	DO, DRP, EC, NO_3-N, TP, TN	NPS: agricultural irrigation system and rural fertilizer, Plastic greenhouse cultivation	⩾5	Isotope analysis, MD	15.7 /3000	1007
2012**[78]**	Fuxian Lake in Yunnan	COD, TN, TP	Livestock: short term high nutrient concentrations directly stimulate algae outbreaks	1	MD, 3-dimensional hydrodynamic and water quality model	206.2 /1084	879.1
2010**[79]**	Yangzonghai Lake in Yunnan	As, TOC	Arsenic contamination accident	3	MD	5.9 /192	963.5

Reference &date	Reservoir or Lake Location	Parameters of pollutant	Pollution sources or pollution drivers	Water quality (class)	Methodologies used	Volume ($10^8 m^3$) and Catchment area (km^2)	Annual mean rainfall (mm)
2009**[80]**	Taihu Lake in Zhejiang	DOC, SRP, NO_3-N, NH_4-N, TP, TN	Industrial pollution, anthropogenic pollution.	⩾5	PCA, CA	57.68 /36500	1181
2011**[81]**	Caiyun Lake in Chongqing	DO, TP, TN	Algae pollution: blue-green algae	NA	MD	NA	NA

NA: data not available.

3.2 Analysis of the 58 selected papers

Based on Table 2 information, Table 3 demonstrates that the main point pollution source in Chinese lakes and reservoirs are industrial effluents and domestic sewage, which contain organic pollutants, chemicals and heavy metals. NPS pollution include agriculture, mine sites, etc. Agriculture is the most relevant NPS. Besides, based on the papers selected, it is observed that NPS are the most serious problem, which carries sediments, nutrients, toxins, organic materials and other pollutants into receiving waters.

Table 3: Number of studies from the 58 cases that concern Point and NPS pollution

Pollution sources	Point		NPS	
	Industrial	Domestic	Agricultural	Mining activities
Lake	11#	9#	13#	2#
Reservoir	10#	11#	15#	4#
Total	21#	20#	28#	6#

As Table 2 shows the parameters of pollutant, TP and TN are the most common mentions, suggested that P and N pollutants were mostly related to the NPS; NH_4-N (NH_3-N), DO and COD are the second common parameters mentioned; NO_3-N and BOD are regarded as the third common one. This information is summed up in Table 4.

Table 4: Number of studies from the cases that concern the common water quality parameters

Parameters	TP	TN	NH_4-N (NH_3-N)	DO	COD	NO_3-N	BOD
Total	30#	29#	17#	16#	13#	8#	8#

According to the monitoring data and standard GB3838 [23], the water quality of 52 water bodies from the selected papers is counted as shown in figure 5: 19 of them are of class 3, 10 of class 2, 8 of class 4, 6 of class 5 and 4 of inferior class 5 (of which only 1 in class 1). The remaining 4 do not have the available data. It is observed that most of the selected water bodies are of class 3. On the other hand, among the 11 water bodies regarded as class 1-2, 9 of them are reservoirs and 2 of them are lakes; among the 18 water bodies of class 4, class 5 and inferior class 5 level, 15 of them are lakes and 3 of them are reservoirs. Therefore, it seems that the water quality of reservoirs is likely to be better than that of lakes.

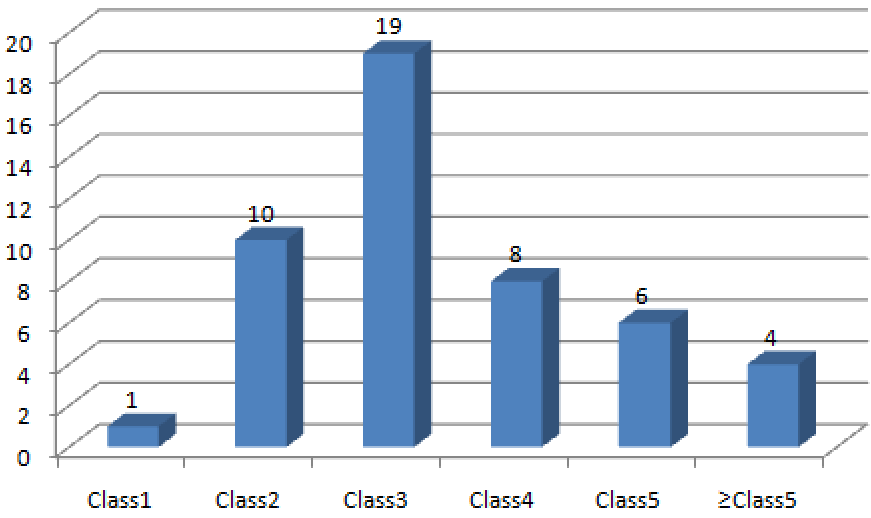
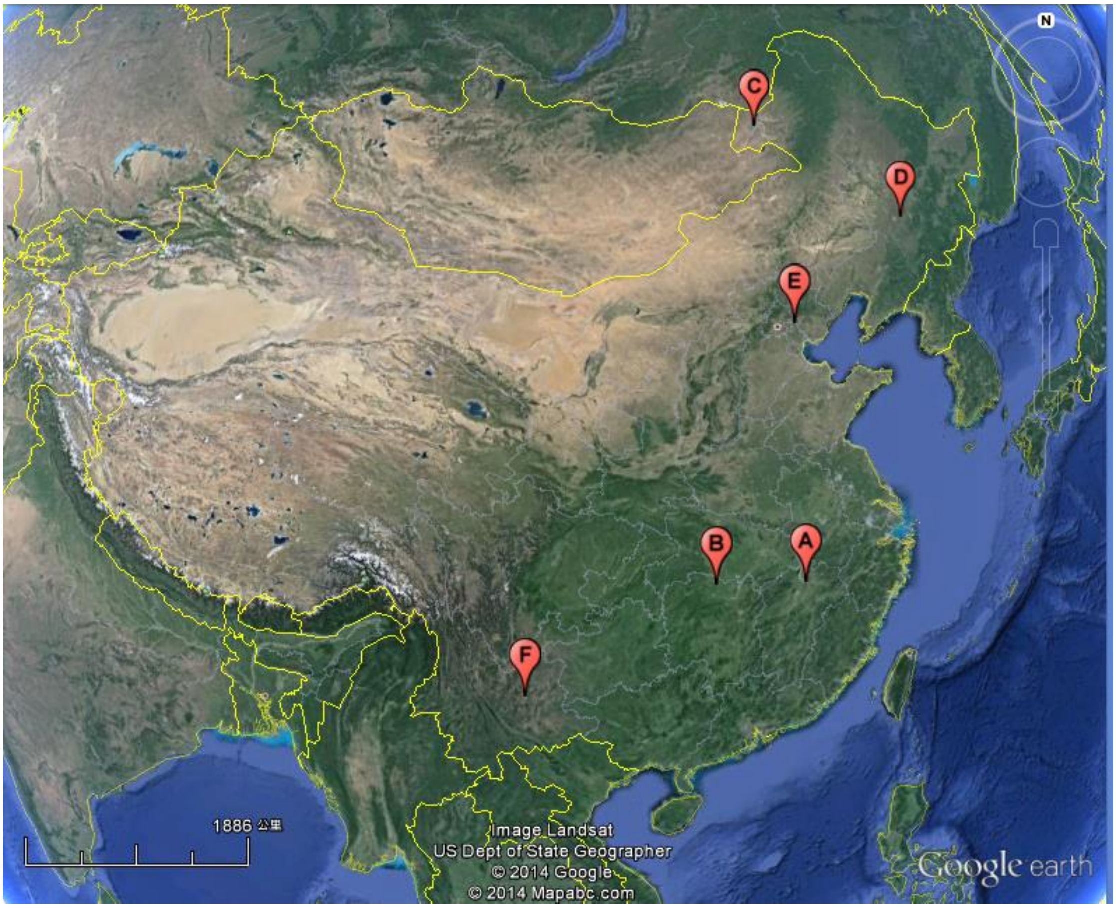


Figure 5: Water quality distribution in the 52 water bodies according to GB3838 standard

3.3 Selection of 6 case studies (two groups)

Based on Table 2, two groups of three reservoirs and lakes were selected as the case studies for this work. Figure 6 shows that the 6 case studies are located in different regions of China. Table 5 includes a summary of the 6 studies.

All the selected reservoirs and lakes have similar pollutants which mostly include TP and TN. The papers include information about water quality processes and seasonal variations, a summary of these case studies is presented in Table 5.



Group 1 A: Poyang Lake in Jiangxi Province
B: Dongting Lake in Hunan Province
C: Hulun Lake in the inner Mongolia

Group 2 D: Shitoukoumen Reservoir in Jilin Province
E: Yuqiao Reservoir in Tianjin
F: Dianchi Lake in Yunnan Province

Figure 6: Location of the reservoirs and lakes selected for analysis [28]

Table 5: Summary of the 2 groups of 3 studies used for analyzing the water quality issues in reservoirs or lakes

Reference & date		Location	Parameters	Pollution sources	Methods
Group 1	[67] 2011 [68] 2012	Poyang Lake in Jiangxi Province	COD, TP, TN	Agricultural and industrial pollution, domestic sewage	MD
	[63] 2007	Dongting Lake in Hunan Province	DO, EC, NH_3-N, TN, TP	Organic pollution, domestic sewage and agricultural pollution	FA, MD
	[70] 2012	Hulun Lake in the inner Mongolia	COD_{Mn}, DO, DOC, DOM, EC, OM, TN, TP	Livestock and agricultural pollution	FA, MD, PCA
Group 2	[14] 2012	Shitoukoumen Reservoir in Jilin Province	COD, NH_4-N, TN and TP	Municipal, industrial, and agricultural sources, domestic sewage	Modeling, MD
	[33] 2008	Yuqiao Reservoir in Tianjin	COD_{Mn}, TN and TP	Farmland fertilization, fishponds	Modeling, MD
	[18] 2013	Dianchi Lake in Yunnan Province	COD, DO, EC, NO_3-N, TP, TN	Agricultural fertilizer, domestic sewage	MD, PCA

3.4 Comparison of the two groups of case studies

Concerning the types of pollutant source, all studies include NPS pollutant. Among them, 4 include both point source and NPS pollutants. More specifically, as Figure 7 demonstrates, 6 studies mention agricultural pollution, 4 concern domestic sewage, 2 focus on industrial pollution, and 2 includes other pollutions.

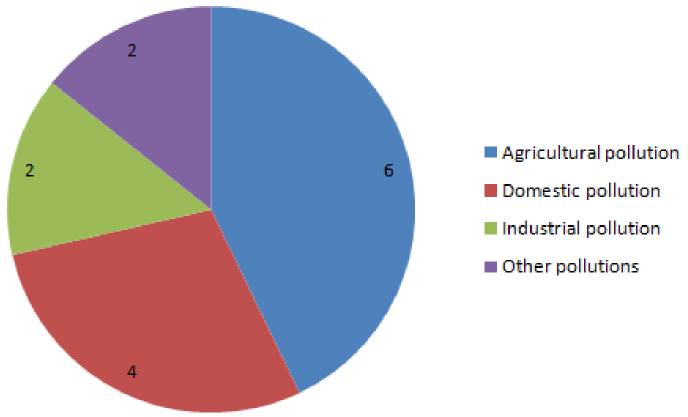


Figure 7: Different pollutant sources analyzed in the 6 lakes and reservoirs

Analyzing the different methodologies used for assessment of water quality on the selected references, as Figure 8 shows, it is concluded that 6 studies use monitoring, 3 use statistic methods, and 2 use modeling approaches.

Particularly worth mentioning is that the most used statistic methods are Principal Component Analysis (PCA, 2 papers [18][70]), Faction Analysis (FA, 2 papers [63][70]). Among them, 1 paper [70] includes both PCA and FA. The used modeling tool is the Soil and Water Assessment Tool (SWAT) [14] and a hydrodynamic and water quality model [33].

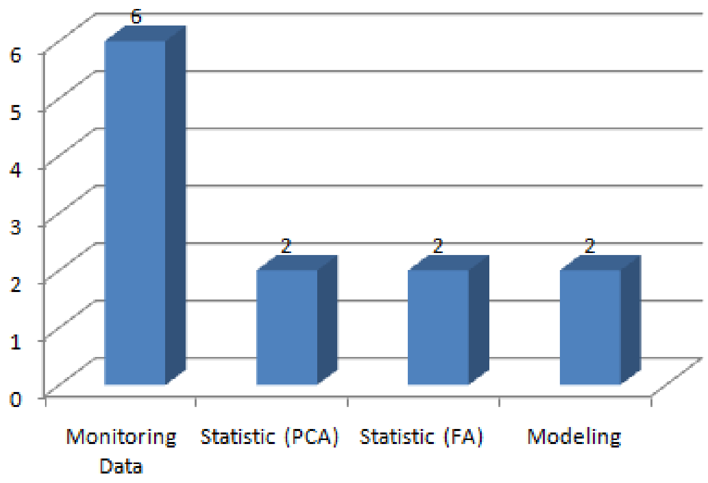


Figure 8: Different methodologies used to assess water quality at the 6 case studies

4. Characterization of the selected case studies

Each group consists of reservoirs or lakes of comparable dimension characterized by the volume and catchment area. Additionally they are placed in different precipitation regions of China, as shown in Table 6.

Table 6: Characteristics of the case studies

Group 1:

	Poyang Lake (29°15'N, 116°15'E)	Dongting Lake (29°30'N, 111°50'E)	Hulun Lake (48°55'N, 117°15'E)
Catchment area (km^2)	162200	262800	153700
Volume ($10^8 m^3$)	276.0	170.0	131.3
Annual mean rainfall (mm)	1636	1250	319
Surface area (km^2)	3283	2691	2339
Maximum depth (m)	25.1	18.6	8.0
Mean depth (m)	8.4	7.0	5
Water quality level according to GB3838	Class 4	Class 5	≥ Class 5
Water uses	Supply water for aquaculture, agricultural and industrial uses	Supply water for aquaculture, agricultural and industrial uses	Supply water for aquaculture and agricultural uses

Group 2:

	Shitoukoumen Reservoir (43°58'N, 125°45'E)	Yuqiao Reservoir (40°02'N, 117°25'E)	Dianchi Lake (24°49'N, 102°41'E)
Catchment area (km^2)	4944	2060	3000
Volume ($10^8 m^3$)	12.6	15.6	15.7
Annual mean rainfall (mm)	565	750	1007
Surface area (km^2)	117.0	135.0	309.5
Maximum depth (m)	12.0	14.0	10.9
Mean depth (m)	7.3	9.0	4.4
Water quality level according to GB3838	Class 3	Class 3	≥ Class 5
Water uses	Drinking water source, supply water for agricultural uses	Drinking water source, supply water for agricultural uses	Supply water for aquaculture, agricultural and industrial uses

Concerning the catchment area and precipitation, as Figure 9 shows, the water body from Group 1 with highest volume is Poyang Lake. Dongting Lake is the water body with the largest catchment area. The catchment area of Poyang Lake are similar to that of Hulun Lake. However, Poyang has the largest annual mean rainfall while Hulun has the smallest one, only accounting 319mm. Dianchi Lake has the biggest volume in Group 2. However, Yuqiao Reservoir has the smallest catchment area but a volume comparable to Dianchi Lake. Therefore, they are interesting cases to be studied.

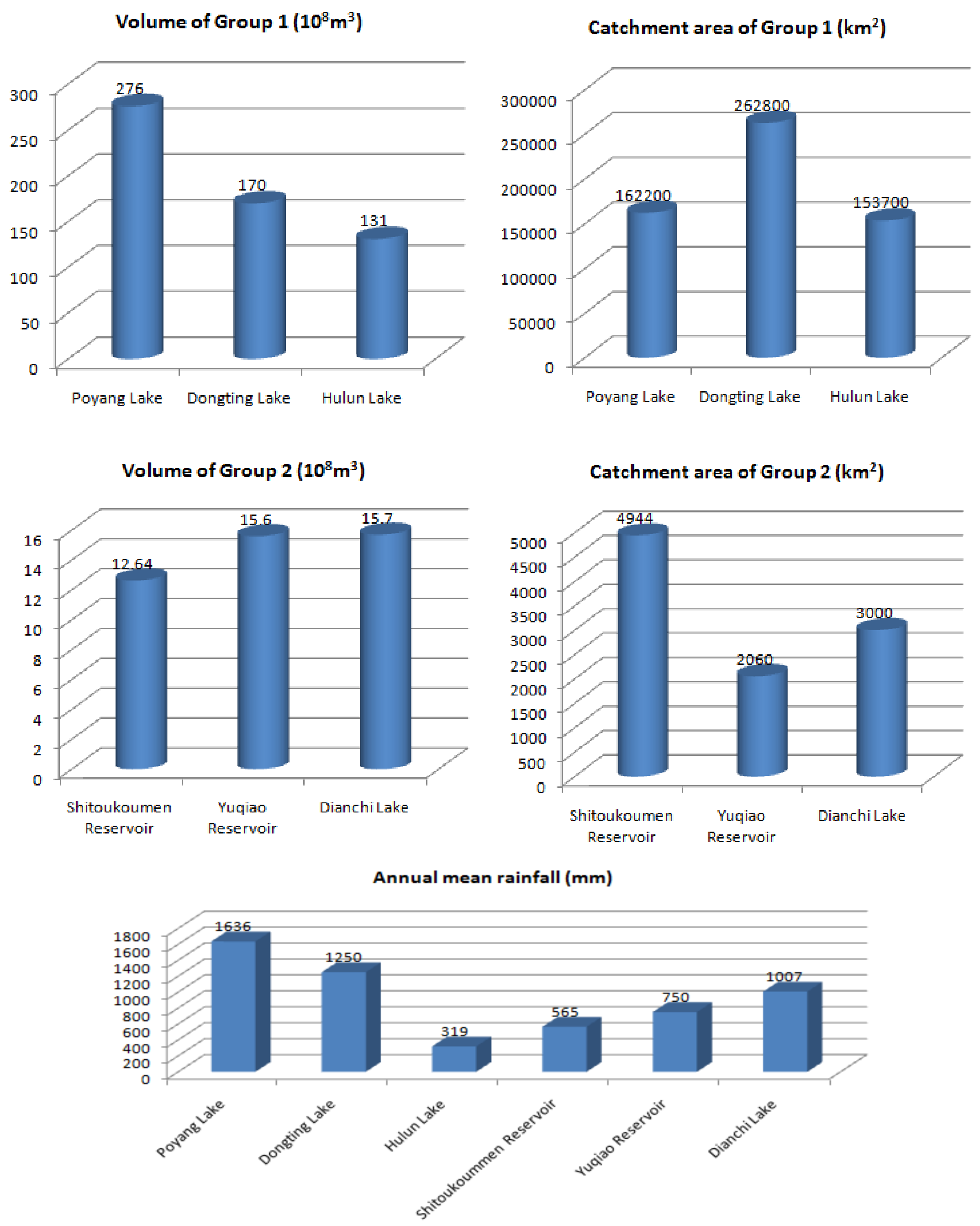
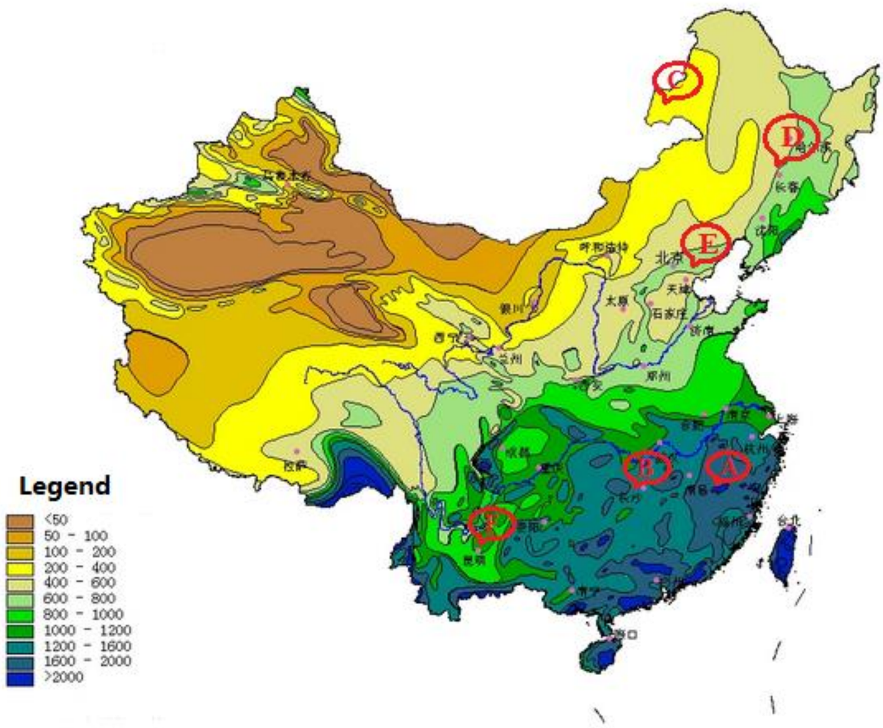


Figure 9: Main characteristics of the 6 lakes and reservoirs

5. Hydrological and water quality processes in the case studies

It is important to understand the distribution of precipitation in China, and this chapter will focus on details about the 6 case studies' catchment, land use and climatic conditions. Increasing rainfall variability can affect watershed biogeochemical processes and surface water quality through interactions between hydrology and biogeochemical processes, including the production, release, and transport of natural materials and anthropogenic pollutants [82].

As the Figure 10 shows, in regions such as the Southeast part of North China, the lower reaches of the Yellow River and most parts to the South of the Weihe River, the annual precipitation is over 500 mm. Among them, the middle and lower reaches of the Yangtze River, most of the region to its South bank and some areas of the Eastern part of Southwest China receive 1000 mm - 2000 mm of precipitation. As for the remaining of China, the precipitation is less than 500 mm.



Group 1 A: Poyang Lake in Jiangxi Province
B: Dongting Lake in Hunan Province
C: Hulun Lake in the inner Mongolia

Group 2 D: Shitoukoumen Reservoir in Jilin Province
E: Yuqiao Reservoir in Tianjin
F: Dianchi Lake in Yunnan Province

Figure 10: Distribution of annual mean precipitation of China [83]

In the Southeast of China there is higher rainfall volume whereas in the Northwest there is less rainfall; on the other hand, the distribution of freshwater resources is highly unbalanced in China. Northwest China accounts for 64% of the national territory, but provides only 19% of the country's available water resources. Southeast China possesses 81% of the total national water resource [84]. As Figure 10 shows, the water bodies marked A, B and F are located in Southern China while the study cases marked C, D and E are in Northern China.

Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Owing to tremendous differences in latitude, longitude, and altitude, the climate of China is extremely diverse (as shown in Figure 11).

Figure 11: China climate types [28]

5.1 Hydrological and water quality characteristics of the 3 lakes of Group 1

The lakes from Group 1 have a bigger size than that of Group 2. They are Poyang Lake (A), Dongting Lake (B) and Hulun Lake (C). The aim of this sub-chapter is to describe the hydrological conditions of Group 1, including geographical position, rainfall pattern and climate and land use and to summarize the pollutant and water quality of the case studies

5.1.1 Poyang Lake

Poyang Lake, located in the North of Jiangxi Province and South bank of the middle and lower reaches of the Yangtze River, is the largest inland fresh water lake in China [68]. The Poyang Lake has a quite sophisticated ecological structure and is rich in aquatic plants, which create a hospitable environment for many rare species of freshwater fish. In addition, many kinds of rare birds are attracted to the lake, making it a popular destination for birdwatchers.

The Poyang Lake region is influenced by subtropical monsoon [85]. The seasonality of precipitation, combined with the smooth terrain and other factors, results in significant variations in the lake's inundation area throughout a year. Annual mean precipitation amounts to 1636 mm .

The lake is geographically divided into two parts and Songmen Mountain is generally regarded as the division: the Southern portion is wide and shallow, while the Northern portion is a narrower and deeper outlet. The lake receives several local rivers including Ganjiang, Fuhe, Xiushui, Xinjiang, and Raohe, and sometimes Yangtze River also discharges in summer months. Figure 12 shows the location of Poyang Lake. Figure 13 shows the land use type of the study area.

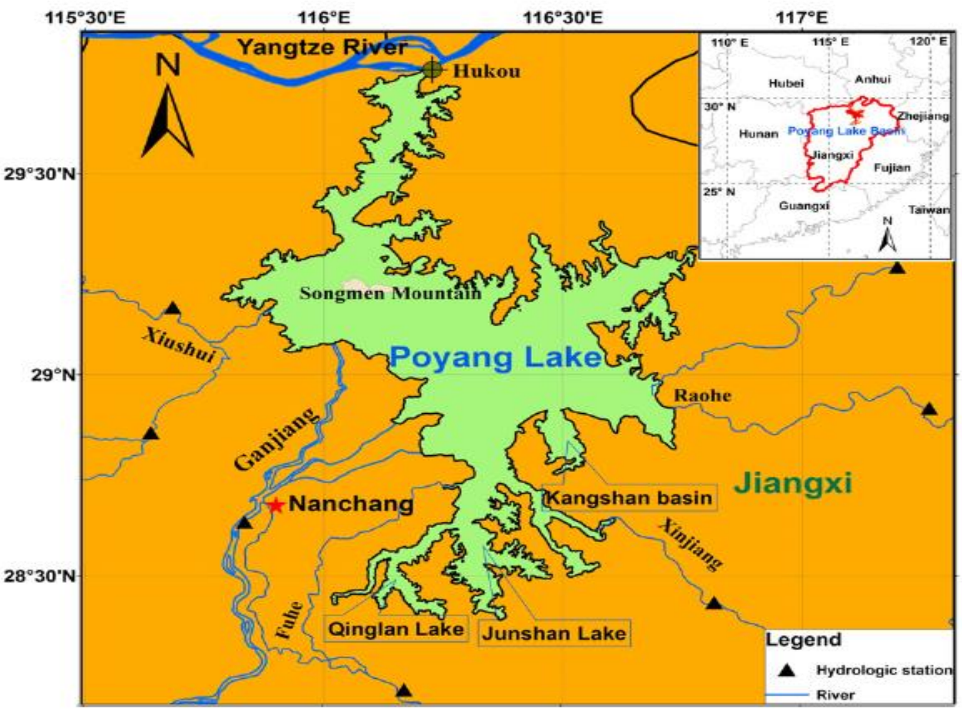


Figure 12: Location of Poyang Lake and its boundary [68]

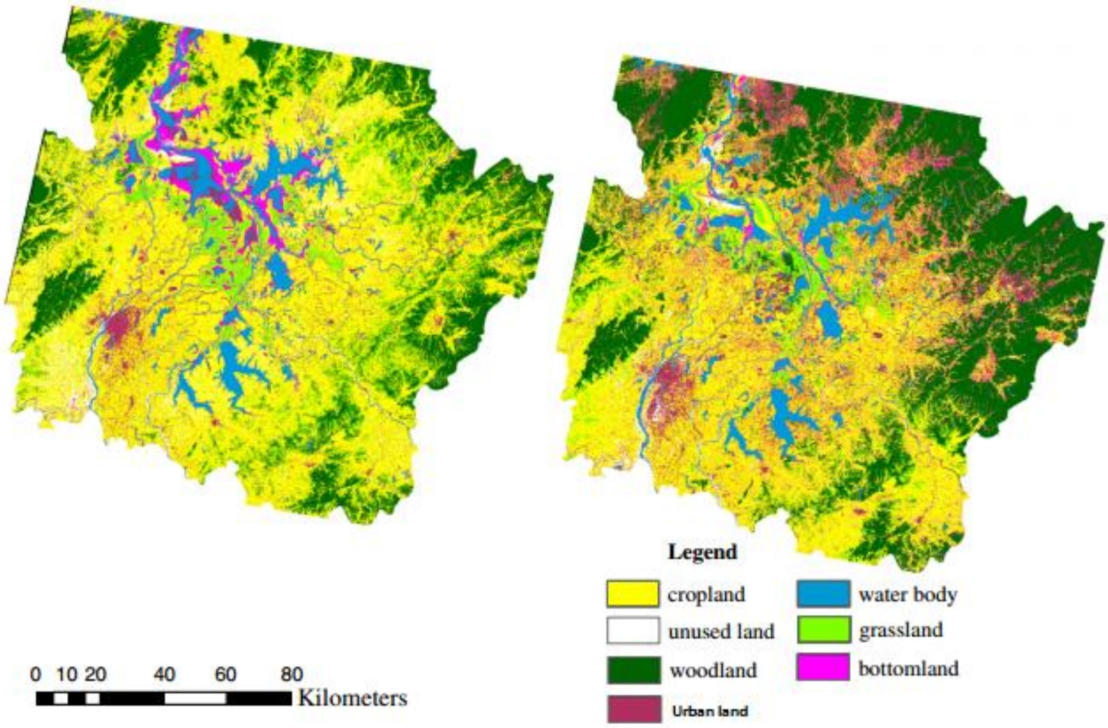


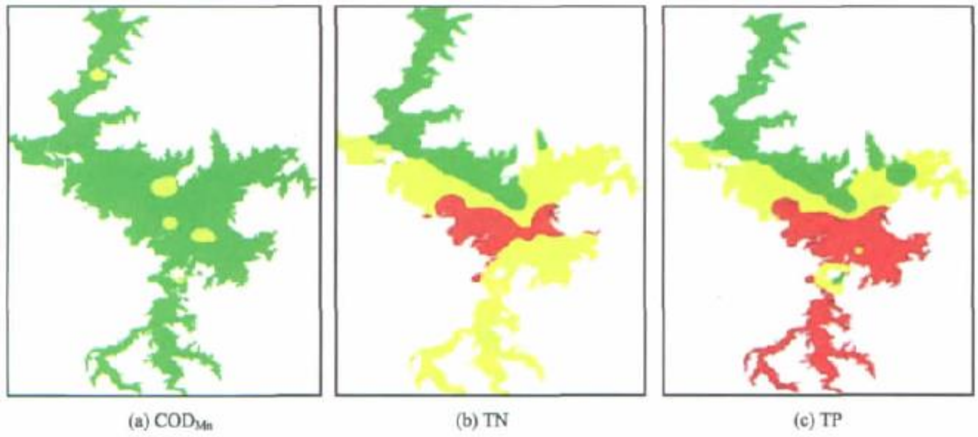
Figure 13: Land use type of the study area in 1999 and 2009 [86]

By the analysis on the database [87], the pollutants in the Poyang Lake area are mainly the TN and TP. The monitoring data of main pollutants is shown in Table 7. The higher density areas of TN and TP are mainly located in the Southern part of Poyang Lake area, namely Kangshan and Lian Lake, and the Benghu area.

Table 7: Results of monitoring data of pollutants and the corresponding standard value in 2009 Unit: mg/L [87]

	TN	TP	COD	BOD
Monitoring concentration	1.40	0.64	11.03	1.49
Class 4 level of GB3838	1.5	0.3	30	6

Poyang Lake has a large area of water body. Although the quality level of major parameters is mostly regarded as class 2-3 [23], that of some parts have deteriorated into area class 4 or even class 5 level. Paper [67] demonstrates that the water quality of Poyang is classified into class 4. As Figure 14 shows the spatial distribution feature of COD, TN and TP. It can be seen that the Southern part of the lake area has a higher concentration. The distributions of pollutants in the lake are uneven. Under the influence of the coming water from the South branch of rivers Gan and Xinjiang, concentration of TN in the estuary is of class 4 level according to GB3838 [23], but TN concentration of the lake can be stable in class 2-3 level. Due to the influence of the phosphate fertilizer industry near Xinjiang river, TP concentration in estuary of Kangshan basin exceeds class 5 level. The river is the main source of pollution load into the Poyang Lake, and it accounts for about 80% of the total pollution. In addition, due to the less quantity of pollution load directly into the Northern part of lake Poyang, as well as the unique self-purification function of wetland, water pollution degree of Poyang Lake decreases from South to North.



Area in green represents class 2-3 level. Yellow represents class 3-4. Red represents class 4-5.

Figure 14: The regarding COD, TN and TP water quality classes of Poyang Lake in 2010 [88]

5.1.2 Dongting Lake

Dongting Lake is the second largest freshwater lake in China, located at the South of the middle Yangtze River and it is a large and shallow freshwater lake. It covers a catchment area of 262,800 km^2 and has a storage capacity of 170×10^8 km^3 [63].

The climate of Dongting Lake is between middle and Northern subtropical, so most of the time, it is warm and humid, but cold air from the North sometimes enters in spring and summer. The temperature is variable, while in late summer and autumn it is sunny and hot with high rainfall. Occasionally in autumn, it's cold and windy. The area around the lake has tremendous agricultural production ability with a long history of development. Since the plain is graced with fertile soil, proper temperature and plentiful rain, Dongting Lake is called "a land flowing with milk and honey".

As Figure 15 shows, the inflow of Dongting Lake is mainly from the Xiang, Zi, Yuan, Li and Yangtze rivers; they flow into the Western and Southern parts, and drain into the Yangtze through the Eastern part [89]. Annual mean precipitation amounts to 1100-1400mm . Dongting lake is an internationally important wetland [90]. Dongting Lake is the taker and sender of Yangtze rivers and acts as a tremendous natural flood-basin. It plays an important role in adjusting the flow of the Yangtze River. The land use type of study area is shown in Figure 16.

Figure 15: Location of Dongting Lake [91][28]

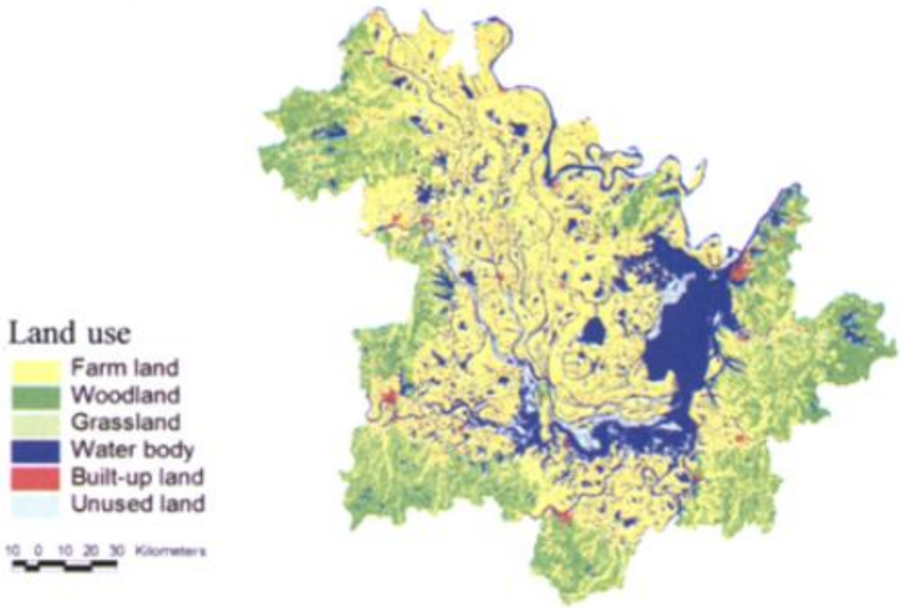
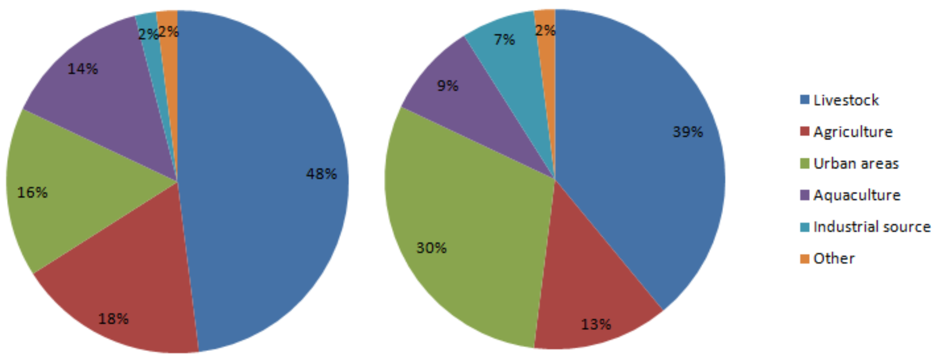


Figure 16: Land use type of the study area in recent years [90]

In recent years, water quality of Dongting Lake has been deteriorating because of the increasing pollution from NPS. In 2007, the emissions of TP and TN were of 6913 t and 59049 t respectively. Figure 17 shows the contribution of each pollution source of nitrogen and phosphorus pollutants into the lake. Livestock, agricultural and urban areas are the main sources of pollution [63].



(a) TP (b) TN

Figure 17: Composition of the main pollution sources of Dongting Lake in 2007

Concerning the water quality of Lake Dongting, paper [92] analyzed 14 monitoring sections and concluded of which the quality of common parameters such as TP and TN are from class 3 to inferior class 5 level of surface water quality standard GB3838 [23]. Among them, class 4-5 and class 5- inferior 5 are accounting for 78%. As shown in Table 8, the catchments namely Shahekou which connected Li river and Dongting, a part of West Dongting lake namely Nanzui and a part of South Dongting lake namely Yugongmiao sections are in light pollution condition. The catchment namely Zhangshugang which connected Xiang river and Dongting, a part of South Dongting lake namely Wanzihu areas are in the severe pollution state. The remaining of the sites are in the moderate pollution state. The water quality of Dongting is in moderate pollution on the whole which is classified into class 5.

Table 8: Water quality assessment for different sections of Dongting Lake in 2008 [92]

Monitoring sites	Rivers discharging to Dongting Lake				Dongting Lake
	Xiang river (Zhangshugang)	Zi river (Wanjiazui)	Yuan river (Potou)	Li river (Shahekou)	
Water quality (class)	>5	5	5	4	5

As Table 9 concluded that TP and TN are the main parameters of pollutants [63]. The indices exceeding class 3 level of the standard mostly were TN, TP and NH_3-N. The changes of the pollutants concentration in the East Dongting Lake were bigger than in the South and West Dongting Lake.

Table 9: Results of pollutants assessment in Dongting Lake [63]

<table>
<tr><th></th><th>COD (class)</th><th>TN (class)</th><th>TP (class)</th><th>NH_4-N (class)</th><th>NO_3-N (class)</th></tr>
<tr><td>April to October</td><td rowspan="3">2</td><td>⩾5</td><td>4</td><td>2</td><td rowspan="6">1</td></tr>
<tr><td>November</td><td>4</td><td rowspan="4">3</td><td>3</td></tr>
<tr><td>December</td><td rowspan="2">5</td><td>4</td></tr>
<tr><td>January</td><td>4</td><td rowspan="3">3</td></tr>
<tr><td>February</td><td rowspan="2">3</td><td rowspan="2">⩾5</td></tr>
<tr><td>March</td><td>4</td></tr>
</table>

5.1.3 Hulun Lake

Hulun Lake is the fifth largest lake in surface area in China and is the largest lake in the Northern part of the country. The lake is located in Hulun Buir Steppe. There are a large number of groundwater recharges in it. Besides, the water input to Hulun is from more than 80 rivers, the two largest of which are the Orshen River and Crulen River (Mongolia) [70], as shown in Figure 18 with the Hulun location in Google earth [28]. The catchment area of Hulun is of 153,700 km^2, and it has a storage capacity of 131×10^8 km^3 [70].

Concerning the morphology of Hulun Lake, it appears irregular rectangular, long axis from Southwest to Northeast direction. The West side of the lake is made of rolling hills and steep cliff, while East and South of the lake is smooth and open.

The lake, located in high latitude area with low temperature, belongs to the temperate continental climate. It is warm in summer while cold and dry in the winter. Huge day-night temperature difference occurs in Hulun. Average annual precipitation is of 319 mm. The icebound period is about 180 days [70]. It is one of the most important lakes in Northern China for fisheries, the regional environment, water resources and as a bird habitat.

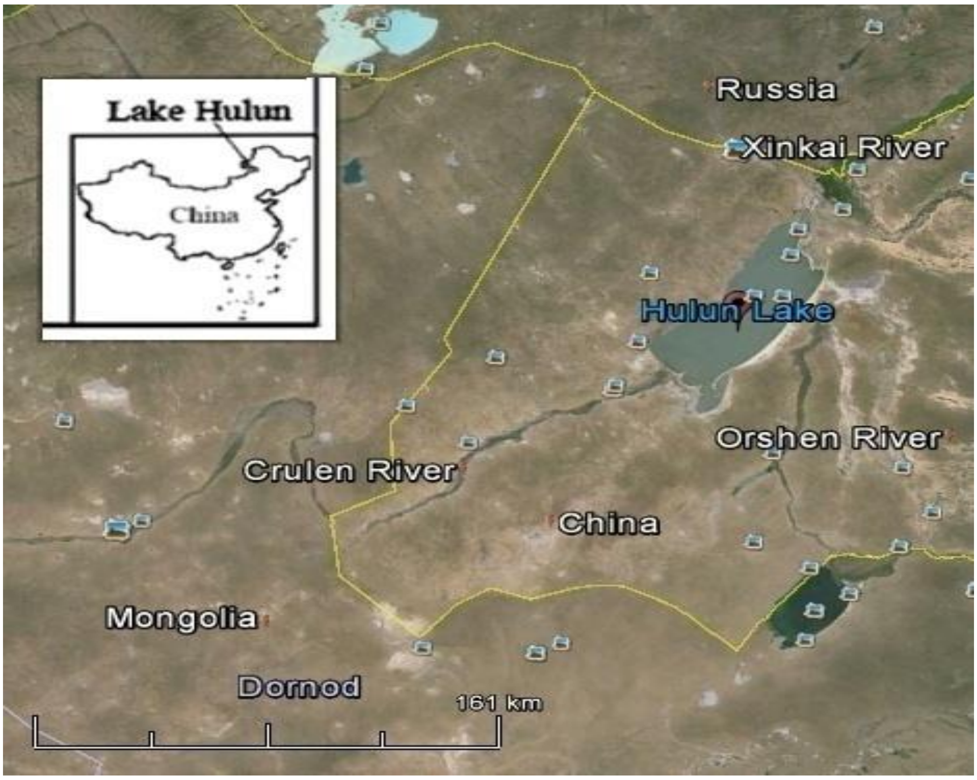


Figure 18: Location of Hulun Lake [28]

Concentration of dissolved organic matter (DOM) in Lake Hulun is abnormally high and reaches about 59 mg/L [70]. It seems that such values can be caused by climate and land use change. The people of inner Mongolia prefer to graze near the rivers or wetlands, which leads to overgrazing in these areas. In addition, the annual average temperature of Hulun increases at the rate of about 0.05 °C a year [70]. Due to the warming-associated drying trend, the water level of lake Hulun has decreased from 544.8 m in 1991 to 540.2 m in 2009 [70]. Thus, the warmer conditions and long term heavy intensity grazing at specific locations are the most important factors driving the increase of DOM concentrations in lake Hulun.

Nitrogen and phosphorus are the major cause of eutrophication for Hulun Lake. Paper [93] described the physical and chemical characteristics of water from Hulun Lake in summer and winter of 2012, listed in Table 10. As the results showed the concentration of TN and TP in the summer respectively, which suggested that the concentration of TN belonged to 4 to inferior 5 classes of the surface water quality standard GB3838 (Table 1) [23], and concentration of TP is of class 4 to class 5. In the winter, the quality level of TN is from class 3 to inferior class 5, and that of TP is from class 5 to inferior class 5.

As a comprehensive evaluation result of these, the author of paper [93] concluded that a lower eutrophication grade happened in Hulun Lake in the summer and a few parts of the region were belong to moderate eutrophication (class 5). Therefore, the water quality of Hulun is classified into class 5 on the whole.

Table 10: Concentrations of different parameters of lake water in different periods of 2012 [93]

Parameters	Summer			Winter		
	Minimum	Maximum	Average	Minimum	Maximum	Average
TN (mg/L)	1.468	2.961	1.890	0.992	2.070	1.629
TP (mg/L)	0.200	0.274	0.226	0.196	0.315	0.229

The spacial distribution of TN concentration in the Northern part was higher than that in the Southern part and central part of the lake. The TP concentration was higher in the Northern part and gradually decreased to the Southeast part of the lake.

5.2 Hydrological and water quality characteristics of the lake and the reservoirs of Group 2

The reservoirs and lake from Group 2 have smaller sizes, compared to Group 1. They are Shitoukoumen Reservoir (E), Yuqiao Reservoir (F) and Dianchi Lake (G). The location and annual mean rainfall are indicated in Figure 9.

5.2.1 Shitoukoumen Reservoir

Shitoukoumen Reservoir, located in Jiutai City, Jilin Province, is a large reservoir at the middle reaches of the Yinma River in a tributary of the Songhua River. It is the main drinking water source of Changchun City. It covers a catchment area of 4,944 km^2 [14]. The larger basins of the region belong to the Yinma River and the Chalu River (as shown in Figure 19). The Shitoukoumen Reservoir catchment lies in the North Temperate Zone, with a continental, seasonal, temperate, and semi-humid monsoon climate. The dam construction was completed in October 1965.

The area is dry and windy in spring, warm and rainy in summer, dry with early frost and rapid cooling in autumn, and with long, cold and Northwest winds in winter. The annual average temperature is 5.3°C. The lowest average temperature is -17.2°C (January), and the highest average temperature is 23.0°C (July). The annual mean rainfall is 319 mm, and it is mainly concentrated from May to September, which accounts for 80% of the annual precipitation [14].

Figure 19: Location of the Shitoukoumen Reservoir [28]

In recent years, the water quality of Shitoukoumen Reservoir has deteriorated because of point sources pollutants from domestic sewage and industrial activities and NPS pollutants from agricultural irrigation, soil erosion and mining enterprises in protected areas [14]. 5584 t COD and 1057 t TN were annually discharge to the water body in 2009 [94]. Shuangyang basin is the main source of pollutant discharge to Shitoukoumen Reservoir and the pollutants emissions are accounted for 46.9% of that of the whole area. Pollutants emissions of Yinma river basin are second, accounted for 30.5% of total emissions [94]. In contrast, according to the emissions of annual, the NPS pollution is more serious. Average concentration of target pollutants in 2008 are shown in Table 11.

Table 11: Average concentration of target pollutants in 2008 [95]

Average concentration of target pollutants in the reservoir				
Parameters	COD	NH_4-N	TN	TP
Concentration of pollutants (mg/L)	3.58	0.28	0.54	0.036
Quality (class)	1	2	3	2
Average concentration of target pollutants in mid-stream				
Parameters	COD	NH_4-N	TN	TP
Concentration of pollutants (mg/L)	3.65	0.32	0.58	0.038
Quality (class)	1	2	3	2

According to the monitoring and evaluation results from 2005 to 2008, water quality of Shitoukoumen reservoir and mid-stream is Class 3 level. The main pollutants that exceed class 2 level of the surface water quality standard GB3838 [23] are permanganate total nitrogen, ammonia nitrogen and total phosphorus. However, all evaluation factors have below class 3 level of GB3838 and the water quality was well on the whole. The water quality evaluation results are shown in Table 12.

Table 12: Water quality assessment for different sections of Shitoukoumen Reservoir [94]

<table>
<tr><td colspan="2">Water quality of regions\Year</td><td>1997</td><td>1998</td><td>1999</td><td>2000</td><td>2001</td><td>2002</td><td>2003</td><td>2004</td><td>2005</td></tr>
<tr><td colspan="2">Water quality of Shitoukoumen</td><td>2</td><td>3</td><td>2</td><td>3</td><td colspan="3">2</td><td colspan="2">3</td></tr>
<tr><td rowspan="3">Rivers discharging into Shitoukoumen</td><td>Chalu river</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="3">2</td><td colspan="2">3</td></tr>
<tr><td>Shuangyang river</td><td colspan="3">ND</td><td colspan="2">3</td><td>4</td><td>5</td><td>4</td><td>3</td></tr>
<tr><td>Yinma river</td><td>2</td><td>3</td><td>2</td><td>3</td><td colspan="3">2</td><td colspan="2">3</td></tr>
</table>

ND: not determined

5.2.2 Yuqiao Reservoir

The Yuqiao Reservoir is located in the Northeast of Tianjin city as shown in Figure 20. The dam construction was completed in the year of 1960. Yuqiao Reservoir belongs to the temperate continental monsoon type, semi-humid climate [33]. The annual mean rainfall is about 750 mm [28].

It is one of the reservoirs regarded as drinking water source of Tianjin city and is a key regulating reservoir of the Project of Water Transfer from the Luanhe River to Tianjin (PWTLT). It provides drinking water for more than four million Tianjin residents [33].

There are two kinds of processes driving the water movement at the reservoir: freshwater inflow and wind stress. The Yuqiao Reservoir basin include the Shahe River, the Lihe River and the Linhe River. The Shahe River and the Lihe River flow into the Guohe River that discharges into the Yuqiao Reservoir. The outflow of the Yuqiao Reservoir is Zhouhe River. From 1983 to 2000, there was 4.2174×10^9 m^3 water from the basin flowing into the Yuqiao, corresponding to fractions of the Shahe, the Lihe and the Linhe Rivers of respectively 57.9%, 30.2% and 11.9% [33].

Figure 20: Map of Yuqiao Reservoir showing the location of Guohe, Linhe, Shahe and Lihe rivers inflow in the basin [28]

In recent years, along with the development of farmland fertilization and fishery in this area, tons of animal waste were spread in fields in the low lying areas. The problem was exacerbated by the discharge of nutrient rich water that continues to increase around the reservoir. As a result, the content of Nitrogen and Phosphorus in the water keeps rising, resulting in massive reproduction of undesirable organisms such as fungus and waterweeds and their over-nutrition.

The author of paper [96] used mathematical models, with the monitoring data, to make clear the values of the target pollutants in the water, including COD, TN and TP. Water quality of Yuqiao Reservoir is classified into class 3 according to the surface water quality standard GB3838 [23]. Concerning the quality level of parameters, as Table 13 shows, average concentrations of TN is 1.5 times of class 3 level of GB3838. On the other hand, average concentrations of TP and COD did not exceed the standard of class 3. Thus, the eutrophication in the water body of Yuqiao is a result from N pollutants.

Table 13: Concentrations of different parameters of water bodies from Yuqiao Reservoir [96]

Parameters	**Statistics (mg/L)**			**Class 3 level of GB3838 (mg/L)**
	Maximum	Minimum	Average	
TN	3.525	0.219	1.500	≤ 1.0
TP	0.170	0.005	0.036	≤ 0.2
COD	8.950	1.950	3.920	≤ 20
Chla	314.66	3.580	7.130	

As Figure 21 demonstrates, in Yuqiao Reservoir, the water quality decreases from East to West because of the pollutant discharges. Main sources of nitrogen nutrient are from agriculture of the upstream watershed. The average annual application of N fertilizer to the surrounding was about 600 kg/hm^2 [96]. Phosphorus occurs mainly in the middle part of the reservoir, due to livestock breeding pollution.

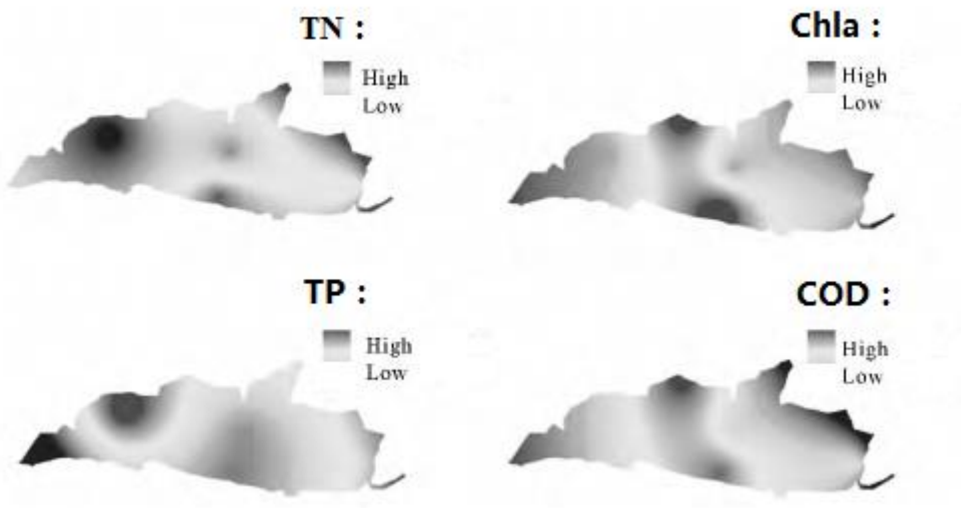


Figure 21: Spatial distribution of different pollutants in Yuqiao Reservoir in 2014 [96]

5.2.3 Dianchi Lake

Lake Dianchi, located 1886.5 m above the sea level, is the eighth largest lake in China and the largest in Yunnan Province. It is a lake with a total storage capacity of 15.7×10^8 m^3 and a catchment area of 3000 km^2 [18]. The lake has a maximum water depth of 10.9 m and an average water depth of 4.4 m.

Lake Dianchi belongs to the Southeast monsoon climate area. The warm rainy season occurs in summer and autumn (from June to September). The dry season appears in winter and spring (from February to May). The annual average temperature of this region is 14.5°C. The annual mean precipitation is of 1007 mm [18].

As Figure 22 shows, Dahe River is located in the coastal area of Southeast lake Dianchi and branches of several rivers. Lake Dianchi provides water to Baiyuhe river and Chaihe river by pumping when water is scarce for irrigation. Consequently, hydrology in this area is very complicated. There is a main water gate before the branches that flow into Baiyuhe river and Yunihe river. The gate is open to river Yunihe constantly, but also to river Baiyuhe when the rainfall is heavy. Land use types are likely to have influences on concentration distributions of the main pollutants. As shown in the Figure 23, arable land and urban area may have more P loads due to its high P content in agriculture and human activities.

Figure 22: Map of lake Dianchi and the location of study site [28]

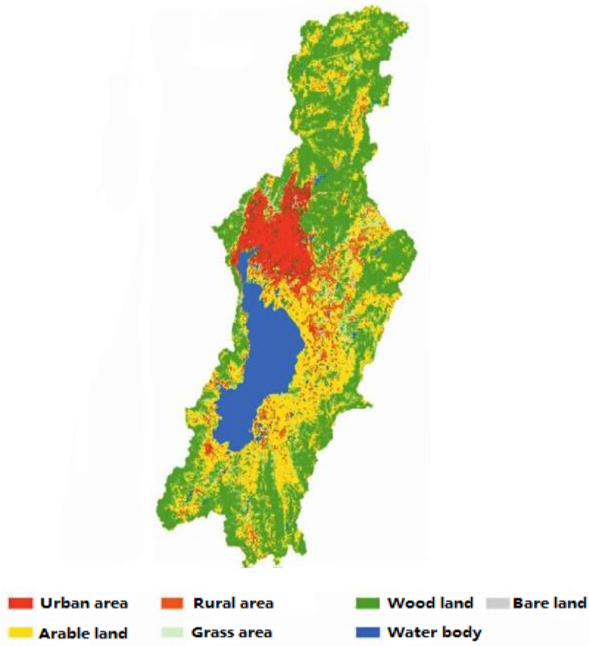


Figure 23: Land use distribution of Dianchi Basin in 2007 [97]

Due to population growth and increasing application of chemical fertilizer around lake Dianchi, which is higher than the national average level in China, the degree of eutrophication in the lake is getting larger. The eutrophication problem of this lake is serious: algal blooms break out almost every summer and the lake water cannot be used for drinking water during that period of the year.

The author of paper [98] regarded P and N as the main pollutants and selected NH_3-N, TN, COD_{Mn} and TP as the main parameters affecting the water quality of Dianchi Lake. Water quality of Dianchi is classified to inferior class 5 level based on the whole. The concentration distribution of the target pollutants in the different parts of the lake is presented in Figure 24.

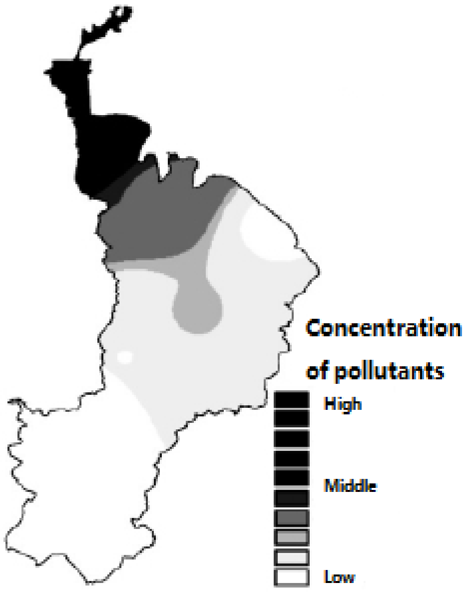


Figure 24: Spatial distribution of pollutant in Dianchi Lake in 2007 [98]

About 1/3 of total Nitrogen (TN) and 1/4 of total Phosphorus (TP) are originated from nonpoint source pollution (NPS) [18]. Agriculture is a the key point in recovery of lake Dianchi water quality. TN concentration is increasing and the COD does not show any change trend. Concentrations of these water quality parameters are shown in Table 14.

Table 14: Concentrations of different parameters of water bodies from Dianchi Lake [98]

Parameters	Values (mg/L)		
	Minimum	Maximum	Average
TP	0.430	0.698	0.565
TN	4.471	7.712	5.791
NH_4-N	1.349	4.925	2.800
COD_{Mn}	6.420	10.678	7.859

5.3 Comparison of two groups of three case studies

In Group 1, as Table 7 shows, pollution of phosphorus in Poyang Lake is more serious than that of other pollutants. It is because phosphate fertilizer industry near Xinjiang river, TP concentration in estuary of Kangshan basin being of class 5 level. The average TP concentration of the lake is 2 times of class 4 level of GB3838 and exceed class 5 level. In contrast, as Table 9 and Table 10 illustrate, nitrogen pollution is serious in the Dongting Lake and Hulun Lake. Among them, the average TN concentration of Dongting Lake remains at class 5 to inferior class 5 level while the other parameters are not higher than class 4 level (including class 4). In lake Hulun, the annual average concentration of TN reaches class 5 level and that of TP does not exceed class 4 level. Research has shown that the 3 case studies of Group 1 in China have a relatively severe problem of pollution, which mainly results in eutrophication from excessive loads of TP and TN. Hulun Lake and Dongting Lake are the worst cases of Group 1, concerning water quality.

As Chapter 5.1 illustrates, phosphate fertilizer industries distribute around the Xinjiang river which discharge to Poyang Lake. It is the main source of pollution load into the lake, and accounts for about 80% of the total pollution. Therefore most of the pollution of Poyang is related to point sources. The pollution sources of lake Dongting are livestock, aquaculture and agricultural irrigation, and there is serious overgrazing problem around lake Hulun. Poyang Lake has the largest annual mean rainfall and volume of the 3 water bodies, which is likely to lead to the dilution of point source pollutants. Thus, Poyang Lake has a relatively better water quality than Dongting and Hulun.

In Group 2, as shown in Table 11 and Table 13, the eutrophication in the water bodies of reservoirs Shitoukoumen and Yuqiao result mainly from N pollutants. N pollution is more serious than P pollution in both Shitoukoumen and Yuqiao. TN concentrations in Shitoukoumen and Yuqiao are classified into class 3 and class 4 respectively. Compared to Shitoukoumen and Yuqiao, Dianchi Lake has the worst water quality of the 3 case studies of Group 2. TN and TP concentrations of Dianchi are higher than that of class 5 of GB3838, therefore this lake is classified into inferior class 5.

As Chapter 5.2 and Table 6 demonstrates, Shitoukoumen and Yuqiao are drinking water resources of the cities. This requires that the water quality must have a good quality level. Thus, it is likely that the water quality of the reservoirs is better than that of the lake. Yuqiao Reservoir and Shitoukoumen Reservoir have a similar and relatively good quality water. Compared to Yuqiao, Dianchi has a similar volume but has a higher annual mean rainfall, accounting 1007 mm. In addition, as shown in Figure 23 with the land use of the lake Dianchi, the water body is surrounded by arable area and urban area. Therefore, NPS pollution is relevant in Dianchi. On the other hand, Yuqiao Reservoir is a key of the Project of Water Transfer from the Luanhe River to Tianjin (PWTLT). Water inside the reservoir come and go more often than Dianchi Lake. So the rate of water renovation in Yuqiao is faster. Besides, the region around Luanhe river is a mountainous area of agriculture without irrigation, therefore the Luanhe River water discharging into Yuqiao is abundant and relatively clean. Thus, water quality of Yuqiao is better than that of lake Dianchi.

5.4 Seasonal variations in the 6 case studies

Seasonal variation is a component of a time series which is defined as the repetitive and predictable movement around the trend line in one year or less. It is detected by measuring the quantity of interest for small time intervals, such as months. Concerning the seasonal variation of the case studies, based on the relevant references, as Table 15 shows, 4 water bodies including Poyang Lake, Dongting Lake, Yuqiao Reservoir and Dianchi Lake have obvious seasonal water quality changes but neither Hulun nor Shitoukoumen show this phenomenon. That maybe because Hulun Lake and Shitoukoumen Reservoir have low annual mean rainfall, and the hydrological characteristics are relatively stable. Thus, seasonal water quality changes in Hulun Lake and Shitoukoumen Reservoir are low.

Table 15: Seasonal variation of the case studies.

Water bodies and reference	Is there seasonal variation or not	Characteristics of wet season in summer			Characteristics of dry season in winter			Characteristics of normal season	
		Months	Water quality	Average water temperature	Months	Water quality	Average water temperature	Water quality	Water temperature
Poyang Lake [68][99][100][101]	Yes	July to September	Class 3	28°C	December to February	Class 5	6°C	Class 4	18°C
Dongting Lake [91][63]	Yes	July to August	Class 5	29°C	December to February	Class 4	4°C	Class 5	17°C
Hulun Lake	No	NA	Class 5	20°C	NA	Class 5	3°C	Class 5	14°C
Shitoukoumen Reservoir [14][95][102]	No	NA	Class 3	22°C	NA	Class 3	4°C	Class 3	15°C
Yuqiao Reservoir [33][96][103]	Yes	July to September	Class 4	29°C	November to April	Class 2	8°C	Class 3	18°C
Dianchi Lake [97]	Yes	June to September	Class 5	22°C	February to May	≥Class 5	10°C	Class 5	16°C

NA: Data not available.

Concerning the general comparison of two groups, water bodies in Group 1 are of bigger size than that of Group 2, but the water quality of Group 1 which include 3 lakes is worse than Group 2 which include 2 reservoirs and 1 lakes on the whole. Both groups have water bodies characterized by three kinds of situations: 1) water quality in the wet season is better than that of the dry season (Poyang Lake and Dianchi Lake); 2) water quality in the dry season is better than that of the wet season (Dongting Lake and Yuqiao Reservoir); 3) water quality is equal during different periods of the year (Hulun Lake and Shitoukoumen Reservoir). The reason of the differences between the first and the second situation for similar water body volumes probably is: dilution effect occurs more easily in the water body which have a longer period of wet season and higher annual average rainfall, resulting in lower concentration of pollutants in the wet season than in the dry season. Both Poyang Lake and Dianchi Lake are the water bodies which have a higher rainfall in each group and the result matches the tendency demonstrated above.

Poyang Lake is historically a region of significant floods and there is a obvious fluctuation of temperature happening in the lake during different seasons. From July to September, the high water level of the Yangtze River may impede the lake–river water flow [99]. During the summer wet season, the lake surface area can exceed 3500 km^2. During the relatively dry fall and winter, the lake water level decreases and the lake area will typically shrink to less than 3000 km^2. In general, the concentrations of the target pollutants of dry season are higher than those of wet season, suggesting that the water quality of the wet season is better. The volume of the water body (water level) may be a the key factor that affects water quality, the influence of external pollutant sources may be relatively small. Point sources are the major pollution sources of Poyang.

The lake area of Dongting fluctuates from less than 500 km^2 in the dry season (December to February) to around 2500 km^2 in the flood season (July to August) [91]. Water quality classes of Dongting begin to rise from May, reaching the highest value in July, then decrease slightly, but after September it begins to rise again, and reaches a peak in October [63]. At this time pollution occurs mainly because this is a busy farming period as well as the rainy season. A large number of pollutants is transported by the surface runoff into the water body. The water quality in the remaining periods of this year show lower pollution levels. Water quality in the dry season (low flow conditions) mainly reflects the contribution of point sources, whereas that of the flood period (high flow conditions) is mainly related to the presence of NPS pollution [63]. NPS are the major pollution problems of Dongting Lake.

Compared to Poyang Lake, Hulun Lake has a similar catchment area but has a relatively lower volume within Group 1. Besides, average annual precipitation in Hulun Lake is much lower (319 mm) than that of other two lakes (1250 mm and 1636 mm). Thus, the water levels observed in Hulun during one year were roughly the same. In addition, it is located in a high latitude inland area. Hydrological characteristics are relatively stable. The fluctuation of temperature is lower than that of other two water bodies. Therefore no obvious seasonal variations occurs.

Similar to lake Hulun from Group 1, Shitoukoumen Reservoir presents the lower annual mean rainfall (565 mm), higher latitude inland location within Group 2, and little changes in the water level throughout the year. The monthly concentrations of the target pollutants are roughly equal at different periods of time [14] [95] and all of them meet class 3 level of the surface water quality standard GB3838 [23]. Therefore the differences of water quality between wet season and dry season are not evident and the reservoir has the same water quality classification (class 3) all year.

The author of paper [33] concludes that the water quality contamination is transferred directly from the inflow river estuaries to the center of Yuqiao Reservoir at a higher speed when water diversion is done in the reservoir. For this reason, the water quality of Yuqiao Reservoir in the dry season is slightly better than that of the wet season.

The water quality of lake Dianchi is the worst in Group 2. There is a high concentration of pollutants in the lake body. During the wet season, the volume of rainfall is much higher than that of dry season, causing a lower concentration of pollutants, due to dilution in the water body. Therefore, the water quality of Dianchi Lake during the wet season is slightly better than that of the dry season.

6. Analysis of variables that control the water quality in reservoirs and lakes in China

6.1 Most important water quality problems

As it is well known and was mentioned in Chapter 3 of this report, activities such as agriculture, industrialization, and urbanization are a cause of increase of pollution in lakes and reservoirs.

As Table 5 shows, the main sources of point pollution in China analyzed in this study are industrial effluents and discharge of domestic sewage, which contain organic pollutants, chemicals and heavy metals. According to the gathered information, agricultural is the most relevant source of nonpoint pollution present in China. Fertilizer, pesticide and other pollutants from agricultural land can reach water bodies transported by surface runoff. The excessive nutrients loading from agricultural watersheds are considered to be the principal reason of eutrophication of water masses. Except for the Shitoukoumen Reservoir, most of the 6 case studies which are most representative situations in China selected in this report, have serious eutrophication problems. The water quality problems in Dongting Lake, Hulun Lake and Dianchi Lake are more serious. Figure 25 shows the process of eutrophication. This problem in China is probably due to the fact that there is a high rate of fertilizer application in agriculture in order to support the large population.

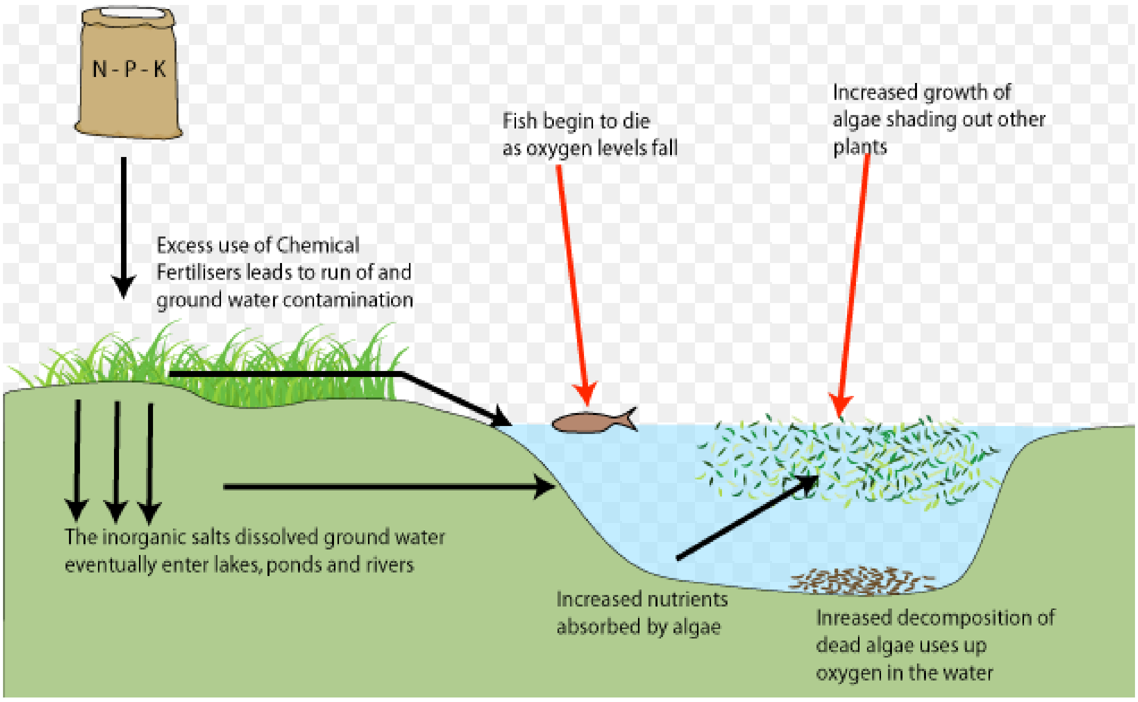


Figure 25: Schematic representation of the Eutrophication process

6.2 Relevant variables that control water quality

Many variables may affect the water quality, and they can have origin in natural conditions and in human activities. Chapter 1.3 has already described how the climate and land use type influence the quality of water. In addition to these variables, the evaluation of the water quality of the six case studies showed the combined effect of human activities, hydrological characteristics of the water bodies (e.g. : shape, depth and age of the reservoirs) and the role of legal regulations.

6.2.1 Human activities

It is known that social and economic activities have important influence on pollutant concentration of the water bodies. For example, lakes in Beijing are polluted by organic chemical produced by human-beings. PAEs are anthropogenic chemicals present in the composition of many products such as cosmetics, detergents, soaps and shampoos. The author of paper [57] finds that PAEs concentrations in sediment and suspended particle samples were higher than those in water samples, and the dominant compounds detected are related to human activities. Therefore in order to deal with this chemical pollution problems, the relationships between spatial distribution of PAE in the lakes and human activities should be taken into consideration. Figure 26 shows the annual GDP and population density of the cities surrounding Dianchi Lake. The author of paper [97] finds that the degree of eutrophication of Dianchi Lake is significantly related to the urban population near the catchment and GDP of the local city. Therefore, the growth of population density and economic development are two of the major causes of eutrophication of Dianchi Lake.

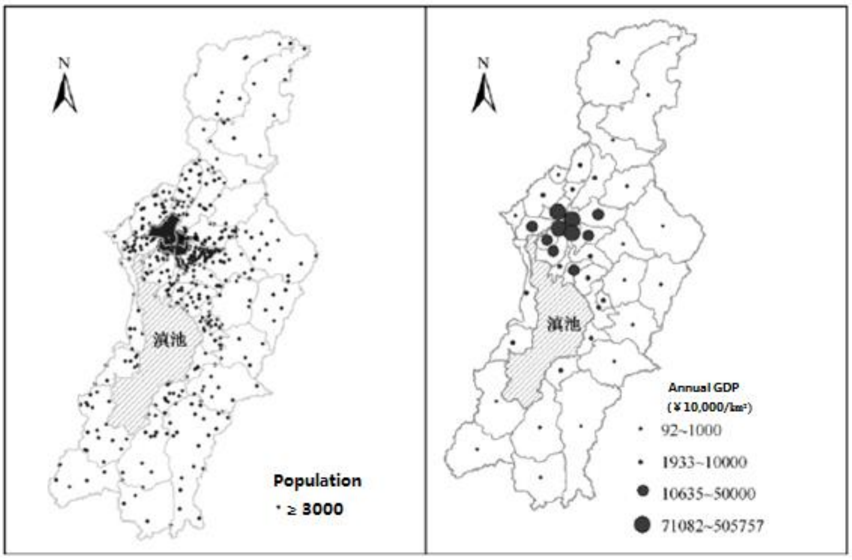


Figure 26: Distribution of population density and GDP per square kilometers based on town or sub-district area in Dianchi Lake in 2007 [97]

As it is well known, sand is an important building material. Due to the rapid development of infrastructures, the demand of sand increased dramatically. From all kinds of sand, the one distributed in the upstream of rivers is the best. In recent years, in order to support construction, there is large sand extraction next reservoirs, as shown in Figure 27. Although sand dredging can increase the volume of the reservoir, the sand is a natural filter layer on both sides of the channel that contributes to filter impurities in the water. The illegal exploitation of this natural filtering layer may decrease the self purification of the reservoir water, while in the process of mining, stirring the water, the filtered impurities and harmful substances are re-suspended in the water, causing secondary pollution.

Figure 27: Sand factory beside the Danjiangkou Reservoir

Another example are regions with a high scale of touristic activity, where the population fluctuation during the seasons of the year may have consequences in wastewater discharge and water pollution. Figure 28 shows the dramatically increase of population due to tourism on the shore of the West Lake.

Figure 28: The West Lake during the busy travelled season

In summary, the human activities with higher impacts on water resources can be summarized as follow: 1) agriculture; 2) application of chemicals; 3) urban and industrial development; 4) irrigation and drainage systems; 5) tourism.

6.2.2 Physical and hydrological characteristics of the water bodies

The hydrological characteristics of water bodies include volume, surface area, depth, shape, average annual runoff, water retention time and so on. All of them play a role in the water quality. When the water body is very shallow or with a longer retention time, the eutrophication of the water body may tend to increase. The water temperature of lakes or reservoirs varies with the depth, and directly affects the concentration of dissolved oxygen (DO). Usually, the large and deep lakes have lower temperature and weak biological process. The annual concentration of DO in a lake depends on the changes of water temperature. DO is higher in the winter, and lower in the summer. Small lakes contain high DO due to the strong photosynthesis in the summer period which means a better heat condition compared to water bodies which are large and deep. On the other hand, at the bottom of lakes, the decomposition of organic matter due to the lack of oxygen, under the action of anaerobic microbes, produce hydrogen sulfide (H_2S) and methane (CH_7). Therefore, biological production levels in the lake surface are not the same as at the bottom. Vertical changes in water quality are the combined effects of the vertical distribution of water temperature, depth and other variables. As shown in Figure 29, in recent years, Hulun Lake, which is the most shallow water body from the 6 case studies, having a mean depth of 5 m, suffers seriously from eutrophication [70]. The continuous drought of the region (reduced precipitation and increasing evaporation) result in a decline of water levels and increase concentration of nutrients, leading to the occurrence of algae blooms.

Figure 29: Eutrophication in Hulun Lake

6.2.3 Reservoir construction and required water quality

The economic life time of a reservoir construction is generally of fifty to one hundred years. China has more than 80000 reservoirs, from which more than 30000 sites are in critical conditions. The Chinese Ministry of Water Resources Department states the reason for this situation: most of the dams in China were built from the 1950s to the 1960s, being today more than 50 years old [51], therefore having entered to the end of their expected life time. They will inevitably have more chances to suffer from different pollution than the reservoirs built recently. So the water quality and structure conditions of older reservoirs are unsatisfactory. Guanting Reservoir, as an example, it is a dam that was completed in 1954. At that time, it was the drinking resource of Beijing city. But in the 1980s, due to the discharge of pollutants from a pesticide plant, the reservoir was polluted with DDT and it got worse in the following years [54]. Therefore, it has not served as a drinking water source any more since 1997. At present, the water from Guanting Reservoir is mainly used to supply the industry in the West area of Beijing city [54].

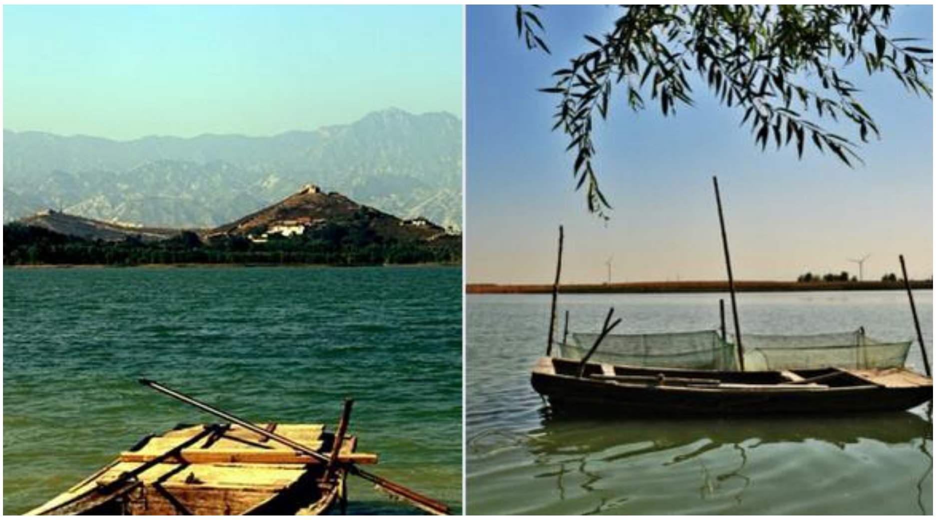


Figure 30: The appearance of water body of Guanting Reservoir in 1980 and 2000

Additionally to supplying water for drinking purposes, a reservoir has many other different uses, such as flow and flood control, supplying water for irrigation, power generation, aquaculture, shipping and tourism. It has important social, economic and ecological functions. A variety of specific purposes determine the water quality requirements for each reservoir and the corresponding water quality standards it should meet.

In China, water storage, power generation, and flood control are the main purposes of most reservoirs while supplying water for farming and tourism are subsidiary functions. For example, the main purpose of the Yantan Reservoir is power generation, flood control and navigation, and its water quality is of class 4 level [45]. Xiaowan Reservoir is used to power generation and flood control [104]. Shitoukoumen Reservoir supplies water to the city (drinking water resource) and the water quality is classified into class 2 during some seasons [94]. The water quality situation of reservoirs in China is not the best. Except for the water quality of a few reservoirs reaching class 2 level, the vast majority is classified into class 3. The content of suspended particles and nutrients in the water body are high. Eutrophication problems occur in many water masses with a tendency to get worse. Such water bodies, basically, can only supply water for agricultural and industrial uses which require lower water quality. An example of relationships between water quality, the purposes and ages of some reservoirs is shown in Table 16.

Table 16: Summary of relationship between water quality and the factors of the reservoirs

Name of reservoir	**Present purpose of the reservoir**	**Year of completion of dam construction**	**Present water quality according to GB3838**
Songtao Reservoir	Power generation, supply water for agricultural uses	1970	Class 2
Three Gorges Reservoir	Flood control, power generation	1997	Class 2
Shitoukoumen Reservoir*	Flood control, supply water for agricultural, drinking water resource	1965	Class 3
Dahuofang Reservoir	Drinking water resource	1958	Class 2
Yuqiao Reservoir*	Flood control, drinking water resource	1960	Class 4**
Shengzhong Reservoir	Supply water for agricultural uses	1984	Class 3
Baixi Reservoir	Flood control, drinking water resource	2001	Class 2
Hongfeng Reservoir	Tourism	1960	Class 3
Wujiangdu Reservoir	Flood control, power generation	1983	Class 3
Fenhe Reservoir	Flood control, supply water for agricultural, drinking water resource	1961	Class 3
Yantan Reservoir	Power generation	1995	Class 4
Changtan Reservoir	Flood control, power generation, water resource	1964	Class 2
Muyu Reservoir	Flood control, supply water for agricultural and industrial uses	1960	Class 3
Manwan Reservoir	Flood control, power generation, drinking water resource	1995	Class 2
Danjiangkou Reservoir	Flood control, power generation, drinking water resource	1973	Class 2
Guanting Reservoir	Supply water for industrial uses	1954	Class 4

* Included in the 6 case studies of this report.

** The Yuqiao reservoir is the key point of the Project of PWTLT. Therefore water quality of the main part of the reservoir is classified into Class 4, but in some parts with a good quality water (Class 2) can still be used to be the drinking resource.

It is generally observed that the water bodies used for flood control and power generation have relatively worse water quality, and the water quality of the most recent reservoirs tend to be better. The reservoir as a drinking resource is required to have a good water quality.

6.2.4 The role of legislation in the water quality of lakes and reservoirs in China

Water law has a significant contribution to control human activities that can impact the water quality. Public involvement have played a constructive and indispensable role in environmental protection. Discharges of pollutants from different activities decrease due to the mandatory role of law in forbidding human-beings to do something. For instance, Danjiangkou Reservoir is the water source area of the SNWDP's Middle Route, therefore its water quality is of great concern [52]. "Regulations of supplying water for management of South to North Water Diversion Project" was issued by the State Council at the thirty-seventh executive meeting in 22 January 2014 [105] and provide a very intensive and detailed series of provisions to protect the water. For instance, Article 26 of Chapter 3 explicitly show that catering business activities are forbidden in the area around the Danjiangkou Reservoir, Hongze Lake, Luoma Lake, Nansi Lake and Dongping Lake. This will guarantee that these water bodies can keep a good water quality, preventing the pollution from human activities.

In addition, legislation also plays a role in encouraging the establishment of ecological compensation mechanisms. The local government (Province or city) or the legal representative can get some reward from the financial department of the State Council [22][24]. For example, "Interim Measures of water environmental ecological compensation in Henan province" was formulated in 2010 and establishes the surface water environmental ecological compensations, applied to the administrative water bodies of Henan province including the Yangtze River, Huaihe basin, the Yellow River, Haihe basin and others. Article 11 states that: 1) For the water body of Class 1 to Class 3, when the compliances rate of NH_4-N and COD are both greater than 90% in the water body, the local government of the water body awards 1000000 Yuan for that year. 2) For the water body of Class 4 and Class 5, when the compliances rate of NH_4-N and COD are both greater than 90%, the local government awards 200000 Yuan per each 1% increasing of the standard rate over the previous year; and the local government awards 1000000 Yuan when the compliances rate of NH_4-N and COD is both of 100% in two continuous years. 3) For the water body of inferior Class 5, when the compliances rate of NH_4-N and COD are both greater than 90%, the local government awards 100000 Yuan per each 1% increasing of the standard rate over the previous year; the local government of the water body awards 500000 Yuan when the compliances rate of NH_4-N and COD is both of 100% in continuous two years.

There is no doubt that the enforcement of applicable laws will improve the condition of water resources, but only a combination of education, scientific knowledge and planning can provide mechanisms for slowing the rate of degradation and provide human and environmental protection. Each individual can play an important role by practicing conservation and by changing certain everyday habits.

7. Final Remarks

It is well known that natural aquatic systems have a capacity to detoxify a certain quantity of pollutants discharged into them. This phenomenon is called self-purification. A water body will be polluted when the pollutants discharged into it exceed its capacity of self-purification. By looking back in the history of water pollution, it is easy to understand that the expansion of human activity is the main reason for it [106]. Water pollution problems occurred even before the industrial revolution. Human activity has caused the rapid, widespread degrading of water resources in the last few centuries.

This study focus on the water quality issues in China and tried to analyze the most representative problems and the relevant variables that control the water quality. It was based on literature research analysis and a large number of scientific papers and other documents have been consulted. It is considered that the objectives have been achieved and the author of this thesis greatly improved his understanding of water quality issues. There were some limitations in this study, for example the time duration of three months, and the fact that the author has never been involved in experimental studies of water quality.

The surface water quality is a matter of serious concern today in China as everywhere in the world. After analyzing 52 water bodies based on 58 scientific papers, it was concluded that the main reasons for the deterioration of water quality in China are the large population and agricultural areas, that place a huge pressure on watersheds.

As Table 17 shows, agricultural constitute the most common NPS pollution and produce a serious level of pollution in most of the lakes and reservoirs taken as case studies. Rain water flowing over the land surface collects and transports natural and man-made substances such as fertilizers and pesticides. This surface run-off is a seasonal phenomenon, affected by the precipitation pattern of the region. Water dilution has a strong effect on the concentration of pollutants in lakes and reservoirs.

Table 17: Degree of pollution from different pollutants sources of 6 case studies

<table>
<tr><th></th><th>Poyang Lake</th><th>Dongting Lake</th><th>Hulun Lake</th><th>Shitoukoumen Reservoir</th><th>Yuqiao Reservoir</th><th>Dianchi Lake</th></tr>
<tr><td>Agricultural pollution</td><td rowspan="2">S</td><td rowspan="3">S</td><td>S</td><td rowspan="3">M</td><td>L</td><td rowspan="2">S</td></tr>
<tr><td>Domestic sewage</td><td>M</td><td>M</td></tr>
<tr><td>Industrial pollution</td><td>M</td><td>L</td><td>L</td><td>M</td></tr>
</table>

S: serious degree of pollution. M: medium degree of pollution. L: light degree of pollution

It is important to consider the conditions at the watershed before analyzing the quality of a given water body such as a lake or a reservoir. As discussed in this thesis, the researchers must consider the environmental conditions including the natural climatic conditions and geological conditions of the study area and sources of pollution, human activities, land use types and laws, regulations or standards.

It is important to know the typical precipitation during the year, and precipitation data can be gathered from several nearby meteorological stations. The yearly average temperature can be gathered from meteorological agencies, including the different patterns in the dry season and the rainy season. How long is the monsoon months and non-monsoon months in each region, etc. For example, during the rainy season, the diffuse pollution discharge is influenced by the precipitation. At the initial stage of rainfall, peak concentration of organic matter comes out before the peak flow rate of the rainfall events. Thus, it is necessary to investigate and manage the first flush in order to control pollutants from NPS. Only understanding these climate factors, can the researchers find a correct time and place to do field monitoring. On the other hand, many factors that regulate water quality such as the nature of surface rocks exposed to the interaction with water, may increase the concentration of heavy metals in the water. Therefore the water quality is also related to geological factors.

Secondly, the researchers must understand the pollutant sources at the catchment level. For example, they should investigate the existence of industrial complexes, urban households, and mining sites. It is also important to know the soil type and land use. For instance low-lying paddy fields are risky to the environment in the rainy season since paddy water normally flows out into the surrounding bodies of water. Another example is, if an area undergoes extensive land change from agricultural use to urban-industrial-commercial then it is noteworthy to consider, new point pollutant sources during the whole year.

Last but not the least, it is necessary to take into account the physical parameters that characterize the water bodies such as the location, the shape, the dimension, the age in the case of reservoir and even the uses of the water. They are significant variables that also control the water quality.

References:

[1]. Koichi FJ, Hongying H. Effects of human activities on water quality. Water Quality and Standards. 2010; 2.

[2]. David S. Weird water lurking inside giant planets. In New Scientist, Magazine issue 2776. 2010.

[3]. Tingyao G. Water pollution control engineering. Higher Education Press (in Chinese). The third version. 2007.

[4]. Business solutions for a sustainable world. Water Facts & Trends. March 2009.

[5]. USGS. Water Use in the United States, National Atlas.gov. 2010. Available from: http://water.usgs.gov/watuse/.

[6]. BBC. Healthy Water Living. Retrieved 1 February 2007. Available from: http://www.bbc.co.uk/health/healthy_living/nutrition/drinks_water. shtml.

[7]. Odlare M, M.L.U.V. Introductory Chapter for Water Resources. Elsevier Inc. 2014.

[8]. Greenburg R. The Ocean Moon: Search for an Alien Biosphere, in Springer Praxis Books. 2005.

[9]. Hydrologic Unit Geography. In Virginia Department of Conservation & Recreation. 2010.

[10]. Subramanya K. Engineering Hydrology. In Tata McGraw-Hill. 2008; p. 298.

[11]. James EH, Stribling L. Water Quality And Pollution Control Handbook. Alabama Cooperative Extension System, Alabama A&M and Auburn Universities. 1995.

[12]. Xiao M, Ye L, Meng Z, Fangzhao Z, Shuang D. Assessment and analysis of non-point source nitrogen and phosphorus loads in the Three Gorges Reservoir Area of Hubei Province, China. Science of The Total Environment. 2011; 412-413: p. 154-161.

[13]. Edwin D, Ongley, Zhang X, Yu T. Current status of agricultural and rural non-point source Pollution assessment in China. Environmental Pollution. 2010; 158: p. 1159-1168.

[14]. Fang H, Xiaoquan W, Liping L, Zhiqing Z, Jiaping W. Spatial variation and source apportionment of water pollution in Qiantang River (China) using statistical techniques. Water Research. 2010; 44: p. 1562-1572.

[15]. Lei Z, Wenxi L, Yonglei A, Di L, Lei G. Response of non-point source pollutant loads to climate change in the Shitoukoumen reservoir catchment. Environmental Monitoring and Assessment. 2012; 184(1): p. 581-594.

[16]. Barbosa AE, Fernandes JN, Vieira AR. Analysis of Methodologies for Assessment of Urban Drainage Impacts in Lakes and Reservoirs. The Open Environmental & Biological Monitoring Journal. 2010; 5: p. 30-38.

[17]. Stefan HG, Preud’homme EB. Stream temperature estimation from air temperature. Water Resources Bulletin. 1993; 29(1): 27-45.

[18]. Grant PJ. Water temperatures of the Ngaruroro River at three stations. Journal of Hydrology (New Zealand). 1997; 16(2): 148-157.

[19]. Takashi T, Takahiro S, Kazuo W, Ying W, Dan Y, Hiromo I, Kunzhi L, Tatsuya I. Irrigation system and land use effect on surface water quality in river, at lake Dianchi, Yunnan, China. Journal of Environmental Sciences. 2013; 25(6): p. 1107-1116.

[20]. Jinzhu M, Zhenyu D, Guoxiao W, Hua Z, Tianming H. Sources of water pollution and evolution of water quality in the Wuwei basin of Shiyang river, Northwest China. Journal of Environmental Management. 2009; 90(2): p. 1168-1177.

[21]. Baruch B. Contradictions and Challenges in China's Water Policy Development. International Water Resources Association. 2001; 26(3): p. 335-341.

[22]. Peter-Christoph S. Environmental Laws. Inter Nationes. HTML edition by Lawrence Schäfer and 97 Gerhard Dannemann. 2010.

[23]. Water Law of the People's Republic of China. The National law of the People's Republic of China. 2002.

[24]. Environmental Protection Law and Law of Water Pollution Prevention. (GB3838) The National Standards of the People's Republic of China. Environmental Quality Standards for Surface Water.

[25]. Law of the People's Republic of China on Prevention and Control of Water Pollution. The National law of the People's Republic of China. 1984; Article 56.

[26]. Environmental Protection Law and Law of Water Pollution Prevention. (GB3097) The National Standards of the People's Republic of China. Sea water quality standard.

[27]. Environmental Protection Law and Law of Water Pollution Prevention. (GB8978) The National Standards of the People's Republic of China. Integrated Wastewater Discharge Standard.

[28]. Jinshan M. Features of water function zoning in different river basins in China. China's water conservancy(in Chinese). 2012; 07: p. 38-42.

[29]. Application, Google, Google Earth. 2014.

[30]. Lingyan Y, Lixin F. Study on the Reservoir Water Quality Change Rule in Northern China. Journal of Harbin industrial university, the English version. 2013; 4: p. 26-30.

[31]. Shengtian Y, Guotao D, Donghai Z. Coupling Xinanjiang model and SWAT to simulate agricultural non-point source pollution in Songtao watershed of Hainan, China. Ecological Modelling. 2011; 222(20-22): p. 3701-3717.

[32]. Jinhua W, Yongming S, Hong Z, Yu F, Zaixing W, Xu Y. Three-dimensional numerical modelling of water quality in Dahuofang Reservoir in China. Science China Physics, Mechanics and Astronomy. 2011; 54(7): p. 1328-1341.

[33]. Kaihsien C, Shihchieh H, Chuanyao L, Shuhji K, Tzuyi L. Deposition fluxes of PCDD/Fs in a reservoir system in northern Taiwan. Chemosphere. 2011; 3(6): p. 745-752.

[34]. Xiaobo L, Wenqi P, Guojian H, Jingling L, Yuchun W. A Coupled Model of Hydrodynamics and Water Quality for Yuqiao Reservoir in Haihe River Basin. Journal of Hydrodynamics, Ser. B. 2008; 20(5): p. 574-582.

[35]. Xuan Z, Qishan W, Yanfang L, Jing W, Miao Yu. Application of multivariate statistical techniques in the assessment of water quality in the Southwest New Territories and Kowloon, Hong Kong. Environmental Monitoring and Assessment. 2011; 173(1-4): p. 17-27.

[36]. Xiaosong C, Michael T. M, Xiaoyun L, Qing Z, Hao C, Jian C, Zhiqun Q, Lan Y, Jia C, Weiqun S. Determination of antibiotics in sewage from hospitals, nursery and slaughter house, wastewater treatment plant and source water in Chongqing region of Three Gorge Reservoir in China. Environmental Pollution. 2010; 158(5): p. 1444-1450.

[37]. Anonymous. Notice of Retraction. International Journal of Pharmaceutical Sciences Review and Research. 2013; 23(1): p. I.

[38]. Yuquan Y, Xuegong Z, Haisheng C. Studies on Seasonal Variation of Water Quality of Baixi Reservoir in Zhejiang Province and Ecology Protection. Anhui agricultural science. 2009; 15: p. 7125-7127.

[39]. Xinxian L. Characteristics of water quality comprehensive evaluation model and nutrition status analysis of Major reservoirs in Xinjiang. The arid geography. 2005; 05: p. 588-591.

[40]. Wei H, et al. Stable isotope composition of suspended particulate organic matter in twenty reservoirs from Guangdong, southern China: Implications for pelagic carbon and nitrogen cycling. Water Research. 2013; 47(11): p. 3610-3623.

[41]. Tianrong H, Xinbin F, Yanna G, Guangle Q, Haiyu Y, Bo M. Distribution and speciation of mercury in the Hongfeng Reservoir, Guizhou Province, China. Chinese Journal of Geochemistry. 2008; 27(1): p. 97-103.

[42]. Hongmei J, Xinbin F, Guanghui L, Guangle Q, Haiyu Y. Seasonal distribution of total mercury and methylmercury in sediments of the Wujiangdu Reservoir, Guizhou, China. Chinese Journal of Geochemistry. 2007; 26(4): p. 414-417.

[43]. Yongqiang T, Bangqin H, Chaochao Y, Nengwang C, Huasheng H. Dynamics of phytoplankton communities in the Jiangdong Reservoir of Jiulong River, Fujian, South China. Chinese Journal of Oceanology and Limnology. 2014; 32(2): p. 255-265.

[44]. Weihong L, Yingze T, Guoliang S, Changsheng G, Xiang L, Yinchang F. Concentrations and sources of PAHs in surface sediments of the Fenhe reservoir and watershed, China. Ecotoxicology and Environmental Safety. 2012; 75: p. 198-206.

[45]. Yingze T, Weihong L, Guoliang S, Yinchang F, Yuqiu W. Relationships between PAHs and PCBs, and quantitative source apportionment of PAHs toxicity in sediments from Fenhe reservoir and watershed. Journal of Hazardous Materials. 2013; 248-249: p. 89-96.

[46]. Jianyu L. Reservoir water quality analysis before and after Guangxi yantan hydropower station built library. Hongshui river. 1998; 17(2): p. 67-69.

[47]. Wenhua Y, Yingjie C. Studies on Seasonal Variation of Water Quality Indexes of Changtan Reservoir in Zhejiang Province and Their Correlation. Jiangxi agricultural journals. 2010; 22(1): p. 148-151.

[48]. Zhongwu Z, Degang Y, Yueqin Z. Study on the Problems and Their Mechanisms of Water Environment in Xinjiang. in Challenges in Environmental Science and Computer Engineering (CESCE), International Conference on. 2010; 2: p. 438-441.

[49]. Naili H. Water quality evaluation and prediction research of YuQing reservoir. Shandong university. 2008; 01: p. 123.

[50]. Zhenjun S, Chunyang S. Eco-restoration engineering and techniques in the Muyu reservoir watershed in Shandong, People's Republic of China. 1998; 11: p. 209-219.

[51]. Daming H, Wenjuan Z, Lihui C. The ecological changes in Manwan reservoir area and its causes. Journal of Yunnan University (NATURAL SCIENCE EDITION). 2004; 03: p. 220-226.

[52]. Tingzhu C, Chaoxing Y. Study on the Ecological Safety under the Industrial Development in Danjiangkou Reservoir Areas ——A Case Study of the Danjiangkou Reservoir Area in Xichuan County of Henan Province. Regional research and development. 2007; 26(6): p. 75-78.

[53]. Siyue L, Xiaoli C, Zhifang X, Hongyin H, Quanfa Z. Spatial and temporal patterns of the water quality in the Danjiangkou Reservoir, China. Hydrological Sciences Journal. 2009; 54(1): p. 124-134.

[54]. Minghua N, Yi Y, Min L, Caixia Y, Hao S, Wenbo D, John LZ. Environmental estrogens in a drinking water reservoir area in Shanghai: Occurrence, colloidal contribution and risk assessment. Science of The Total Environment. 2014; 487: p. 785-791.

[55]. Guojian H, Hongwei F, Sen B, Xiaobo L, Minghong C, Jing B. Application of a three-dimensional eutrophication model for the Beijing Guanting Reservoir, China. Ecological Modelling. 2011; 222(8): p. 1491-1501.

[56]. Min Z, Congxin X, Lars-Anders H, Wanming Hu, Jiapu C. Trophic level changes of fishery

catches in Lake Chaohu, Anhui Province, China: Trends and causes. Fisheries Research. 2012; 131-133: p. 15-20.

[57]. Shiping Z. Water quality evaluation and bloom prediction method research and system implementation of Beijing Lakes. Beijing industry and commerce university. 2010; p. 80, Beijing industry and commerce university. p. 80.

[58]. Xiaoxia Z, Botao Z, Yanguo T. Distribution of phthalate acid esters in lakes of Beijing and its relationship with anthropogenic activities. Science of The Total Environment. 2014; 476-477: p. 107-113.

[59]. Jun L, Hairong C, Gan Z, Shihua Q, Xiangdong L. Polycyclic aromatic hydrocarbon (PAH) deposition to and exchange at the air–water interface of Luhu, an urban lake in Guangzhou, China. Environmental Pollution. 2009; 157(1): p. 273-279.

[60]. Liuting S, Congqiang L, Zhongliang W, Xiangkun Z, Yanguo T, Lili L, Suohan T, Jin L. Iron isotope fractionation during biogeochemical cycle: Information from suspended particulate matter (SPM) in Aha Lake and its tributaries, Guizhou, China. Chemical Geology. 2011; 280(1-2): p. 170-179.

[61]. Zhiqi Z, Congqiang L, Wei Z, Qilian W. Historical lead pollution in the central region of Guizhou province, China: A record of lead stable isotopes of lake sediments. Applied Geochemistry. 2011; 26: p. S267-S270.

[62]. Zhao Y. Assessment of water quality in Baiyangdian Lake using multivariate statistical techniques. Procedia Environmental Sciences. 2012; 13: p. 1213-1226.

[63]. Linxi Y, Shihua Q, Xiaoguo W, Chenxi W, Xinli X, Xiangyi G. Spatial and temporal variations of organochlorine pesticides (OCPs) in water and sediments from Honghu Lake, China. Journal of Geochemical Exploration. 2013; 132: p. 181-187.

[64]. Jing L. The evaluation of water quality and annual analysis of the change of the Xiangjiang river and Dongting lake in Hunan province. Hunan agricultural university. 2007; 02: p. 72.

[65]. Yuandong W, Dianwei L, Kaishan S, Jia D, Zongming W, Bai Z, Xuguang T, Xiaochun L, Yanqing W. Characterization of water constituents spectra absorption in Chagan Lake of Jilin Province, Northeast China. Chinese Geographical Science. 2011; 21(3): p. 334-345.

[66]. Jun G, Haifeng Z, Guoqing P, Jizhong W, Boqing C. Factors Influencing the Persistence of Organochlorine Pesticides in Surface Soil from the Region around the Hongze Lake, China. Science of The Total Environment. 2013; 443: p. 7-13.

[67]. Guangxi X. N pollution sources and denitrification in waterbodies in Taihu Lake region. Science in China(Series B). 2001; 03: p. 304-314.

[68]. Xiong P, Chaoyang F, Hongwen C, Zhigang L, Bin L, Minglei F. Establishment of Water Quality Monitoring Database in Poyang Lake. Procedia Environmental Sciences. 2011; 1(10): p. 2581-2586.

[69]. Lian F, Chuanmin H, Xiaoling C, Xiaobin C, Liqiao T, Wenxia G. Assessment of inundation changes of Poyang Lake using MODIS observations between 2000 and 2010. Remote Sensing of Environment. 2012; 121: p. 80-92.

[70]. Fuqun Z. Stability analysis and evaluation research of Wolong lake wetland ecological system. Northeastern university. 2010; 03: p. 143.

[71]. Xiaofeng C, Xiaoming C, Liuyan Y, Huiying Z. Climatic warming and overgrazing induced the high concentration of organic matter in Lake Hulun, a large shallow eutrophic steppe lake in northern China. Science of The Total Environment. 2012; 431: p. 332-338.

[72]. Chuntao R, Changyou L, Keli J, Sheng Z, Weiping L, Youling C. Water quality assessment for Ulansuhai Lake using fuzzy clustering and pattern recognition. Chinese Journal of Oceanology and

Limnology. 2008; 26(3): p. 339-344.
[73]. Guoqing Z, Hongjie X, Tandong Y, Hongyi L, Shuiqiang D. Quantitative water resources assessment of Qinghai Lake basin using Snowmelt Runoff Model (SRM). Journal of Hydrology. 2014; 519: p. 976-987.
[74]. Jing P, Yongliang Y, Cunzhen G, Lwy Y, Xinde C, Tianyou D. Polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans in marine and lacustrine sediments from the Shandong Peninsula, China. Journal of Hazardous Materials. 2010; 176(1-3): p. 274-279.
[75]. Weina Z, Lin Y, Liquan Z. Analyzing the spectral response of submerged aquatic vegetation in a eutrophic lake, Shanghai, China. Ecological Engineering. 2013; 57: p. 65-71.
[76]. Wang K, Heping C, Dong Y, Chen L. The Application of Cluster Analysis and Inverse Distance-Weighted Interpolation to Appraising the Water Quality of Three Forks Lake. Procedia Environmental Sciences. 2011; 10: p. 2511-2517.
[77]. Kaihsien C, Shangde L, Shuhji K, Tzuyi L. Sources and deposition fluxes of PCDD/Fs in a high-mountain lake in central Taiwan. Chemosphere. 2013; 91(2): p. 150-156.
[78]. Xingqi L, Herzschuh U, Shen J, Qingfen J, Xiayun X. Holocene environmental and climatic changes inferred from Wulungu Lake in northern Xinjiang, China. Quaternary Research. 2008; 70(3): p. 412-425.
[79]. Lei Z, Xiaoling Z, Yong L, Bin H, Xiang Z, Rui Z, Yuanguan Z. Three-dimensional hydrodynamic and water quality model for TMDL development of Lake Fuxian, China. Journal of Environmental Sciences. 2012; 24(8): p. 1355-1363.
[80]. Zhenhua W, Bin H, Xuejun P, Kegang Z, Chang W, Jing S, Zhaojun Y, Guibin J. Levels, trends and risk assessment of arsenic pollution in Yangzonghai Lake, Yunnan Province, China. Science China Chemistry. 2010; 53(8): p. 1809-1817.
[81]. Hai X, Linzhang Y, Gengmao Z, Jiaguo J, Shixue Y, Zhaopu L. Anthropogenic Impact on Surface Water Quality in Taihu Lake Region, China. Pedosphere. 2009; 19(6): p. 765-778.
[82]. Gongduan F, Zhang Z, Jing L, Ping X, Xin W, Chao L, Shiqing Z. The Characteristics of Lakes of Water Source Heat Pump Systems in Chongqing. in Computer Distributed Control and Intelligent Environmental Monitoring (CDCIEM). International Conference on. Changsha. 2011; p. 1848-1852.
[83]. Jihyung P, Edu I, Mohd HA, Agustiyani D, Duan L, Thithuong H, Kyoung-Woong K, Sangdon K, Nguyen H, Pekthong T, Vibol S. Antonius Sarjiya. Sianouvong Savathvong. Suthipong Sthiannopkao. J. Keith Syers. Wanpen Wirojanagud. Implications of rainfall variability for seasonality and climate-induced risks concerning surface water quality in East Asia. Journal of Hydrology. 2011; 400: p. 323–332.
[84]. Annual mean Precipitation of China. 2014, The China institute of water resources and hydropower research.
[85]. Lianjun B, Keith AM, Shane AS, Eddy YZ. China's water pollution by persistent organic pollutants. Environmental Pollution. 2012; 163: p. 100-108.
[86]. Zhang B. Research of Poyang Lake. Shanghai, China: Shanghai scientific & Technical Publishers. 1988; p. 572.
[87]. Zuobang Z, Changqin K, Yingjuan S. Studying Changes in Land Use Within the Poyang Lake Region. Indian Soc Remote Sens. 2014; 42(3): p. 633-643.
[88]. Jinxiang Y, Yafei L, Xiaolan Z. Study on Water Environment Carrying Capacity and Main Pollution Sources of Poyang Lake. Agricultural Sciences Journal of Jiangxi. 2009; 21(3): p. 90-93 (in Chinese).

[89]. Shengrui W, Jianmin S, Zhaokui N, Minglei F, Zhigang L. Investigation on Pollution situation and countermeasures in Poyang lake. Journal of Environmental Engineering Technology. 2013; 4(6): p. 342-349.

[90]. Huang SF, J.G L, Xu M. Water surface variations monitoring and floodhazard analysis in Dongting Lake area using long-term Terra/MODIS data timeseries. Nat. Hazards. 2012; 62(1): p. 93-100.

[91]. Y.X W, Cheng S, H.B J, H.Q Z, Jiang D, D.F Z. Evaluatingsustainability of wetland system: a case study in East Dongting Lake Area, China.Afr. J. Agric. Res. 2011; 6(28): p. 6167-6176.

[92]. Guofeng W, Liangjie L, Fangyuan C, Teng F. Developing MODIS-based retrieval models of suspended particulate matter concentration in Dongting Lake, China. International Journal of Applied Earth Observation and Geoinformation. 2014; 32: p. 46-53.

[93]. Dilan Q, Yueping L, Zhe H, Jun H, Juan F, Yuehua L. Pollution status and source analysis of water environment in Dongting Lake. Environmental science and technology. 2012; 35(8): p. 193-198.

[94]. Chaoyu D, Sheng Z, Biao S, Xiaohong S. Assessment of Hulun Lake Water Quality in Summer and Winter. Inner Mongolia Agricultural University. 2014; 4: p.64-69 (in Chinese).

[95]. Liqiang S, Wei T, Muqing Y, Guangqing M, Bin G, Ning X. Ecological Risk Assessment for Drinking Water Source Land of Shitoukoumen Reservoir. Bulletin of soil and water. 2011; 31(1): p. 211-214.

[96]. Yong C. Study on causes and control countermeasure for water pollution of Shitoukoumen Reservoir in Changchun. The northeast normal university. 2010; in Chinese.

[97]. Yuan X, Ruqin X, Wei L, Yuqiu W. Evaluation and spatial characteristics of eutrophication in Yuqiao reservoir. Journal of Water Resources and Water Engineering. 2014; 25(1): p. 1-6 (in Chinese).

[98]. Jinhua S, Xiaofeng C, Yi H. Relationships between spatial-temporal trends of water quality and the human activities in Lake Dianchi. Lake science. 2012; 24(3): p. 347-354 (in Chinese).

[99]. Junli Z, Gufen Y. Spatial and Temporal Trends in Water Quality of Dianchi Lake from 1999 to 2008. Environmental Science Survey. 2014; 3: p. 1-7 (in Chinese).

[100]. Shankman D, Keim BD, Song J. Flood frequency in China's Poyang Lake region: Trends and teleconnections. International Journal of Climatology. 2006; 26: p. 1255-1266.

[101]. Jinbao W, Huayan H, Haiyan Z, Yuanyuan L. Application of Principle Component Analysis in Evaluating Water Quality of Poyang Lake. Journal of Nanchang University: engineering. 2010; 32(2): p. 113-117 (in Chinese).

[102]. Rongfang L, Yin Z. Analysis of spatial and temporal variation of water quality and its influencing factors in Poyang Lake. Water Resources Protection. 2011; 27(6): p. 9-13, 18 (in Chinese).

[103]. Yanling T, Guangxin Z. Analysis of Environmental Factors Influencing Non-point Source Pollutants. Agricultural journal of environmental science. 2010; 29(4): p. 725-732 (in Chinese).

[104]. Shuirong C, Guanghong W, Ruixian S. Change characteristics of water quality and its impact factor at the Yuqiao Reservoir in Tianjin. Reservation of water resource. 2011; 27(4): p. 27-30 (in Chinese).

[105]. Chunling Z. A preliminary study on the temporal and spatial characteristic of water environment and nitrogen and phosphorus nutrient salt of Xiaowan Reservoir. Yunnan University. Master thesis. 2013.

[106]. Supplying water regulations for management of South to North Water Diversion Project. Environmental Protection Law and Law of Water Pollution Prevention. The National Standards of the People's Republic of China. 2014.