Water Situation In China – Crisis Or Business As Usual?

Elaine Leong

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Department of Management and Engineering

Sub-department

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Elaine Leong

Supervisor at LiU: Niclas Svensson

Examiner at LiU: Niclas Svensson

Supervisor at Shell Global Solutions: Gert-Jan Kramer

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Summary

Several studies indicates China is experiencing a water crisis, were several regions are suffering of severe water scarcity and rivers are heavily polluted. On the other hand, water is used inefficiently and wastefully: water use efficiency in the agriculture sector is only 40% and within industry, only 40% of the industrial wastewater is recycled. However, based on statistical data, China's total water resources is ranked sixth in the world, based on its water resources and yet, Yellow River and Hai River dries up in its estuary every year. In some regions, the water situation is exacerbated by the fact that rivers' water is heavily polluted with a large amount of untreated wastewater, discharged into the rivers and deteriorating the water quality. Several regions' groundwater is overexploited due to human activities demand, which is not met by local. Some provinces have over withdrawn groundwater, which has caused ground subsidence and increased soil salinity. So what is the situation in China? Is there a water crisis, and if so, what are the causes?

This report is a review of several global water scarcity assessment methods and summarizes the findings of the results of China's water resources to get a better understanding about the water situation. All of the methods indicated that water scarcity is mainly concentrated to north China due to rapid growth, overexploitation from rivers and reduced precipitation. Whereas, South China is indicated as abundant in water resources, however, parts of the region are experiencing water scarcity due to massive dam constructions for water storage and power production. Too many dam constructions in a river disrupts flow of the river water and pollutants are then accumulated within floodgates.

Many Chinese officials and scholars believe that with economic growth comes improved environmental quality when the economy has reached to a certain of per-capita level. However, with the present water situation it is not sustainable or possible for China to keep consuming and polluting its water resources. Improvement of environmental quality does not come automatically with increased income, and policies, laws and regulations are needed in order to stop further deterioration of the environment.

China's water situation is not any news and the key factor is human activities, but the question is how to solve it. China's water crisis is much more complex than over exploitation of groundwater and surface water. There are three water issues in China: "too much water – floods, too little water – droughts, and too dirty water – water pollution" (Jun & Chen, 2001). Thus, solving China's water crisis is a huge challenge to solve without negatively affecting the economic growth.

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Elaine Leong, April 2013

Abbreviations and Acronym

BOD   Biochemical Oxygen Demand

COD   Chemical Oxygen Demand

EKC   Environmental Kuznets Curve

EPA   United States Environmental Protection Agency

EWR   Environmental Water Requirements

IPCC   Intergovernmental Panel on Climate Change

IWMI   International Water Management Institute

MAR   Mean Annual Runoff

MWR   Ministry of Water Resources of the People's Republic of China

UN   United Nations

WRI   Water Resources Institute

WSI   Water Stress Indices

1 Introduction

1.1 Background

There is much talk about the water crisis in China and for decades the country has been suffering from water shortages, water pollution and floodings. In addition, rapid growth and urbanization is exacerbating the water problem further. As Guan et al. (2007), pointed out, the severe water issues have become one of the bottlenecks for the growth of many provinces in China, since water is the primary input of all goods and services (either directly or indirectly). Restricted availability of water (either quality or quantity) will affect the production of goods and services negatively and will influence the level of economic activities, especially for a developing country which is transforming from agricultural-based economy towards an industrialized economy.

Considering there are several water studies indicating China is short of water (e.g. Amarasinghe, Giordano, Liao, & Shu, 2005; Bai & Shi, 2006; Cai, 2008; Chen, Zong, Zhang, Xu, & Li, 2001; Chen, Zhang, Sun, Liu, & Wang, 2005; Cheng & Hu, 2012; Feng, et al., 2005; Liu & Xia, 2004; Piao, et al., 2010; Zhang, et al., 2011b), the country is surprisingly abundant in water. Based on statistical data of the world's most water rich countries, China's total water resource is ranked as sixth in the world (Shalizi, 2006). In China's statistical yearbook (2011) it is estimated that all surface and ground water is approximately to be 2,956 billion m^3 per annum, and 76% of its total water resources are estimated to be surface water and 24% is groundwater. However, due to the large population, water availability per capita is low; it is estimated in the statistical yearbook for year 2011 that national water per capita is in average 2,310 m^3 per year and looking at regional levels some provinces' water per capita is below 500 m^3 per year.

China's water resource is divided into 21 river basins and the nine major basins are: Yangtze, Yellow, Hai-Luan, Huai, Song-Liao, Pearl, Southeast, Southwest and Northwest (figure 1.1). Moreover, Yangtze River is the river which divides China into a humid south and an arid north and is often called the "the equator of China" (Varis & Vakkilainen, 2001) and from now on, the author will refer to this when discussing about north and south China. With other words, north China is referred to provinces which are located above the Yangtze River basin and south China is referred to provinces below Yangtze River basin.

Due to the different climate in south and north China, water resources are unevenly distributed, both geographically and seasonally. According to Zhang J. et al. (2010), north China has: 44% of the total population, 65% of the total cultivated land and less than 13% of the total renewable water resources; and south China has: 56% of the total population, 35% of the total cultivated land and 87% of the total renewable water resources. With the unevenly distributed water resources, population and cultivated land, it is not a surprise that north China is the most water scarce region. The arid climate in the north makes the agriculture sector being dependent on irrigation and the sector is no doubt the largest water consumer (China Statistical Yearbook, 2011). In addition, a lot of water intensive industries are located in the north such as fossil fuel production (coal, natural gas and oil), iron mining, paper and pulp mills, breweries, and chemical industry, and resulting surface water from rivers being over exploited and heavily polluted (Bai & Shi, 2006; The World Bank, 2009; Economy, 2010; Wang, Ji, & Lei, 2012; Qi, et al., 2005). As a consequence, several rivers dries up in the estuary due to sparse precipitation and human's water

demand is higher than the nature manage to replenish rivers' water resources. Rivers' water resource is recharged 98% by precipitation and the remaining 2% comes from melting glaciers (Aquastat, 2010).
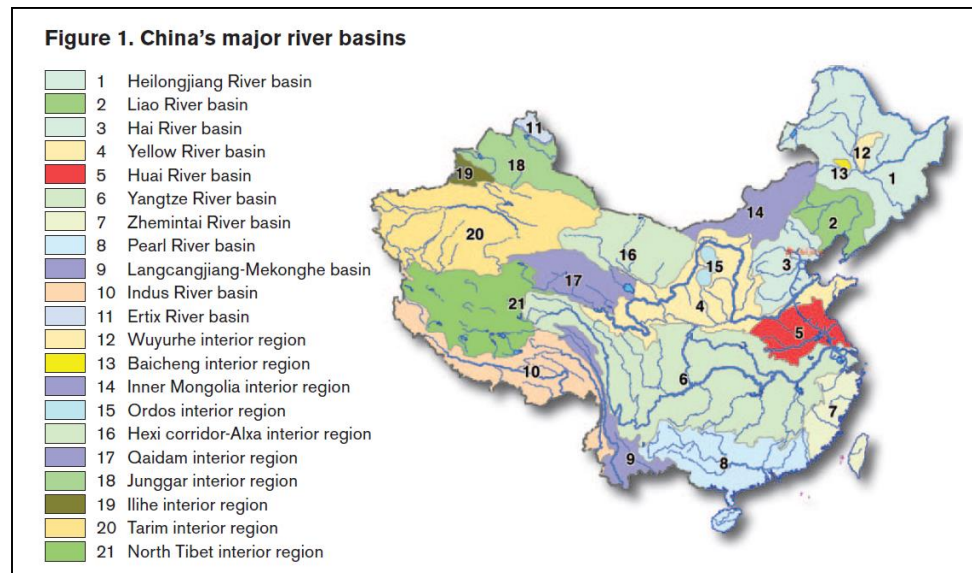
Figure 1.1. Map of China's major river basins. Each color represent the basin's area coverage. The nine major river basins are Yangtze, Yellow, Pearl, Heilong Jiang, Liao He, Hai He and Huai He. Source: Bai & Shi, 2006

Data from China's annual statistical yearbook shows that the annual average precipitation in the south exceeds 1400 mm/yr and is fairly spread over the year, while for the north the annual average precipitation is less than 400 mm/yr. Because of the monsoonal climate, rainfall is mainly concentrated to the summer (May–August) with about 60-70% of the annual precipitation. Except these variations, recent also studies show the north has become drier during the summer due to declined precipitations and warmer temperature with increased droughts as consequence, and the south has increased precipitation with more severe and frequent floods during the summer (Cheng & Hu, 2012; Deng, Shan, Zhang, & Turner, 2006; Liu & Xia, 2004; Piao, et al., 2010).

Moving on, water pollution is another issue in China's water problems and especially in the north among the many water intensive activities. Industries discharge large amount of untreated industrial waste water into the rivers and the agriculture sector contribute to the problem by fertilizers and pesticides gets into river water from subsurface runoff.

Water scarcity and pollution are annually causing tremendous economic losses in China and the World Bank presented some of the economic losses in their report, "Addressing China's Water Scarcity", based on data from 2003:

- Approximately 7.4% of the nation's irrigated lands (4.05 million hectares land) are irrigated with polluted water, which reduces harvest due to quality of the soils and crops are degraded. The economic loss caused by irrigation with polluted water has been estimated at 0.64% of GDP (85.4 billion yuan).

- Approximately 25 km^3 of water is held back from usage due to water pollution and the economic losses has been estimated at 0.64% of GDP (85.4 billion yuan).

- The economic cost caused by groundwater depletion has been estimated at 0.69% of GDP (92.3 billion yuan).

In total, the estimated economic cost of water scarcity was 2.3% of the total GDP in 2003, out of which 1.3% is associated to scarcity of physical water and 1% is associated to scarcity of clean water (Xie, 2009). With increasing economic growth comes also increasing water demand and with the existing water scarcity and water use, China's future economic development, food security and quality of life are now threatened (Jiang Y. , 2009). This water issue might also become a global concern due to China is increasingly connecting with the rest of the world, both environmentally and economically. Between 2001 and 2005 China lost approximately 1.62% of their annual GDP due to water shortages (Jiang Y. , 2009). China's leaders are aware of their aggravating water situation and have introduced a number of policy goals and priorities in their 11th Five-Year Plan (2006-2010) and 12th Five-Year plan (2011-2015), among other things, to reduce water pollution and water use intensity in industry (Xia, 2009; China's 12th Five-Year Plan, 2011). As Jiang (2009) points out in his article, water scarcity is a complex issue since it is integrated and has serious effects on all sectors and systems, such as the agriculture, industry, domestic, the society and environment, and Jiang raised the questions: 'How well do we understand the water problem? What are the causes to China's water scarcity? How can China cope with its water problem?'

In 2006, the World Bank published a report, 'China Water Quality Management', and projected that by 2010 the whole China would be classified as a water stressed country based on 2006's population growth and the threshold definition for water stress from UNDP, UNEP, WRI and World Bank. The organizations' definition of water stress occurs when the annual water resources per capita is 2000 m^3 or less, and water scarcity occurs when the annual water resources per capita is 1000 m^3 or less. Although there are several water studies that shows many provinces in China are suffering from water stress or scarcity, water is used inefficiently and wasteful (Cai, 2008; Deng, Shan, Zhang, & Turner, 2006; Water Resources Group, 2009; Molden, et al., 2007a; Shalizi, 2006; Smakhtin, Revenga, & Döll, 2004a; Jiang Y. , 2009; Vörösmarty, et al., 2010; The World Bank, 2006). Those who are not familiar with China's water situation might not think the it is a water stressed country considering their poor water management, because often one would associate a country with water crisis also has a better water management. According to Jiang (2009) there are many reasons for China's water scarcity: large water pollution in many regions and making water unusable; highly inefficient water use due to a supply-driven water resources management style which ignores the economic nature of water resources and the conflict between water availability and demand; rapid industrialization and urbanization; underdeveloped water rights system; lack in management of water resources; and other policy failures.

According to Lee (2012), the minds of leaders in China and other developing countries are influenced by the concept of the environmental Kuznets curve. The hypothesis of environmental Kuznets curve states an economy increases its pollution while growing and when a certain point is reached, pollution will decline because richer people tend to care more about the environment quality than poor people and there are also more resources (Mäler, 2001). Thus, this mentality could explain parts of the large water pollutions and unsustainable water management style in China.

Defining water scarcity and finding solutions is a very difficult challenge and as White (2012) discussed in his article that the challenge in defining water scarcity depends how a water scarce area is defined, for instance: a) the definitions of water need – how the water needs for the people, environment and nature are defined; b) the definitions of total available water resource – what is considered as available surface water and ground water; c) the temporal and spatial water availability – if the seasonal and geographical water resources are taken into account. With respect to the many different parameters the water studies are based on, the results are sometimes different and might give a vague picture of the water situation in China. For this reason, this project has been developed to find out if there is a water crisis in China and its causation. More specifically, is it due to poor water management or is it a result of a long-term climatic change and part of natural cycle per se? Will environmental quality improve with economic growth?

Up until now, three different terminologies describing a region's water situation have been used in this report – water crisis, water scarcity and water stress; and this might already have created confusion for the reader. Water scarcity is the most frequently used term and is often associated with regions lacking of access to adequate quantities of water, although there is no commonly accepted way to define and differentiate the terms water scarcity or water stress. Based on the author's research, the term "water scarcity" is mostly used when there is an imbalance between water demand and water supply in such way that competition emerges between sectors and groups about the scarce water resources. Whereas the term water stress is often used when water demand exceeds the amount of available and potable water during a certain period, due to the region being physically short of water for a certain time or short of clean water. Since there are no global standards to define different water terminologies, various water studies have provided different results where researchers have defined and used different parameters to evaluate water scarcity. Moreover, some definition is ever-expanding and creates more confusion, such as water crisis. Thus, a section later on in this chapter is dedicated to introduce and explain different water-related terminologies which are used in this report in order to reduce confusion for the reader.

1.2 Objective and research questions

The objective with this project is to identify if there is a water crisis in China and what has caused it. Therefore, the aim of this report is to give an overview of the current water situation in China by reviewing several global water scarcity assessments methods developed by well-established organizations and researchers. Results from the different assessments methods were analyzed in order to understand the status of the present water situation in China. Moreover, this report also study how China's water availability and water use might develop in the future. The assessments methods are based on different parameters and were chosen based on their strengths and weaknesses and whether or not they complement each other.

The main research questions are:

- What is the definition of a water crisis as it pertains to China's current situation? The aim with this question is to find out if there is a water crisis in China as some of the water studies indicate or if the situation is exaggerated and it is only a matter of water management.
- Will the accusation of a water crisis hinder China's economic development? The aim with this question is to look if there is any connection between the country's economic growth and the degradation of water quality.

To be able to answer the main research questions, the author first has to answer some sub-research questions:

- If there is a water crisis in China, is it because of water stress or water scarcity or both, and what are the main causes? This question will if the causes to China's water scarcity is due to direct anthropogenic factors, such as overexploitation of water resources and wasteful water use practices, and can be solved by improving the present water management or is the issue much more complex than that?

- Is there lack of water in terms of quantity or quality? Based on the statistical data China is rich in water resource, but the data might be misleading since the resource is presented as total water availability per year, except precipitation which is also presented per month. China is a large country with a varied climate depending on the region - north China is an arid zone and is annually experiencing droughts, while south China has monsoonal climate and is annually experiencing floods. If there is a water crisis and considering the abundance of water in China, is it because of lack of physical water due to seasonal and geographical reasons or is it due to lack of clean water?

- Are there any signs that water consumption and climate change have any impacts on China's future water resources?

1.3 Scope

Water is a complex resource, since it is integrated with all sectors and systems. Moreover, water resource is dependent on the hydrological cycle which is also a very complex system due to the many impacts from different factors, both indirect and direct anthropogenic factors (Weng, Huang, & Li, 2010). In this report, indirect anthropogenic factors are referred to human activities which have indirect negative environmental impacts, such as climate change and acid rains. Climate change is in turn referred to change of air temperature, precipitation and snowfall. Direct anthropogenic factors are referred to human activities which have direct negative environmental impacts, such as water pollutions, overexploitation of water sources, change of river water flow due to constructions of water reservoirs and dams and etc. Also, in this project only water resources from rivers and river basins were studied since rivers serve as the main water source for both human and environment.

Many water studies have been done about China's water scarcity, however different studies have provided different results since they are assessed from different perspectives for different stakeholders[1], e.g. the water scarcity index physical and economical water scarcity index was developed for a target audience who make investment and management decision in water management for agriculture, the water footprint method was developed to quantify the amount of water that is needed to produce a product, provide a service or a nation. Thus, some studies might obscure important water scarcity information at smaller scale while others might highlight them. For this reason, this project was developed to give a more fully covered and unbiased picture of China's water situation by summarizing results from different water studies and help the reader to get a better understanding about China's present water situation. However, it is important to note the author does not intend to substitute any previous water studies or work. The focus of this report is to clarify the present water situation in China, how it might develop in the future and how China can cope with its water issues.

Furthermore, the author does not attempt to develop a new water scarcity index or make a fully detailed water assessment on China and it is mainly due to data limitation and the many uncertainties among it. Instead, the intention is to pull together existing water scarcity indices and water assessment methods on China (from now on water scarcity index will be referred to as WSI and water assessment will be referred to as WA), and cohesively summarize the findings. Statistical data will also be collected and analyzed to see if there are any connection or even causations to the water problems as the WSI and WA show.

Various WSI have been developed during the past twenty years and various global water studies have been done, but few are used or recognized by international organizations, such as United Nations (UN), World Bank, International Water Management Institution (IWMI) and World Resources Institute (WRI). It is mostly due to the fact that WSI or WA require data which is not available, the method is too sophisticated and requires too many resources (e.g. time, data, and expert knowledge) in order to be able to perform the WSI or WA which the user usually do not have, or provide results that are difficult to interpret. Therefore, the WSI and WA used in this report are those which are well-established and developed by well-known researchers within the water management field and are accepted by

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[1] The author know this after have been reading a numbers of reports and articles about water issues in the world. Based on the stakeholders' interest, the used parameters for defining water scarcity are different.

international organizations. Brief descriptions about each index and assessment methods, and what kind of parameters they are based on will be described.

There is also an intention to study if there is any connection between water pollution to China's economic growth according to the concept environmental Kuznets's Curve (EKC). An important note, the author does not have the purpose to investigate the existence of EKC in this study since there are many factors contributing to a country's economic growth, but rather analyzing if there are any signs indicating China's economic growth will result to reduction of water pollution from industry. The reason is due to lack of too many data and thus: i) this analysis is focused on water pollution from industry and industries gross industrial output value, since industries are the main water polluters and industries gross industrial output value is a good indicator of regions' economic development; ii) water pollution in this analysis is limited to discharge of COD, and ammonia and nitrogen, data on other water pollutants were not available.

Before the discussion and conclusion, there will be a chapter about how China's water future might develop. In 2009, The Water Resources Group published the report, 'Charting Our Water Future', which is a study focusing on how the global competing demands for scarce water resources will develop in 2030 and how it can be met in a sustainable way. The report studied four countries which will have great impact by macro-economic trends on the water sector, i.e. China, India, Brazil, and South Africa. Furthermore, the IPCC made a global analysis and projected how future precipitation will change due to climate change in 2030, based on different scenarios. The author attempts to study the results of projected future water demand and climate change in China, and integrate the results from these two studies with the intention of analyzing how China's future water resources will be affected and what measurements can be taken in order to mitigate the water scarcity.

Lastly, the province Hainan is neglected in this research, because the province is an island and does not withdraw any water from any of the rivers in mainland China.

1.4   Outline of the report

This report contains 6 chapters. Following this introduction, Chapter 2 describes which water assessments methods were chosen, the methods strengths and weaknesses, the theoretical background of the water assessments methods and how data is collected. Chapter 3 is an introduction to China's present water resources and water use, and the results of the WSIs on China's water situation. Chapter 4 covers China's future water use, how the climate change will affect existing water resources and what measurements can be applied in order to mitigate the water shortage. The report closes with discussion and conclusion in chapters 5 and 6, answering and discussing the research questions and what more needs for future water studies.

1.5 Glossary

There are various ways to define water scarcity, water stress, water shortages and etc. in literatures. The intention of this section is to clarify how the author defines different water terminologies in this report in order to reduce confusions for the reader. Definitions of the terminologies are from websites of EPA, FAO, UN, USGS, Water Page of African Water Page, Global Water Forum and IWMI.

Aquifer – An underground layer of permeable rocks or other porous substrate that contains and percolates groundwater to springs and wells.

Groundwater – Water which is found beneath the earth's surface in areas with permeable rocks which are saturated with water under hydrostatic pressure.

River run-off – All water which enters the river stream, i.e. rainfall, snowmelt, groundwater from upper aquifers. After the water enters a stream, it becomes runoff.

Surface water – Water found on the surface of the earth, such as rivers, lakes, seas, oceans, etc.

Water crisis - occur:
- When there is lack of clean potable water in a region to meet the basic human needs.
- When the balance in the ecosystem is disturbed and endangers the biodiversity.
- When the groundwater sources are overexploited.
- Regional conflicts over scarce water.
- Pollution of surface water.
- Poor infrastructure resulting difficulties for people to get access to water.

Water consumption – The amount of water that is withdrawn from a source and used in such way that it will not return to surface water due to it is lost in evaporation during the manufacturing process or incorporated into the finished product, byproducts or solid waste, or the quality of the returned water is deteriorated and cannot be used without treatment.

Water pollution – Substances which contaminate and degrade water quality.

Water pollution from non-point sources – Water pollutions from diffuse sources, e.g. land runoff, precipitation, seepage and etc. Types of water pollutions from non-point source are often fertilizers from agricultural lands runoff, oil and toxic chemicals from urban land runoff, atmospheric deposition (causing acid rains), and bacteria and nutrients from livestock and pet wastes.

Water pollution from point sources – Water pollutions from direct source, e.g. direct discharge of untreated waste water from industrial and sewage treatment plants to a water source.

Water scarcity – The term describe the relationship between water availability and demand rather than a condition. A country or region is usually defined as water scarce when there is an imbalance between water demand and water availability, which leads to competition of water between sectors and activities, degradation of groundwater and water quality. In this report, water scarcity occurs when a region is short

of water such as different sectors and groups competes about the resources and also the unmet water demand lead to negative impact on the economic growth.

Water shortage – Occurs when the water supply does not meet a certain minimum requirements, the requirements differ from place to place.

Water stress – Occurs when the water demand exceeds the available amount during a certain period or when the quality of the water is degraded and restricts its use.

Water use – Proportion of withdrawn water for specific purposes, such as water use for industrial purposes, agricultural purposes, or domestic purposes.

Water withdrawal – Freshwater that is removed from source with surface water or groundwater for human use. Parts of it will return to the catchment area, parts of it will evaporate and be lost, and parts of it will end up in another catchment area or the sea.

2 Method and theoretical background

2.1 Method

In order to understand the present water situation in China, different existing WSI and WA methods will be analyzed since there is no possibility for the author to make any field studies in China. Due to there are many water different kinds of WSI and WA, the selection will be based on the methods' strengths, weaknesses, perspective, and resource requirements in terms of time, knowledge and data in order to understand and/or execute the method. Several methods were selected in such way the methods complement each other's strengths and weaknesses.

Four water assessment methods were chosen: the Falkenmark Water Stress Index, Water Stress Indicator Taking Environmental Water Requirements into Account, Physical and Economical Water Scarcity Index, and Global Map of Human Water Security and River Biodiversity. All four methods focuses on water availability from rivers, and as it is explained in Vörösmarty et al. (2010) article, rivers serve as the main source of renewable water supply for human and the environment, and thus it is often rivers are assessed to identify water availability in a region. The reasons for the author's choice of these four methods are: i) all four methods are developed by well-known water experts and accepted by international organizations, which generate credibility for the methods; ii) the combination of the four methods covers assessment of water availability for human, environment and food production, and water quality, which according to the author are four important factors that needs to be considered in a water assessment and at the moment it does not exist any assessment method that consider all those four factors in one; iii) the three methods, Water Stress Indicator Taking Environmental Water Requirements into Account, Physical and Economical Water Scarcity Index, and Global Map of Human Water Security and River Biodiversity have already been performed on a global-scale by water experts and maps with high spatial resolution are

provided, since it is not possible for the author to perform these three methods due to lack of many data and very few methods have been performed on global-scale and been published with maps.

A table is presented in next sub-chapter and comparing the four methods strengths and weaknesses, required knowledge and data to perform the methods, and whether if water quality and environments water demand are considered or not. Motivation for each method is given after their respective theoretical background. The theoretical background of the four methods are described in the next section and the information is gathered from scientific articles and research reports, which are collected from scientific databases or international organizations' database, such as Scopus, Science Direct, Springerlink, IWMI, World Bank and many more. Some information about the assessment methods are collected from universities' website if it was developed at an institute or university.

Furthermore, the WSI and WA only indicate which parts of China are experiencing water shortage and the level of it - water stress or water scarcity. In order to understand why each specific region is experiencing water shortage, the author has studied the river basins which are located in the water short regions. This was done by reviewing several water studies of each river basin. Information about the water situation for respective river basins was collected from scientific research articles and water studies from several researches and international organizations. Data on water use, water resources, river's length, total population in the major river basins in China and etc. were collected from China's statistical yearbook and international organizations' database, such as UN, World Bank, and Aquastat.

As mentioned in Chapter 1.3, the author intend to study if there is any connection between economic growth and water pollution in China. Data of the gross industrial output value and discharge of water pollutions (COD, ammonia and nitrogen), and the seven major rivers' water quality are collected from China's statistical yearbook and a website named "Circle of Blue". The development of the economic growth and water pollutions were analyzed in order to see if there are any trends – how water pollutions developed with the economic growth and what could be concluded for the coming future. Moreover, it is difficult to compare regions' pollution rate that also reflect the regions' economic growth, since the economic structure of each region is different. For instance, it is difficult to compare province X's and Y's water pollution rate if province X is a large producer of coal and crude oil and province Y is large producer of chemicals industrial, because these two provinces are producing two different kinds of products, and amount of discharged pollutants and gross output value is different. Therefore, to make it more comparable the total amount of discharged industrial pollutants will be divided by the gross industrial output value for each region or river basin and this will then give gram of discharged pollutant per yuen.

Furthermore, some provinces have several rivers flowing through and due to lack of data of the amount of discharged COD, Ammonia and Nitrogen to each river, simplification has to be made by dividing the provinces' total discharge by the number rivers flowing through. For instance, the Sichuan province has two rivers flowing through, Yellow River and Yangtze River, thus the total industrial COD, Ammonia and Nitrogen discharges in Sichuan province are divided by two. In order to make the COD, Ammonia, and Nitrogen discharge more comparable, the total amount of discharges are divided by respective region's gross industrial output value so the discharge will be in gram per yuen. Moreover, the discharge data of COD, Ammonia and Nitrogen discharge, and gross industrial output value that will be studied is between

year 2004-2010 and this short period span is because there is lack of available provincial discharge data earlier than 2004. The website "Circle of Blue" will also be used as a source for data collection of the quality of major rivers in China. The website is founded by leading journalist and scientist and provides data and information about the resource crisis in the world.

To find out how China's future water demand and water resources will develop, the author has studied future projection of the climate change, China's five-year plan (2011-2015), and future projection of China's water demand. Information was collected from reports by IPCC, WRI, and HSBC. The author analyzed the projected climate change and water demand for China, and each province development goals for the coming years, and from that projected how China's future water resources might develop.

Calculations for the water savings measurements was done by finding out which top industry sectors in China are the most water intensive. Information about how much water in average is used for each sector to produce the final product was collected from scientific research articles and reports from international organizations. The estimated amount of water that could be saved in the Chinese industries is calculated by comparing the amount of water needed in average to produce a certain amount of a final product by the industry sector with Chinese standards to an industry sector with developed countries standard.

2.2 Advantages and disadvantages of the WSI

All methods have strengths and weaknesses, and it depends on what parameters the method is based on. The table 2.1 below, present the four selected WSIs' strengths, weaknesses, required data and knowledge, and how the methods complement each other

Application:	Falkenmark Water Scarcity Indicator	Physical and Economic Water Stress Global Map Indicator	WSI taking EWR into account	Global map of threats to human water security and biodiversity
Advantages	- Good tool to get a general picture of available water at Per Capita basis - Required data is readily available - Provides easy and understandable result. - Can be applied at both regional and country level.	- Assess water availability for food production. - Define two different kinds of water scarcity and implying dry areas are not necessarily water scarce. - The water assessment for the map was made at a regional level. - Takes the availability of the infrastructure that modifies the availability of water to users. - The geographic and seasonal water distribution is considered.	- Assess water availability for both environment and human. - The water assessment for the map was made at a regional scale, has a spatial resolution of 0.5° cell grids. - The geographic and seasonal water distribution is considered.	- Assess the impacts of human's activities on rivers' water resources and its biodiversity. - The water assessment is made at a regional scale, spatial resolution of 0.5° cell grids. - The geographic water distribution is considered. - Based on many driving factors (e.g. water pollution, dams development, development of aquaculture and cropland etc.) and provide main reasons to water scarcity in the studied region.
Disadvantages	- Does not consider the seasonal or spatial distribution of the water. - Only assessing water availability for	- The data used to generate the map is old. - Expert knowledge is required if the user want to reproduce the map. - Requires large amount of resources and time to collect all required data and doing the assessment. - The data required is not always readily available.		

	meeting human basin needs (min. water demands for drinking, sanitation, food preparation and bathing)			
Required Knowledge	None	- The user need to understand that parameters this index is based on. If the user want to reproduce the map: - User needs to know how to use the model Watersim.	- The user need to understand that parameters this index is based on. If the user want to reproduce the map: - User needs to know how to use the model WaterGap. - The user need to know how to estimate the EWR for each river basin.	- The user need to understand that parameters this index is based on. If the user want to reproduce the map: - Expert knowledge is needed to produce the weighting sets. - User need to know how to use
Required data	- Total amount of available water of the studied region. - Total population.	Only if the user want to reproduce the map: - Total amount of available water of the studied region. - Amount of nutrition intake in the studied region. - Total water withdrawal from rivers.	Only if the user want to reproduce the map: - Total water withdrawal from rivers for human use. - Environmental water requirements.	Only if the user want to reproduce the map: - Data of different pollution discharge, catchment disturbance, water resource development and biotic factors.
Assessing Environmental Water requirements	No	No	Yes, complements the other three methods that does not assess EWR.	No
Assessing Water Quality	No	No	No	Yes, complements the other three methods that does not assess the quality of the water.

2.3 Theoretical background

2.3.1 The Falkenmark Water Stress Indicator

The most commonly used water scarcity index is Falkenmark Water Stress Indicator and it is mainly due to its simplicity and that the required data is mostly readily available. The indicator was developed in 1989 by the Swedish water expert Malin Falkenmark and looks at the total available water per capita from rivers and aquifers in a region and may be used on both at country or regional scale.

The indicator provides easy understandable and intuitive results, and use annual per capita water availability to define the threshold for water stress and water scarcity (table 2.1) (Falkenmark, Lundqvist, & Widstrand, 1989). The largest advantage with this indicator is it gives fast and easily a general picture of a region's water situation. The only needed data is the annual total water resources and total population of the studied region. However, there are also many clear disadvantages with this indicator. The simplicity stems from many important parameters not considered and important impacts at smaller scale might be obscured, such as the geographic and seasonal distribution of water resources in the region, environmental water requirements, and quality of the water. Thus, regions or countries which are water-short might not be revealed with this indicator and need to be complemented with other assessment methods or water scarcity indicator when assessing a region's water situation.

The thresholds for water stress and scarcity are presented below, in table 2.1.

Index (m³ per capita per year)	Condition
>1,700	No water-stress
1,000-1,700	Water-stress
500-1,000	Water-scarcity
<500	Absolute water-scarcity

Table 2.1. Falkenmark's water scarcity index threshold for water stress and scarcity. The table indicates a region's or country's water situation based on the annual water availability per capita per year. Source: Brown & Matlock, 2011

For a more detailed explanation of how this method was developed, refer to the original article: Macro-scale water scarcity requires micro-scale approaches - Aspects of vulnerability in semi-arid development (Falkenmark, Lundqvist, & Widstrand, 1989).

2.3.2 Physical and Economic Water Scarcity

In 2007, IWMI developed a global physical and economical water scarcity map in the report "The Comprehensive Assessment of Water Management in Agriculture" (2007). The map was generated with the hydrologic and economic model WATERSIM (Water, Agriculture, Technology, Environment and Resources Simulation Model)- a model, which is usually used for scenario analysis and to get better understanding of the linkage between water, food security, and environmental security. Therefore, it is important to note this WSI map mainly indicates water availability for food production and not a regions total water resources.

The model WATERSIM was developed from a joint modeling exercise during the World Water Forums in The Hague (2000) and in Japan (2002). In 2005, IWMI and ICID published the report "WATERSIM" and in the report it is explained how the model was developed based on two integrated modules: the food demand and supply module; the water demand and supply module. Furthermore, in the report it is explained the estimation of the two modules are based on several variables:

The *food demand* is expressed as a function of population, income and food prices, and the growth in crop production is estimated by crop prices and the rate of productivity growth. The *food supply* is expressed as a function which depends mainly on several economic variables such as crop prices, inputs, subsidies, food production management (crop technology and rain fed versus irrigated), climate condition, and water availability. Moreover the demand for irrigation is constrained by the amount of available water. The food demand and supply module was run on an annual time-step.

Water demand for the domestic sector, industrial sector, agriculture sector and environment are estimated at the basin scale. Water supply is defined as function of climate, hydrology and infrastructure. The module deals with blue water, which means water that is withdrawn from river, aquifers, lakes and reservoirs. River basin is used as basic spatial unit, but since food and policy making happens at national level, the river basin cannot be used for the food module. Therefore, WATERSIM uses a hybrid approach for its modeling of the spatial unit. The world is divided into 125 major river basins and 115 economic regions, and river basins were then intersected with the economic regions to produce 282 different food producing units. Relevant parameters and variables over the food producing units for each basin are summed up and modeled for the hydrology processes. Same process is done for economic processes, variables over food producing units for each region is summed up and modeled. Water supply and demand was ran at a monthly time-step.

The model generated a global map (figure 2.1) which distinguishes two different kinds of water scarcities, physical water scarcity and economic water scarcity, and has four levels of water scarcity (table 2.2.). The two types of water scarcity is described below based on International Water Management Institute (2007) definitions from the reports 'The Comprehensive Assessment of Water Management in Agriculture' and 'WATERSIM'.

Physical water scarcity

Regions or countries which total water resources are not enough to meet all demands, including minimum environmental flow requirements, are identified to have physical water scarcity. It is mostly associated with arid regions, however due to over allocation and over development there is a new trend with artificial created physical water scarcity in regions where water is abundant. Physical water scarcity only looks at the physical water availability and is defined by calculating the ratio of the total water withdrawal to the total water resources.

Symptoms of physical water scarcity are: declining water tables, water allocation disputes, failure to meet the needs of some groups, and environmental degradation, such as river desiccation and pollution.

Economic water scarcity

Economic water scarcity is defined as a region or a country which is short of water due to limited financial, human or institutional capacity, even though water resources are relative abundant. All basins that are not physical water scarce but suffer from malnutrition are considered as economic water scarce, the threshold for malnutrition is below 2700 Kcal.

Symptoms of economic water scarcity are: lack of infrastructure development which leads to trouble for people to get sufficient water for agriculture and domestic use, uneven distribution of water even though existence of infrastructure, and high vulnerability to seasonal water fluctuations.

Explanation and thresholds for the different level of water scarcity are presented below, in table 2.2.

Scarcity level	Scarcity threshold
Little or no water scarcity	Abundant water resources, water withdrawals from rivers for human use are less than 25%.
Physical water scarcity	Water resources are approaching or exceeded sustainable limits, water withdrawals from rivers for human use are more than 75% (this implies dry areas are not necessarily water scarce).
Approaching physical water scarcity	Water resources are approaching physical water scarcity, water withdrawals from rivers are more than 60%.
Economic water scarcity	Abundant water resources, less than 25% water withdrawal from rivers from human use but malnutrition exist with less than 2700 Kcal intake.

Table 2.2. Water scarcity level and threshold for physical and economic water scarcity. The table explains the different level of water scarcity and the thresholds. Source: Comprehensive Assessment of Water Management in Agriculture, IWMI, 2007.
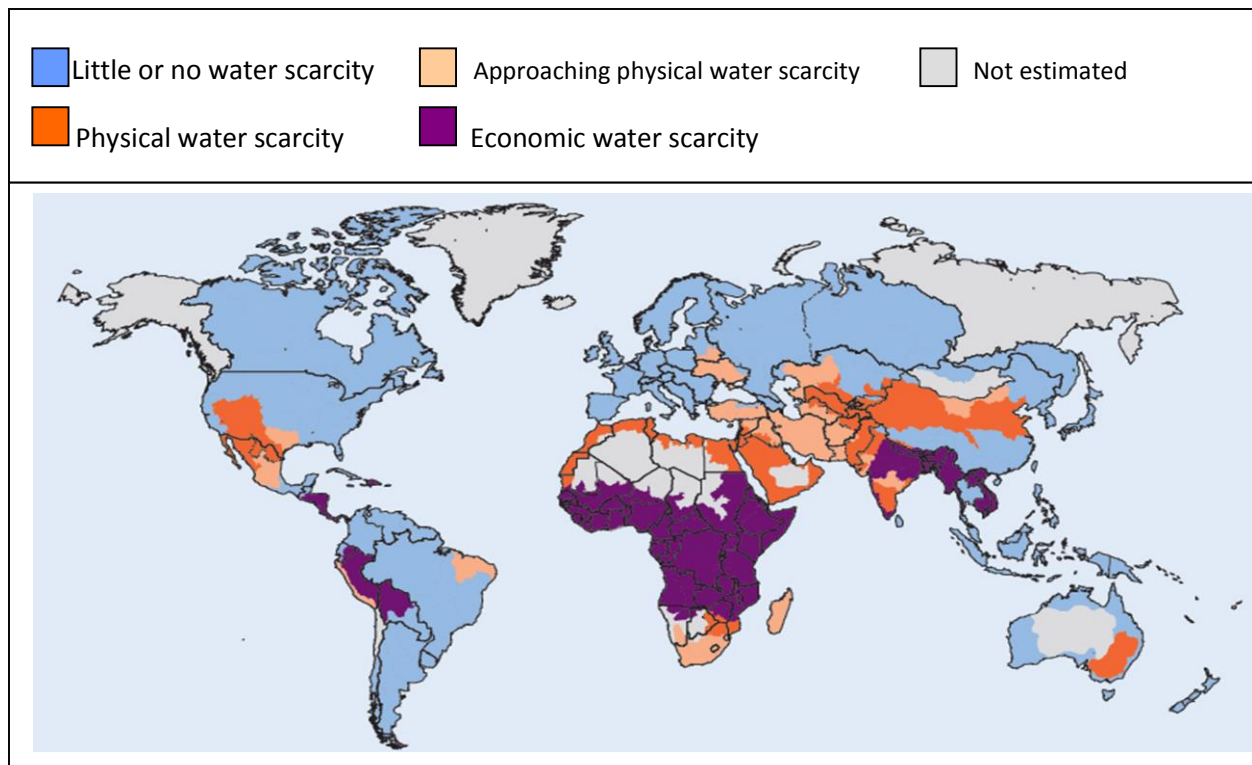
Figure 2.1.Global map of physical and economic water scarcity. The map indicates where in the world there is water scarcity and if it is physical water scarcity or economic water scarcity. Source: Comprehensive Assessment of Water Management in Agriculture, IWMI, 2007.

Data that was used to generate the map (figure 2.1) are from global datasets such as Food and Agriculture Organization (FAO) and Aquastat. Furthermore, most of the data are from year 2000 which was the most updated data at that time when the map was generated (de Fraiture, 2012). Compared to Falkenmark Water Scarcity Index, the advantage with this indicator is that it provides a global map of the global water situation. Spatial and seasonal distribution of the water resources are also considered and it distinguishes two different kinds of water scarcity: physical and economic water scarcity. Water problems are always a regional problem and there are regions that may have both drought and flooding at the same time in different areas, thus it is important to look at the water resources at regional level and not only at national level. A region might also be abundant in water, but it does not mean the water is available for the people if there is lack of infrastructure development or if some groups are favored over other. Therefore it is also important to evaluate water availability for people's direct usage and not only the amount of available water. This indicator is also one of the few indices that assess water availability for food production and not only to meet human basic needs. Food and agriculture products takes 70% of the water withdrawals from rivers and groundwater and if there is not enough water for food production, then food security will be threatened (International Water Management Institute , 2007). Thus, this indicator gives a better picture of a country or regions water situation than Falkenmark Water Scarcity Index.

The disadvantages with this water scarcity map are the used data are from year 2000 and the map has not been updated with newer data since it was made in 2005/06. Moreover, knowledge about the model WATERSIM is required in order to regenerate the map. The model also requires lot of data which might not be readily available, such as crop prices, subsidies, food production management, water demand for different sectors, water supply, etc. In addition, the water assessment of the water resource are mainly for human use and is another disadvantage of this water scarcity index since the quality of the water is not considered which also has impacts on amount of usable water resources.

For a more detailed explanation of how this method was developed, refer to the original article: A Comprehensive Assessment and Agricultural Development (International Water Management Institute , 2007).

2.3.3 Water Stress Indicator Taking Environmental Water Requirements into account

Numbers of global water resource assessments have been carried out, but few studies take the environmental water requirements (EWR) into consideration. Majority of water stress indices estimate the ratio of total use to total surface water availability and mean annual rivers' runoff (MAR) for human use (eq. 1), and put different water stress thresholds depending on how well the total renewable water resources satisfy the human needs (Smakhtin, Revenga, & Döll, 2004a).

$$WSI = \frac{Withdrawal}{MAR} \qquad (1)$$

However, every freshwater ecosystem has specific water requirements to sustain its ecosystem in order for it to provide a range of goods and services for humans, such as fisheries, flood protection, wildlife, etc. (Smakthin, Revenga, & Döll, 2004b). The researchers, Smakhtin, Revenga and Döll (2004b), developed a new WSI based on the former way to compute water stress and included EWR and presented a new concept to define water scarcity (figure 2.2). The researchers distinguish two different kinds of water scarcity:

- Environmental water scarcity: when the human water use tapping into the EWR
- Human water scarcity: when the EWR are satisfied and the utilizable water is not enough to meet the human water needs.
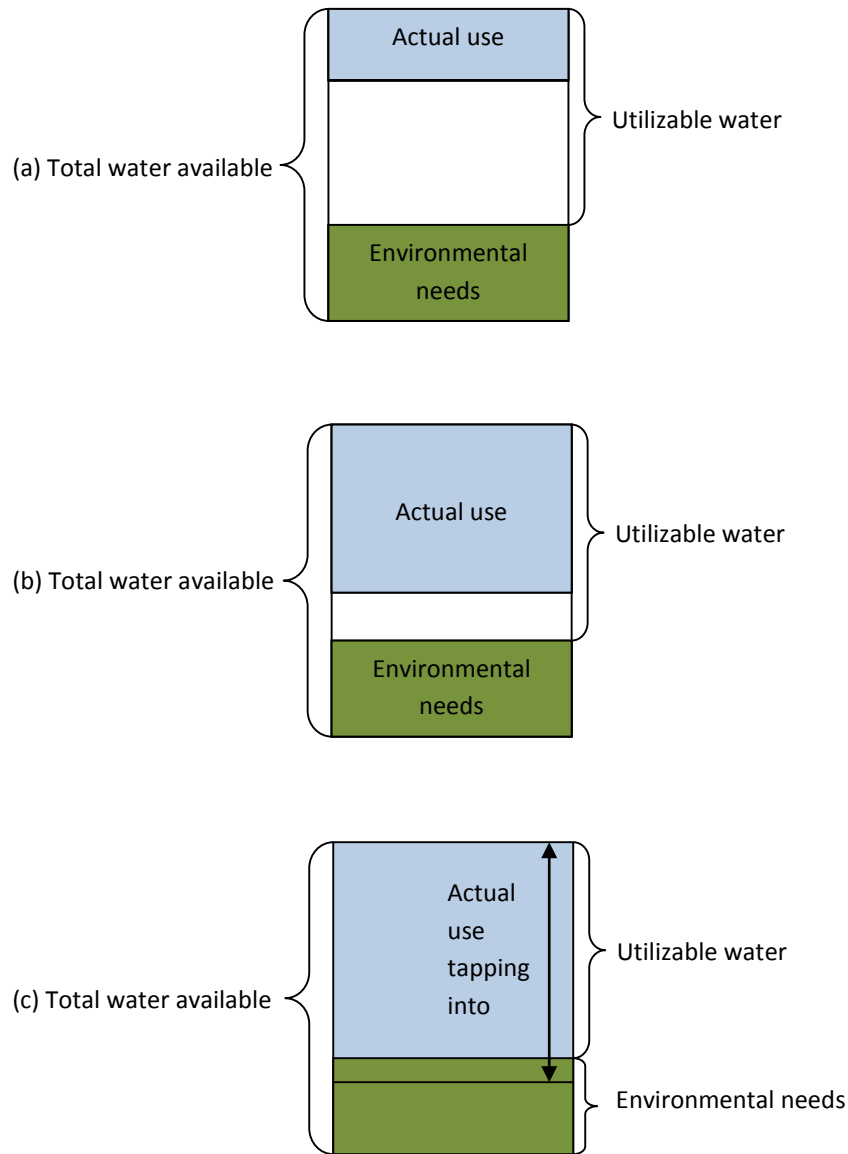
Figure 2.2. An illustration of the relationship between total water availability, EWR and human water withdrawal in (a) environmental safe, (b) environmentally water stressed river basins, and (c) environmentally water scarce. Source: Smakthin, Revenga, & Döll, 2004b.

The new WSI was estimated by incorporating data of annual water withdrawal from rivers for human use with data of environmental water requirements. The estimation was done by taking the ratio of the water withdrawal for human use from rivers to the difference between MAR and EWR (eq. 2).

$$WSI = \frac{Withdrawals}{MAR - EWR} \qquad (2)$$

The new index was then applied in the global water model WaterGAP 2, which gives basin-specific river discharge information for period 1961-1990. The model was first developed by the Centre for Environmental Systems Research at the University of Kassel and has been further developed by both University of Kassel and University of Frankfurt (Goethe University of Frankfurt, 2012). It consists of two main models, Global Hydrological Model and Global Water Use Model, and was developed to access current water resources situation and estimates the impacts on the problem of water scarcity due to global change at both regional and global scale (Döll, Alcamo, Henrichs, Kaspar, & Lehner). The output of the model is in principle based on how water moves between the land and atmosphere due to: water use and water availability; the long-term impacts of hydrological cycle due to demographic, socioeconomic, technologic and climate change.

With the new WSI, WaterGap 2 generated a new global map of water stressed areas which takes EWR into account (figure 2.3). The map has a spatial resolution of 0.5° x 0.5° grid cells, which is equal to 50 km x 50 km. Thresholds for the new WSI are presented below in table 2.3.

WSI (proportion)	Degrees of Environmental Water Scarcity of River Basins
WSI > 1	Overexploited (EWR are in conflict with other uses) – environmentally water scarce basin.
0.6 ≤ WSI < 1	Heavily exploited (0 - 40% of the utilizable water is still available in a basin before EWR are in conflict with other uses) – environmentally water stressed basins.
0.3 ≤ WSI < 0.6	Moderately exploited (40% - 70% of the utilizable water is still available in a basin before EWR are in conflict with other uses).
WSI < 0.3	Slightly exploited.

Table 2.3.Thresholds for water scarcity at river basin scale taking the EWR into account. The table explains the different thresholds for water stress and water scarcity. Source: Smakthin et al., 2004a.
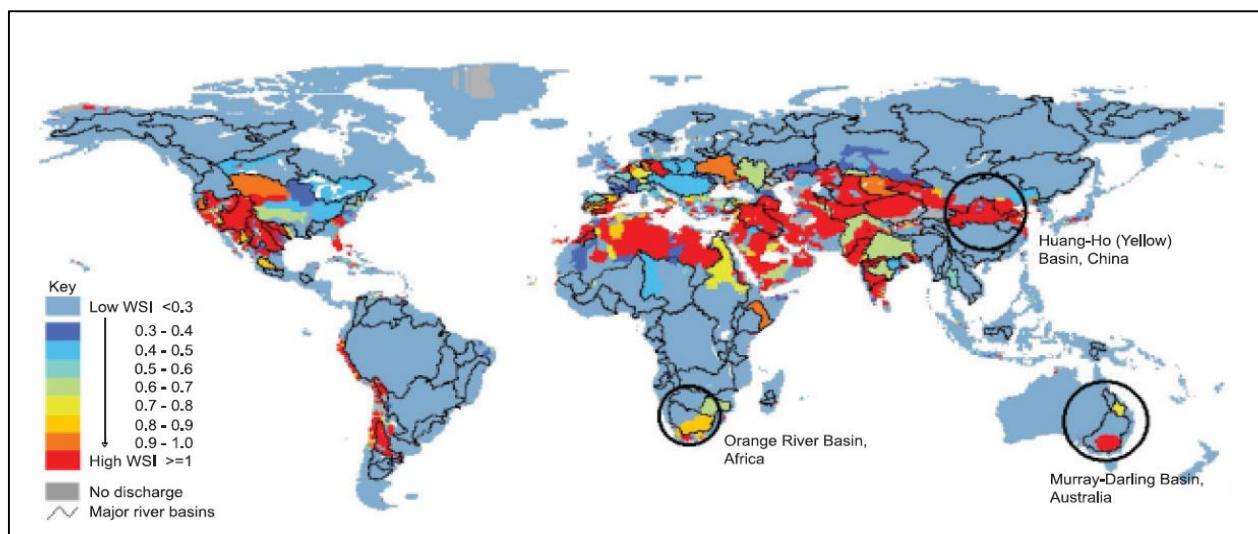

Figure 2.3. Global map with WSI which takes EWR into account. The red areas are those where EWR is not satisfied with water use based on data from 1995, today there are probably more areas where EWR is not satisfied. The circles are examples of rivers

which EWR are not met and the risk for it to be remained like that is high, due to growing water withdrawals in the basin area. Source: Smakthin, Revenga, and Döll, 2004.

Similar to previous WSI, Physical and Economical Water Scarcity, this WSI taking EWR into account also has the advantage of taking the seasonal and spatial distribution of the water resources into consideration. But the greatest advantage with this WSI is it firstly assess if EWR are met, even though the used data is old and many assumptions and simplifications have been made. This is because there is still lack of water data worldwide or the data is very uncertain, since many countries (especially the developing) still do not keep annual statistics of their water use and water resources. Compared to the previous two methods, this one does not primary look at the water availability for human use, instead it assess if rivers' water resources will meet environment's water demand and human's water demand or if these two water demands will get into conflict with each other. Moreover, by taking the EWR into account it shows which area the human water use is exceeding the natural supply capacity of water resources.

The disadvantage with this WSI is one cannot easily reproduce the map, due to: the map being generated by the water model WaterGap and knowledge about the model is required, specific data of water withdrawals from the specific studied river is required, and also knowledge about how to estimate the EWR for the studied river. The rivers' discharge information in the model are also very old, from 1961-1990, which is also a disadvantage since many countries have gone through large development change in the last 22 years and many parts of the world's rivers discharge have changed. Moreover, the quality of river water is also not included in this WSI and in turn does not really give a fair picture of the water situation in a region. A river could be polluted and make the water not usable. Therefore, water scarcity might still occur due to there is short of clean potable water, although the data shows there is enough physical water where the EWR and human's water demand are met.

For a more detailed explanation of how this method was developed, refer to the original article: Taking into Account Environmental Water Requirements in Global-scale Water Resources Assessments (Smakhtin, Revenga, & Döll, 2004a)

2.3.4 Map of Global Threats to Human Water Security and River Biodiversity

Vörösmarty et al., 2010, made an assessment at global-scale, for the first time, of the threats to human water security and river biodiversity. Unlike the previous water assessment and provided maps, this water study also assessed the impacts of pollutants, land use and water resource development on human water security and rivers biodiversity, and thus, it is the main reason for the author to select this index.

Vörösmarty et al. (2010) developed a spatial framework which integrates all major human-made drivers of stress on rivers. By merging a series of individual stressors expressed as drivers, 23 different drivers for environmental threats, it yielded two threat indices: one for human water security and one for biodiversity (annex, table 7.1). The selection of the drivers was based on two requirements - firstly, the global-scale data sets had to be readily available or could be generated from existing data; secondly, the selected drivers' main mechanism of negatively impacting freshwater has to be independent of other

drivers. The drivers were then organized under four themes: catchment disturbance, pollution, water resource development and biotic factors. The themes reflect the drivers' varied threats depending on their pathway and spatial scale, i.e. local versus propagating down-stream.

The stressors impact on human water security and biodiversity were then assessed by experts and produced two distinct weighting sets, which is presented in table 7.1 in the annex. Global maps were generated for each driver and together with the weighting sets it generated a two separate threat maps reflecting human water security respective biodiversity (figure 2.4 and 2.5). These two threat maps were then summarized into one global threat map (figure 2.6). The spatial resolution of the maps is 0.5°x0.5° cell grids. Seven driver maps were additionally chosen in order to get a better understanding of the reasons for the threats, the drivers are: river fragmentation, consumptive water loss, nitrogen loading, phosphorus loading, mercury loading, pesticides loading, and organic loading.

River fragmentation – identifies the impacts from dam constructions along the river. Since water is kept in the dams for storing, river runoffs are reduced for downstream. The river's biodiversity will also be put under threat, since the swimmable area is restricted for water species, which will impact species population size and restrict animal migrations.

Consumptive water loss – when water use is high relative to river's flow, biodiversity and human water security will be jeopardized. When the river's water resources declines, its potential to dilute water pollutants is decreased. For the biodiversity, the habitat area will be reduced and reduced river flow will distort the flow pattern of the river.

Nitrogen loading – high nitrogen load in the river water reduces the utility of surface water and nitrate in drinking water results high health risks. Threats to the biodiversity are eutrophication of freshwater and oxygen depletion as associated symptom. Ammonia can also have direct toxic effects.

Phosphorus loading – phosphorus loading of rivers comes often from (i) point source, such as sewage, (ii) from non-point sources, such as fertilizer, manure and weathering, (iii) deposition of phosphorus into rivers via atmosphere due to human activities. Phosphorus in rivers and lakes causes eutrophication and blooms of toxic nitrogen-fixing cyanobacteria, which restrict the utility of the water.

Mercury deposition – mercury is highly toxic for the environment and deposition sources are often mining of mineral resources and emissions from coal-fired power plants. Mercury is toxic for both humans and animals due to its neurotoxicity effects.

Pesticide loading – pesticides are transported to freshwater from landscape via surface runoff and subsurface flow. Depending on the type of pesticide, it imposes either acute or chronic toxicity for both humans and animals.

Organic loading – the studied organic loading is BOD and deposition source is often sewage. BOD causes hygienic problems in drinking water and it has also the potential to release toxic chemicals and nutrients that contribute to health problems for humans. BOD in rivers will change the river's trophic state, releases chemicals and nutrients, and foster oxygen deficits.

The greatest advantage with this WSI, compared to the previous, is that this indicator is based on many driving factors and the result is more certain. Moreover, maps were generated for each driver, and thus, the maps also indicate main reasons to water scarcity if the driver maps are also studied. The disadvantage is same as for all sophisticated WSIs; lots of data and expert knowledge are required in order to reproduce the maps if it is needed, e.g. if region has gone through large developments such as in China and India, it could be necessary to reproduce a regional map to see the changes.
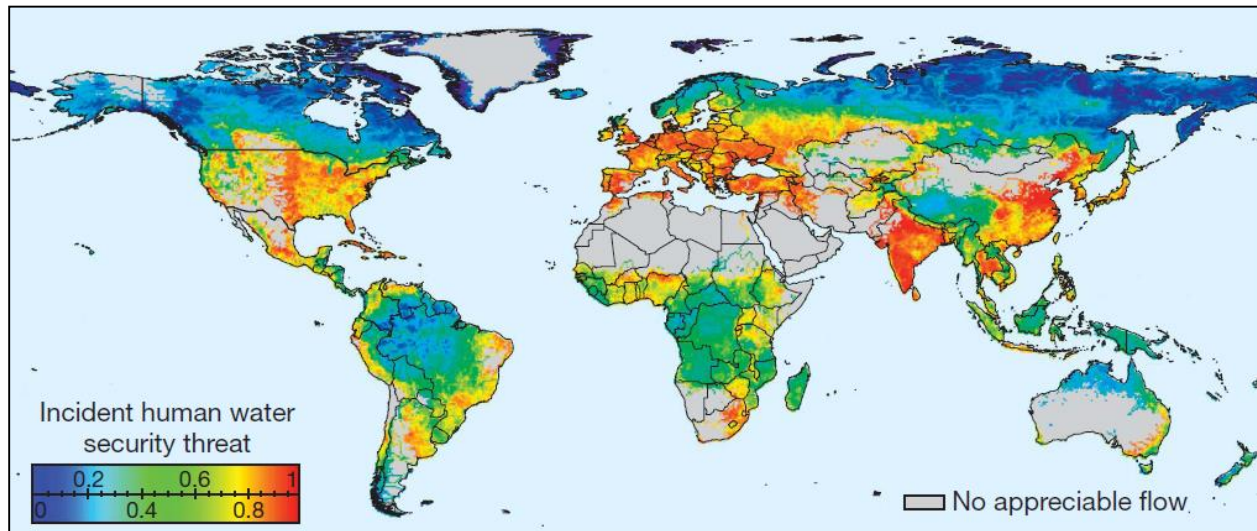
Figure 2.4 Global maps of incident threat to human water security. The map indicates where in the world's rivers are endangered and threatening human water security. Source: Vörösmarty, et al., 2010 and 2010b.
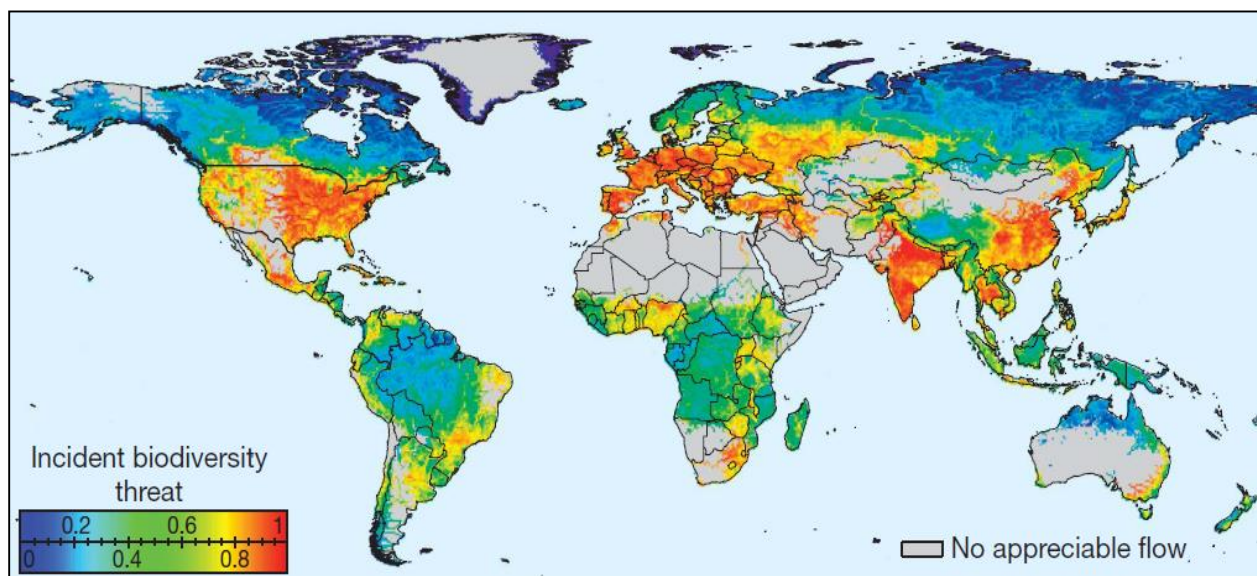

Figure 2.5. Global maps of incident threat to human water security respective biodiversity. The map indicates where in the world's rivers are endangered and threatening river biodiversity. Source: Vörösmarty et al., 2010 and 2010b.
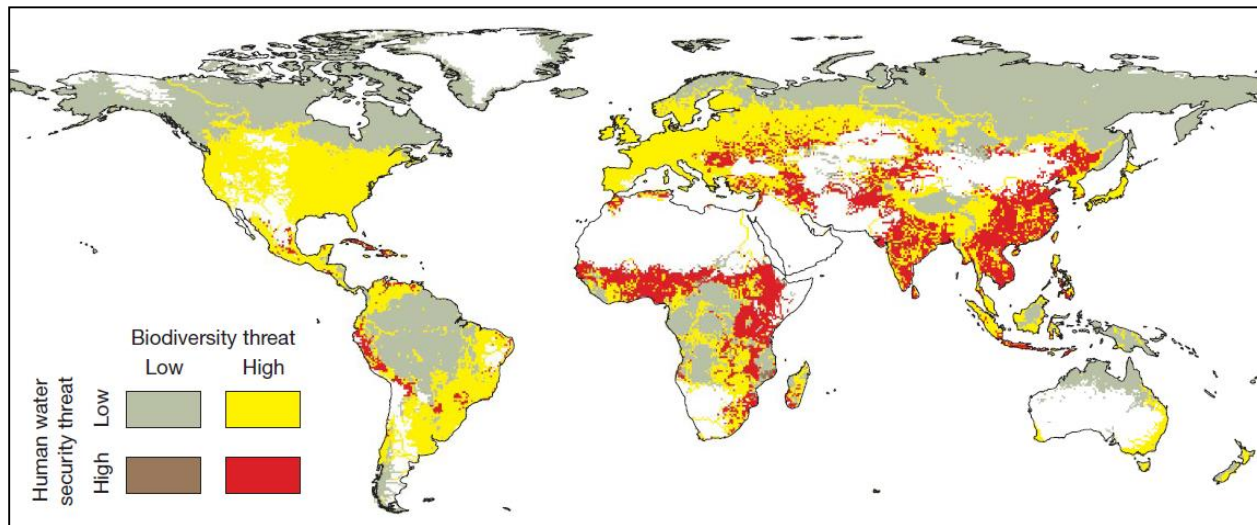
Figure 2.6 Global map of threat to human water security and biodiversity. This map summarizes the previous two maps result (figure 2.4 and 2.5) and indicating where both human water security and river biodiversity are threatened.
Source: Vörösmarty, et al., Global threats to human water security and river biodiversity, 2010.

For a more detailed explanation of how this method was developed, refer to the original article: Global threats to human water security and river biodiversity (Vörösmarty, et al., 2010).

2.4   Economic growth and water pollution

For a long time there has been debates about the relationship between economic growth and the environment (Burgess & Barbier, 2001). Some disciplines claim there is an inverted U-shape relation between economic growth and environmental degradation - this concept is called the Environmental Kuznets Curve (EKC); while some are critical to this concept and argue that the curve does not exist or only holds for a few pollutants (Stern, Common, & Barbier, 1996; van Alstine & Neumayer, 2008; Burgess & Barbier, 2001; Soumyananda, 2004; Jiang, Lin, & Zhuang, 2008; Bartz & Kelly, 2008). Lee (2011) describe the practice approach of the concept of the Environmental Kuznets Curve as "Grow (pollute) first and clean up later". The concept implies that a country will pollute in the beginning of its growth and is usually referred to countries which are transforming from being agricultural-based economy to industry-based economy. During the growing time as an industry-based economy, the country is more focus on increasing the output of material and income than having clean air and water, but once the country has become rich and reached to a certain economic level (i.e. the turning point) it will to invest into cleaner technologies and the environment would then see lots of improvement (Soumyananda, 2004; van Alstine & Neumayer, 2008; Jiang, Lin, & Zhuang, 2008).

The method Environmental Kuznets Curve (EKC) is often used to foresee when the studied region's economic growth will reach the turning point and start to invest into cleaner technology and improve its natural environment. The method is based on mathematical model and the turning point depends on

several factors, among others, the trading and investment across regions are two of the most important factors (Zhang, et al., 2010a).

This analysis is divided into two case:

- The first one analyzes the seven major river basins' (Huai River basin, Hai River basin, Yellow River basin, Songhua River basin, Liao River basin, Pearl River basin and Yangtze River basin) industrial output value and discharge of industrial water pollution.
- The second divides China into four regions and analyzes the regions' industries gross output value and industrial water pollution.

3   China's water situation

3.1   Results from various water index and water assessment methods

This sub-chapter will first present the result of China's water situation by studying where in China each water index and water assessment method indicates there is water scarcity or abundant in water. Then in the next sub-chapter the author will present China's water situation by compiling the results of the indices and methods, and to understand the causes to the water scarcity in those regions the author will make a deeper study on the most water scarce river basins.

3.1.1   Falkenmark Water Stress Indicator

For the Falkenmark Water Stress Indicator, only data of water availability per capita was needed and the data was gathered from China's statistical yearbook 2011. The used data represents water availability per capita for each province and a province map was colored based on this indicator's thresholds (figure 3.1). Based on this WSI, only a few provinces in China experiencing water scarcity and their location are concentrated to the heartland of northeast China. Large part of China has no water scarcity or just limited water stress.

Provinces with absolute water scarcity are (red area): Ningxia, Shandong, Jiangsu, Shanghai, Beijing, Tianjin, Hebei and Shanxi.

Provinces with water scarcity are (yellow area): Henan and Gansu.

Provinces with water stress are (green area): Inner Mongolia, Liaoning, Anhui, Chongqing and Shaanxi.

Provinces with neither water scarcity nor water stress are (blue area): Xinjiang, Tibet, Qinghai, Heilongjiang, Liaoning, Sichuan, Yunnan, Guizhou, Guangxi, Hubei, Hunan, Guangdong, Hainan, Jiangxi, Fujian, and Zhejiang.

The area with water scarcity (i.e. the red and yellow area) is also located in the flow path of Hai River, Huai River and the estuary of Yellow River.

Figure 3.1. Water scarcity map based on Falkenmark Water Stress Index. The map indicates the provinces water situation. The provinces are colored based on their total renewable water resources per capita per year.

3.1.2 Physical and economic water scarcity

According to the global map of physical and economic water scarcity, China only suffers from physical water scarcity and it is concentrated to north China (Molden, et al., 2007a). The rest of China has limited or no water stresses at all (figure 3.2).

Provinces with limited or no water stress: Heilongjiang, Jilin, East Liaoning, South of Qinghai, Tibet, Sichuan, Chongqing, Hubei, South Anhui, South Jiangsu, Hunan, Jiangxi, Zhejiang, Fujian, Guangdong, Guangxi, Guizhou, and Yunnan.

Provinces with physical water scarcity: Xinjiang, East and South Gansu, Central Inner Mongolia, Hebei, East Liaoning, Qinghai, Ningxia, Shaanxi, Shanxi, Shandong, Henan, Central Sichuan, North Anhui, North Jiangsu, South Tibet and Northeast Hubei.

Not estimated are Central Gansu province and West and East Inner Mongolia province.

As in the previous map (figure 3.1), the area with water scarcity is concentrated in the flow path of Hai River, Huai River, the entire flow path of Yellow River, Tarim River and Heihe River.
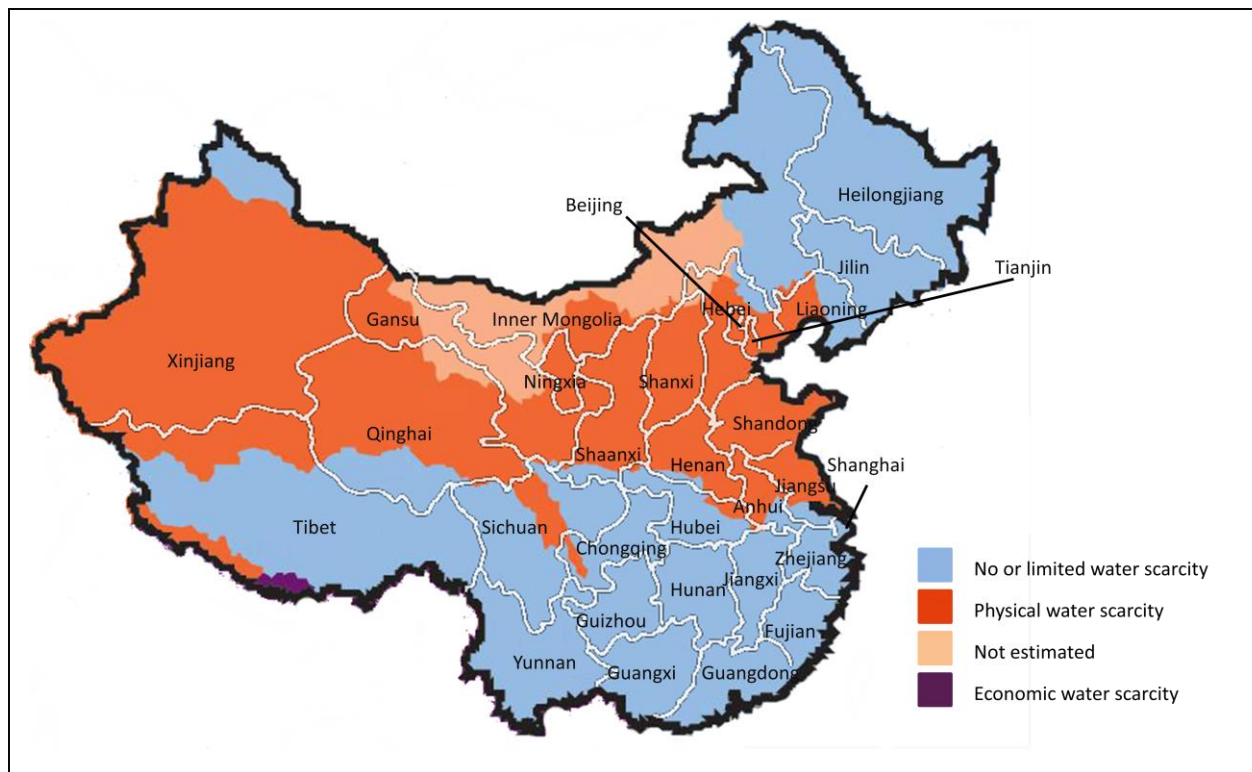
Figure 3.2. Global map of physical and economic water scarcity. The map indicates which provinces have physical water scarcity, or have either limited or no water scarcity at all. In this method water scarcity is defined where there is not enough water to maintain a healthy human life, i.e. lack of water for drinking, food production, keeping a hygienic sanitation, etc. Source: Molden et al., (2007)

3.1.3 Water Stress Indicator Taking Environmental Water Requirements into account

This WSI map shows similar result as previous two WSI maps – water scarcity is mainly experienced by north China. As it can be seen in figure 3.3 below, lower part of north China's water resources are overexploited (the red area, WSI > 1), which means the EWR are in conflict with other activities. The provinces are: Southwest Xinjiang, Northwest Tibet, Qinghai, South Gansu, Ningxia, South Inner Mongolia, North Shaanxi, Shanxi, South Hebei, Jiangsu, Shanghai, Shandong, Tianjin and Beijing. This water scarce area is also located in four rivers' flow path – Hai River, Huai River, Yellow River and Tarim River.

Some minor regions' water resources are heavily exploited (the yellow and orange areas, WSI = 0.7-0.9). The regions are located in Xinjiang, Inner Mongolia, Liaoning and Shandong. However, the water withdrawals from the basins are 40-60% and the EWR are not in conflict with other uses yet.

There are some small areas which have moderately exploited water resources and due to its small size it can be considered to be a very regional water issue. The moderately exploited water resource area (WSI = 0.5-0.6) are located in Inner Mongolia and Qinghai. Areas with WSI=0.3-0.4 are located in Xinjiang, Gansu, Ningxia, Zhejiang, Fujian and Guangdong. The WSI indicate the water withdrawals are between 30%-60% and there are still 40%-70% utilizable water left for the environment before the EWR gets into conflict with human water use.

Large part of China has slightly exploited water resources, but the water withdrawals are below 30% and EWR will not be in conflict at all. The provinces (WSI<0.3) are: Heilongjiang, North Inner Mongolia, Jilin, North Xinjiang, North Gansu, South Tibet, Yunnan, Sichuan, Chongqing, Henan, Hubei, Anhui, Zhejiang, Fujian, Hunan, Guangxi, Guangdong and Hainan.
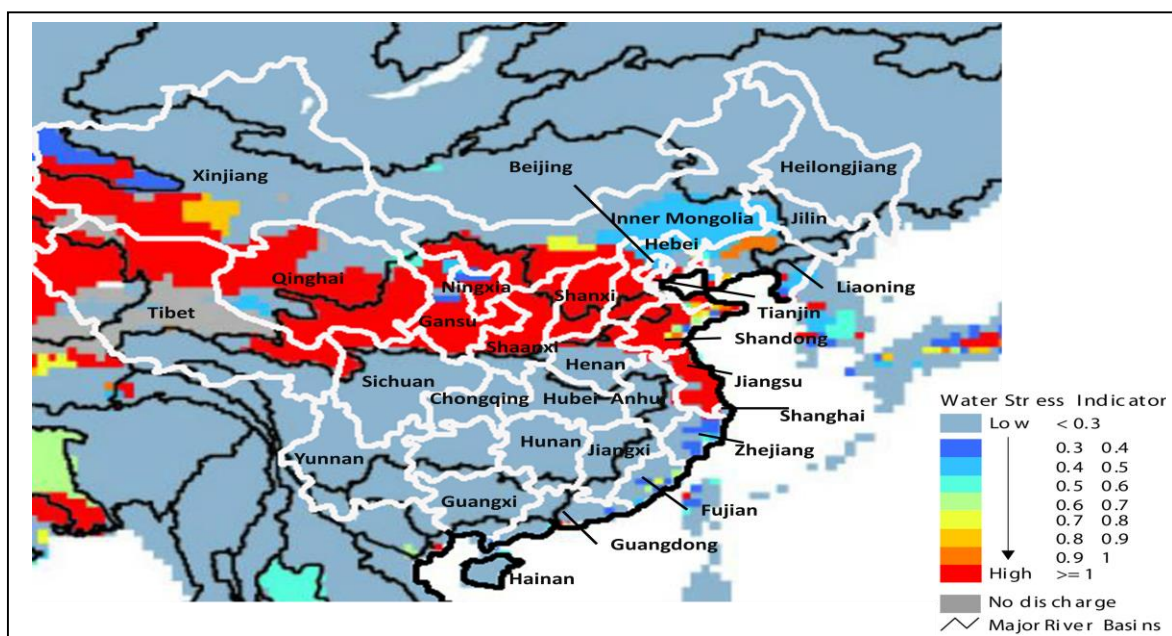
Figure 3.3. Map of China with WSI taking EWR into account. The map indicates which provinces are scarce of water for both human use and simultaneously meeting environment's water requirement. The white lines are the provinces' boundary, the black lines are river basins' boundary. Source: Smakthin et. Al, 2004a and 2004b.

3.1.4   Threats to Human Water Security and River Biodiversity

Unlike the other WSI maps, the threat maps of Human Water Security and River Biodiversity (figure 3.4 and 3.5) are mainly assessing what impacts human activities have on river's water resources, such as land use, water resource developments, water pollution and etc. Therefore, threats the maps are showing do not only indicate physical water scarcity, but also scarcity of clean water and the availability of water and therefore they give a better picture of regions' water situation. Because of more variables are considered in this indicator, the maps do not show similar results as the global maps of *Physical and Economic Water Scarcity* and *WSI taking EWR into account* and *Falkenmark Water Scarcity Indicator*. The threat zones are no longer only concentrated in the lower part of north China, but also in northeastern and southeastern China.

Both global maps, Human water security and River biodiversity, show similar result. Provinces under highly threats are (red areas): Hebei, Shandong, Hunan, Jiangsu, Anhui, Chongqing, Shanghai, Henan, Hubei, Liaoning and parts of Sichuan, Hunan, Zhejiang, Shaanxi, Shanxi, Jiangxi, Jilin and Heilongjiang.

Provinces under heavily threats are (yellow and orange area): Yunnan, Guizhou, Hainan, Fujian, Guangxi and parts of Guangdong, Heilongjiang, Jilin, Gansu, Sichuan, and Shaanxi.

Provinces where the human water security and river biodiversity are not under threats are (green and blur areas): Tibet, Qinghai, West Sichuan and Northeast Inner Mongolia and Heilongjiang. Large part of North China has not been assessed (grey area) due to lack of data.

The highest threatened area is also located in the flow path for Hai River, Huai River, Yellow River, Yangtze River and Pearl River. As mentioned earlier in the Chapter 2.2.4, seven maps main threat driver have been studied additionally in order to get a better understanding of the two summerized threat maps figure 3.4 and 3.5.
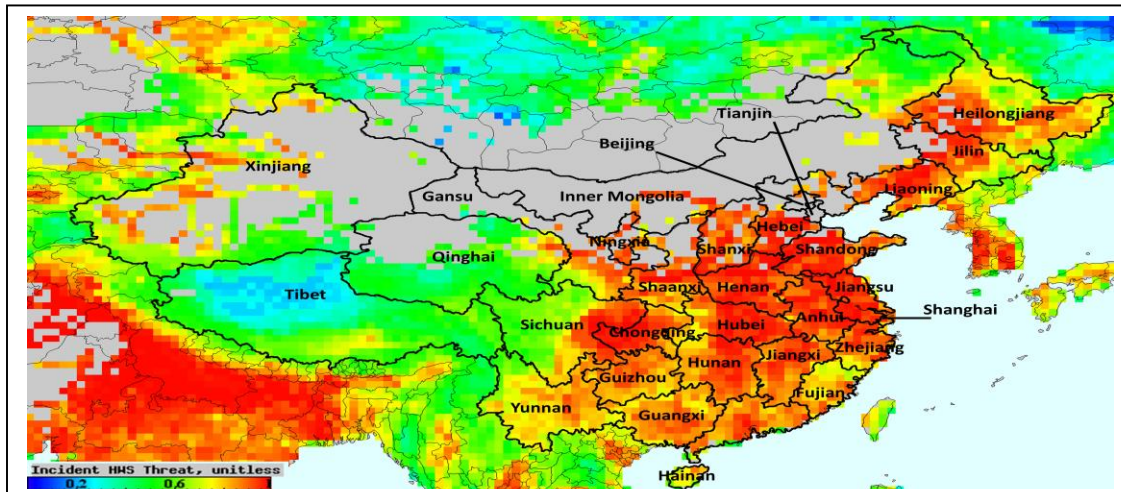
Figure 3.4. Threats to human water security. The map indicates the degree of impacts human activities have on human water security. The impacts degree is ranged from 0-1.0. The higher number, the severe environmental impacts have the human activities on its water resources. Source: Vörösmarty et al., 2010b
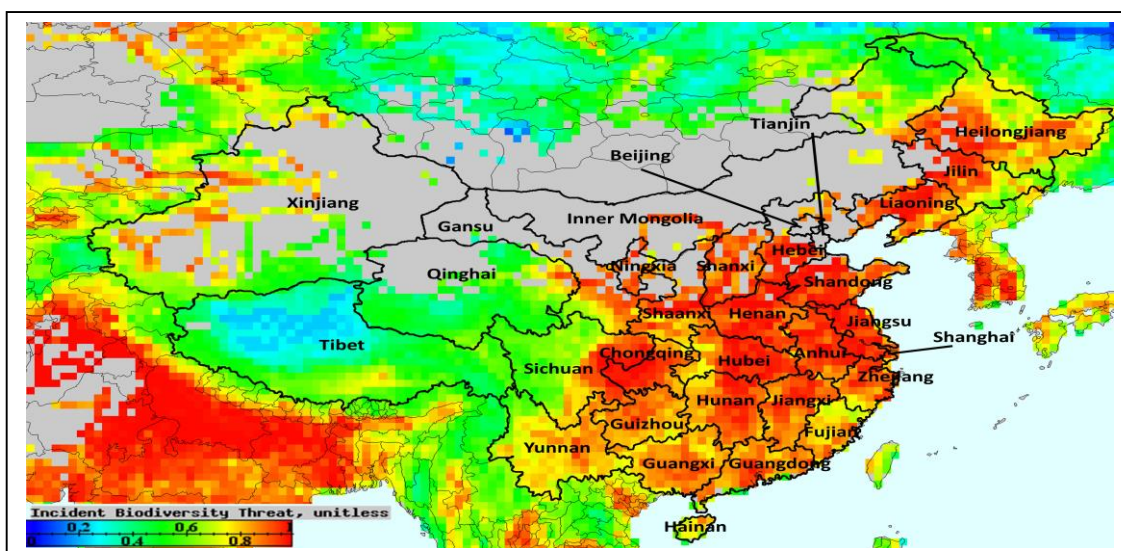

Figure 3.5. Threats to river biodiversity. The maps indicates the degree of impacts human activities have on rivers' biodiversity. The impacts degree is ranged from 0-1.0. The higher number, the severe environmental impacts have the human activities on rivers' biodiversity and the environment around it. Source: Vörösmarty et al., 2010b.

Figure 3.6, *Consumptive Losses,* indicates where water withdrawal is high in relative to river's flow and jepordises both human water security and biodiversity, i.e. the highly threatened areas are experiencing short of physical water resources due to human's water consumption is higher than the nature manage to replenish river's water resources (Vörösmarty, et al., 2010b). According to the map the most threaten areas are in: Shandong province, Anhui province, Henan province, Hebei province and north Jiangsu province. These provinces withdrawn their water from Hai River, Huai River and Yellow River. This mean these three rivers' water resources and biodiversity is threatened.
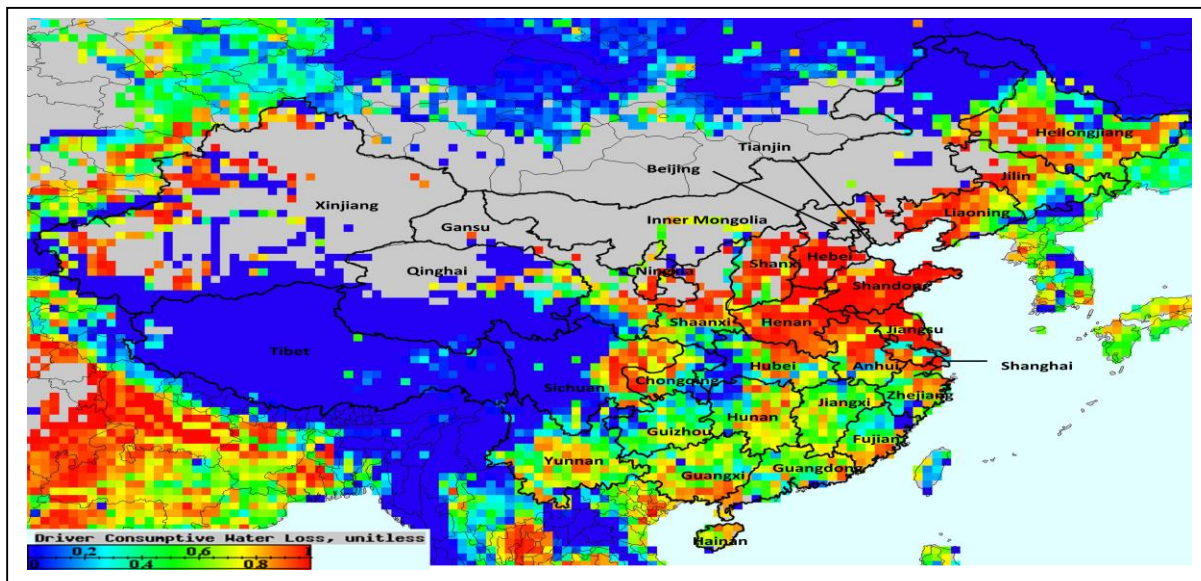
Figure 3.6 Consumptive Water Losses – human's water use impacts on river's water resource and biodiversity. The map indicate how threatened river's water resource is based on human's water consumption. The degree of impacts is ranged from 0-1.0. the higher number, the more water is consumed and not returned to the water source. Source: Vörösmarty et al., 2010b

Figure 3.7, *River fragmentation*, indicates what impacts dams development has on rivers' networks and its biodiversity. Vörösmarty et al. (2010b) explain the main purpose with dams development is mostly storage of water during wet periods for dry periods, but also in some cases for power generation. However, over-expoitation of dam constructions have negative impacts on human water security and river's biodiversity since river's runoff is often reduced in river's estuary and causing that area to dry up. This affects both human's water security for those who are populated in the lower part of the river and river's biodiversity in the dried up area, in addition, dam construction also deteriorates the ecology around the river since the natural vegetation is changed when building the dam.

As it can be seen in the map below, the areas that are under high threats (red area) are mainly concentrated in central China: Henan province, Jiangxi province and parts of Chongqing province and Hubei province. These affected regions are the flow path for Yellow River, Yangtze River and Huai River.
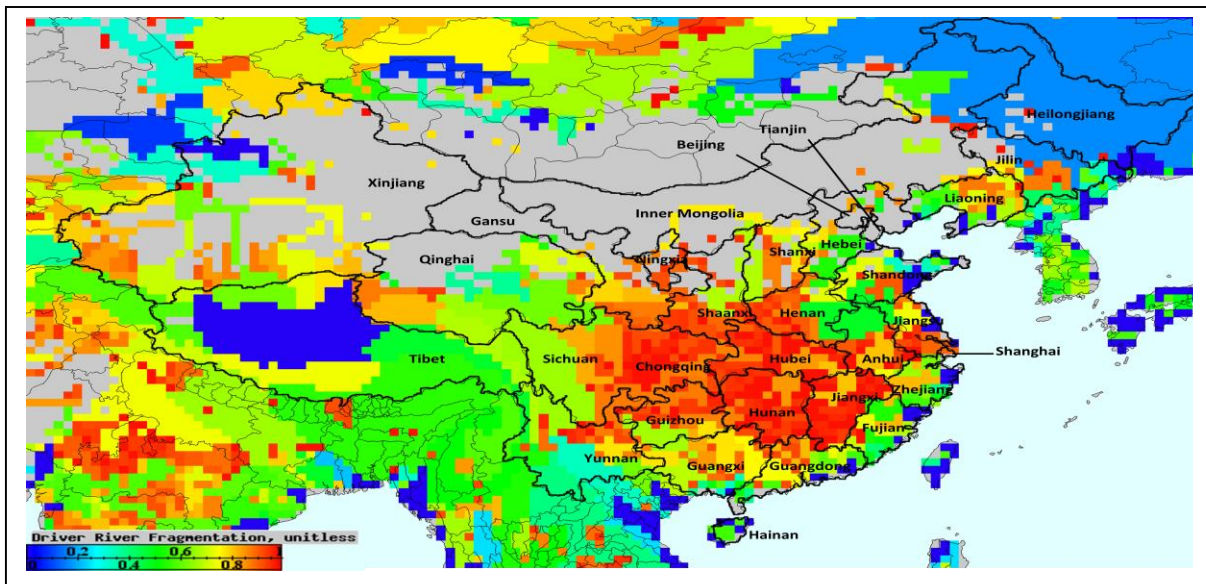
Figure 3.7 River Fragmentation - indicates the impacts of dams development on river's network and its biodiversity. To many dams in a river threatens river's runoff and this in turn might cause to reduction or drying up of the lower part of the river. In addition, too many dams will also deteriorate river's ecology and the environment around it. The threat is ranged from 0-1.0, the higher number the more dams in the area and threatening river's water resource and the ecology. Source: Vörösmarty et al., 2010b

Figure 3.8-3.12 indicates loading of water pollutions of nitrogen, mercury, phosphorus, pesticides and organic pollutants. These five pollution substances deteriorate water quality and have either direct or indirect negative impacts on both human health and river's biodiversity (Vörösmarty, et al., 2010b). These substances are commonly used to estimate the quality of river water and if it is useable or not for human use. Vörösmarty et al. (2010b) explain pollution source of nitrogen, phosphorus, and pesticides are commonly from agriculture sector as surface runoff or subsurface flow to river or sewage which is discharged directly into rivers. Nitrogen and phosphorus reduce the utility of drinkable freshwater since they pose health risks, they also increase the risk for eutrophication and causing bloom of the toxic N-fixing cyanobacteria. Pesticides are toxic since the primarily usage is to target unwanted species. Depending on type of pesticide and dose, it has indirect effects on species interactions (including humans) and ecosystem processes. Mercury contamination occurs often in mining areas, but it has been found coal-fired power plants which have high emissions and volatilization rates have led to deposition of mercury in freshwater. The substance is highly toxic and jeopardizes both human and animal development and health. Pollution source of organic pollutants is from sewage and causes deficit of oxygen in the water, potentially releases toxic chemicals and nutrients and making the water unusable since the pollutants have high health risks for both human and animal.

The five maps have similar result and the most threatened areas are concentrated to northeast China: Shaanxi, Shanxi, Henan, Hebei, Shandong, Anhui, Jiangsu, Liaoning, Jilin, and Heilongjiang; which is also the flow path of Hai River, Huai River, estuary of Yellow River, Liao River.
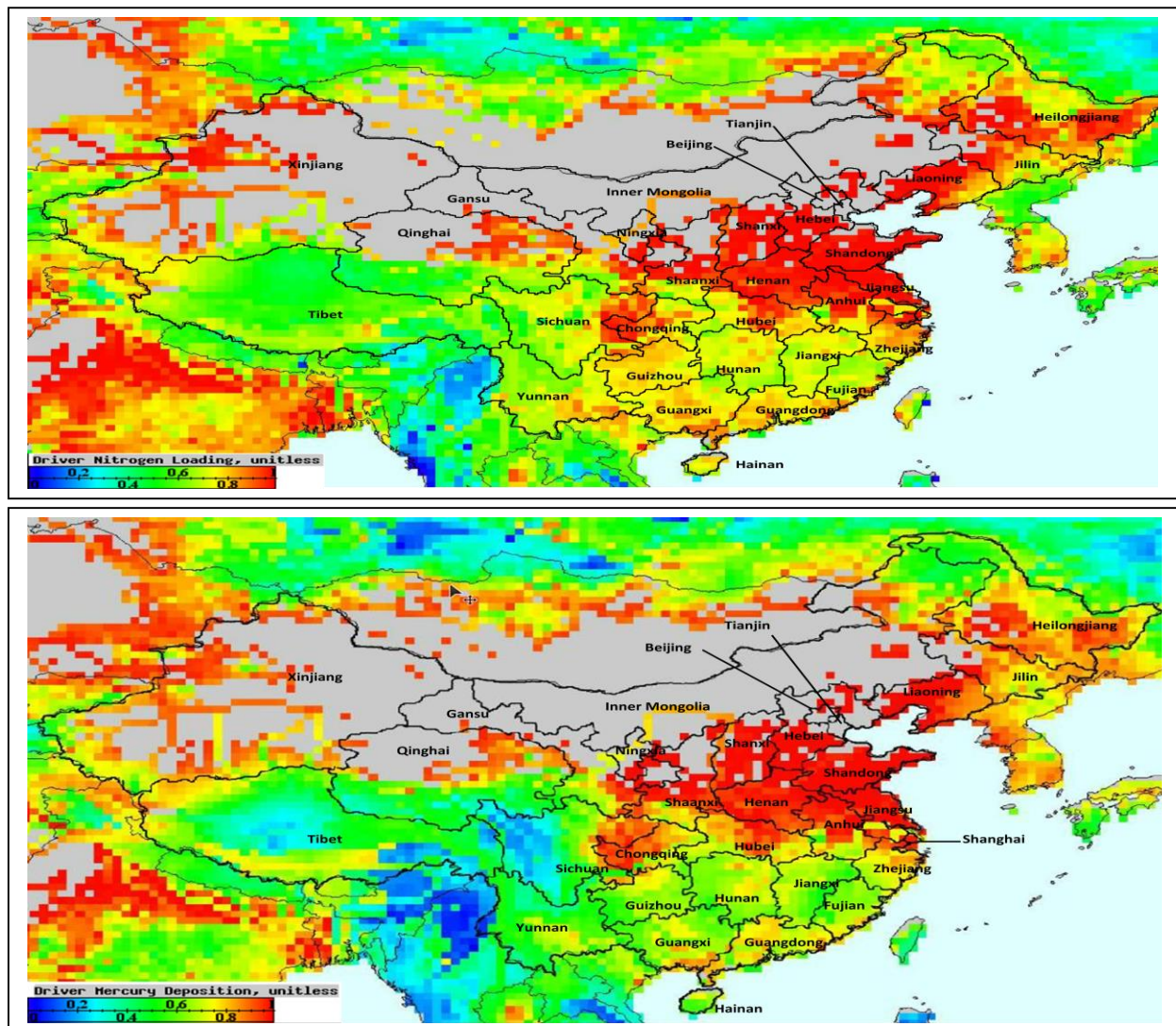
Figure 3.8-3.9. Maps of water pollutions of nitrogen, mercury. Water pollutions degrades water quality and reduces the utility of water. Pollution degree is ranged from 0-1.0, the higher number the higher amounts of pollutants. Source: Vörösmarty et al., 2010

Figure 3.10-3.12. Maps of water pollutions of nitrogen, phosphorus, pesticide, mercury and organic substances. Water pollutions degrades water quality and reduces the utility of water. Pollution degree is ranged from 0-1.0, the higher number the higher amounts of pollutants. Source: Vörösmarty et al., 2010
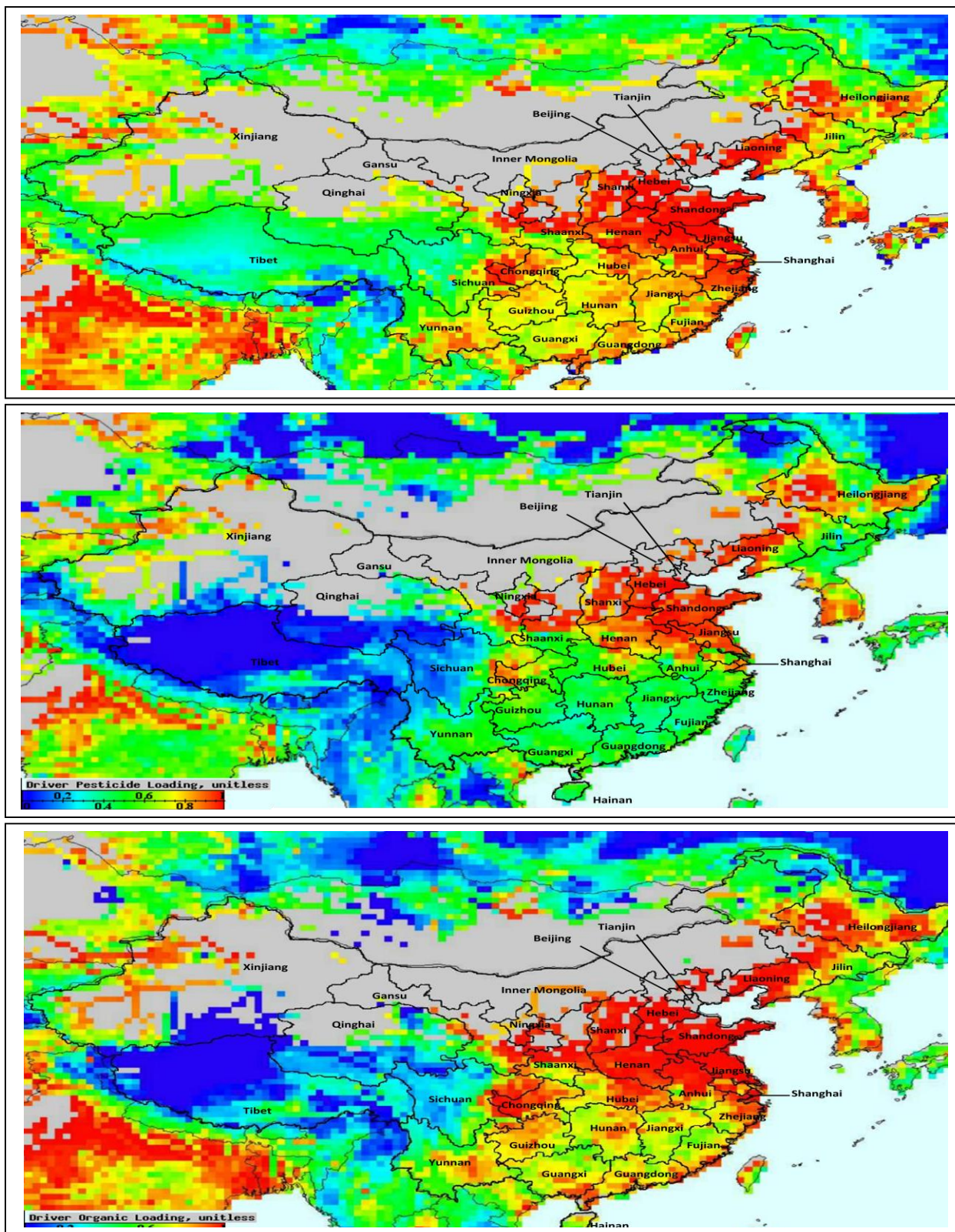
3.2   The present water situation and its causes

The four water methods and maps shows clearly water scarcity is concentrated to the lower part of north China. Furthermore, if one study which river basins are suffering from water scarcity and not only at the provinces, then it is found that the most physical water scarce area are located within the most water scarce river basins. The river basins Hai, Huai, Yellow, Heihe and Tarim are the most water scarce river basins in China and most affected by human activities (figure 3.13) (Bai & Shi, 2006; Chen, Zhang, Sun, Liu, & Wang, 2005; Feng, et al., 2005; Liu & Xia, 2004; Liu, Qin, Wang, Wang, & Yang, 2010; Thevs, 2011; Wu J. , 2011; Zhang, et al., 2011b; Zhang, Xu, & Tao, 2009). Several researchers (Chen et al., 2005; Economy, 2010; Liu et al., 2004; and Qi et al., 2005) found these five rivers are frequently experiencing droughts, and both Yellow River and Hai River do not reach to the sea annually during the dry period. The reasons are mainly human activities with large water withdrawal from rivers with low water-use efficiency which reduces river runoff, but also due to reduced precipitation which is the main source for water recharge in rivers.
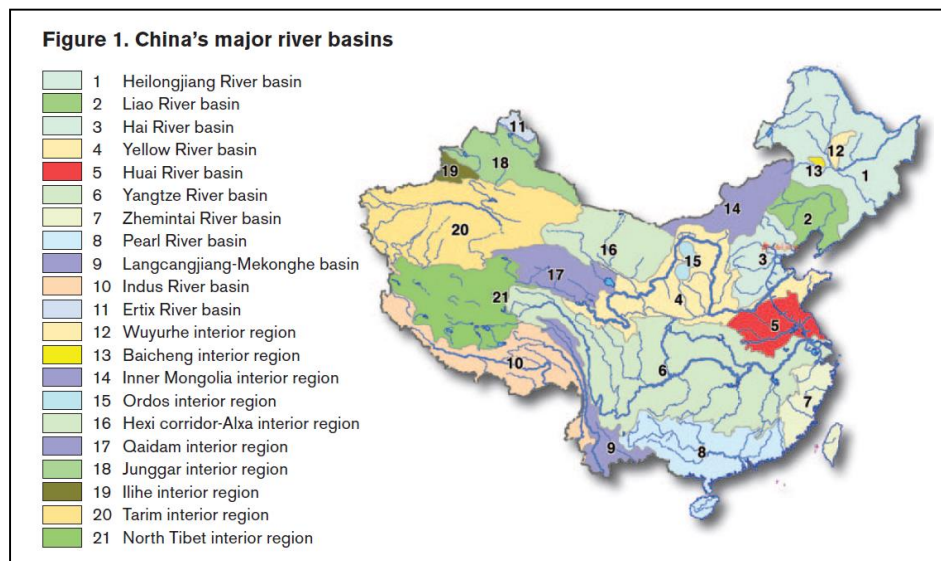
Figure 3.13. Map of the different river basins' location in China. Each color represent the basin's area coverage. Source: Bai & Shi, 2006

Furthermore, the fourth water assessment, 'Threats to human water security and river biodiversity', indicated a small part of northeast and the entire southeast China's rivers' water resources are under high threats, despite south China is considered to be abundant in water. Vörösmarty et al. (2010b) assessment showed rivers runoff are disturbed in large part of south China due to dam developments and water quality is also highly degraded both in northeast and southeast China due to water pollution. Huai River and Yangtze River are the dam densest rivers in China and these two rivers' runoff in their estuary declines annually during dry periods (Ju, Hao, Ou, Wang, & Zhu, 2013; Ju, Hao, Ou, Wang, & Zhu, 2013; Liu & Xia, 2004; Xu, Milliman, Yang, & Xu, 2008; Yang, Milliman, Li, & Xu, 2011). The website 'Circle of Blue' assessed water quality of the seven major river basins and it was found that Hai River basin is the most polluted river in China (chart 3.1), and in Economy's (2010) investigation of Hai River, there are periods when the river's water quality is deteriorated to such bad level that it cannot even be used to wash clothes. The

Chinese government grade water quality in five different grades and depending on the grading, water is used for different sectors and activities (table 3.1). The thresholds for the different grading is unclear due to information about the grading system could not be found.

To find out more detailed water resource availability and the main causes to water scarcity and threats to human water security and the environment, Hai River, Huai River, Yellow River, Heihe River, Tarim River, and Yangtze River are investigated more closely.
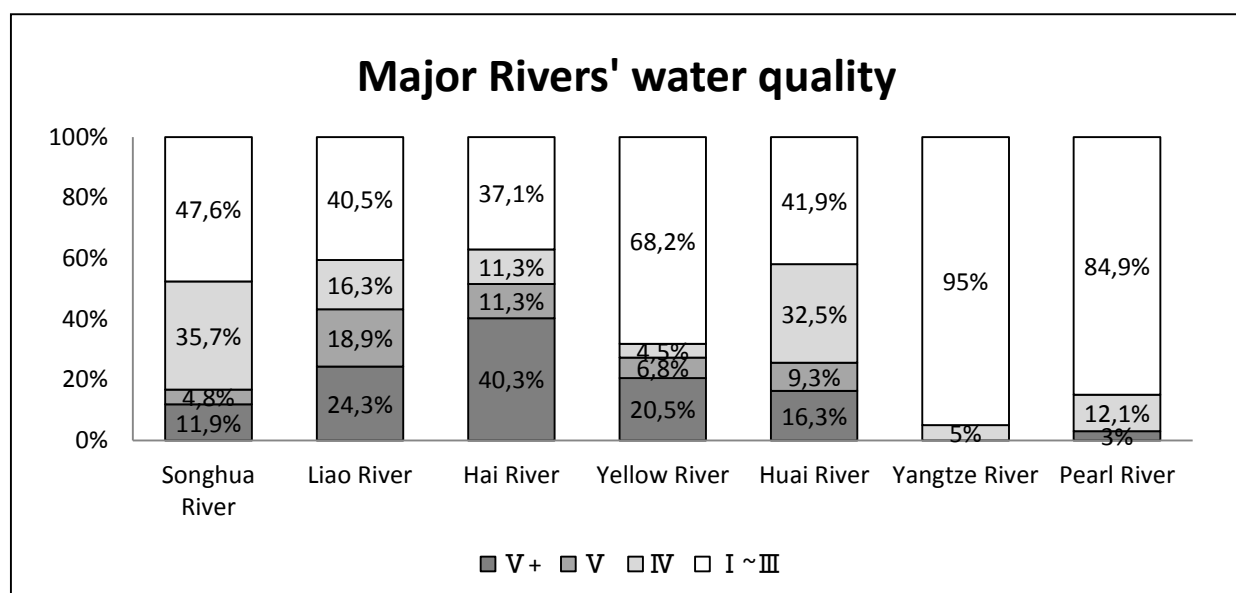
Chart 3.1.Water quality of seven major rivers in China. Water quality in China is graded 1-5 for its usability, if the quality is worse than 5, it is not suitable for anything. The grading are explained in the table below. Data source: Circle of blue, 2011

Grade	
I	Unpolluted
II	Have to be treated first, but is safe for rare and valuable water species
III	Have to be treated first, but is safe for aquafarm and suitable for human use.
IV	Only suitable for industrial production and recreational activities and in some cases no direct contact with the human body.
V	Only suitable for agriculture and landscape design.
V+	Not suitable for any use.

Table 3.1. The Chinese government's five grading of water quality. Source: Circle of blue, 2011.

3.2.1   Hai River

Hai River basin is one of the most physical water scarce basin in China and since 1970s the river dries up frequently due to large water withdrawals, reduced precipitation and decreased reservoir water storage (Liu & Xia, 2004). The river is a large network of smaller rivers and tributaries, which flows together and become Hai River. The smaller rivers and tributaries flows through eight provinces, Shanxi, Liaoning, Inner Mongolia, Henan, Hebei Shandong, Tianjin and Beijing, before emptying into the Yellow Sea. The river basin has a population of 217 million people, a length of 1090 km, a drainage area of 263,631 km², an

estimated total renewable water resource of 42.1 billion m^3 (whereas 28.8 billion m^3 is surface water; 26.5 m^3 is groundwater), a semi-humid and semi-arid temperate continental climate, and the average annual rainfall is 527 mm (Aquastat, 2010; China Statistical Yearbook, 2011; Xie, 2009; Wei, Miao , & Ouyang, 2010; Liu, Qin, Wang, Wang, & Yang, 2010).

According to Wei et al. (2010) the water scarcity in Hai River basin is mainly caused by human's large-scale water projects and about 1900 dams have been built for irrigation and power generation in the basin area, which have caused the river runoff to decrease tremendously. In year 1950 river runoff was about 24 m^3, but due to the intensive water consumption, river runoff has decreased to 1 m^3 in year 2001. Moreover, Hai River basin used to be rich in wetlands but after the water resources have been allocated to primarily meet human demands, environments water demand is not met and from having 100,000 km^2 wetlands it has decreased to 670 km^2. There are also 20 large depression which together covers more than 40,000 km^2 due to over-extraction of groundwater.

Based on findings from Jiang Y. (2009), 91.7% of Hai River's water supply is utilized, and based on data from Cheng H. & Hu Y. (2012), the water resource is overexploited with 26%. Regardless, the total amount of water withdrawals from Hai River are over the international recommended threshold, 40% of river's total water resource, and is one of the key factors to declining river runoff and frequent droughts in the lower reach (Zhang, et al., 2011b; Zhang , et al., 2011d). According to Zhang et al. (2011d), the average precipitation in Hai River during year 2000 has declined with 7.6% compared to the level of 1956 and Fang et al. (2010) says about 70% of the average annual precipitation is concentrated to the rainy season (June-September). This in turn has contributed further reduction of river runoff, since rivers are mainly recharged by rainfall. As a consequence, the river water discharge to the sea has reduced about two thirds. In Zhang et al. (2011d) investigation, Hai River's runoff has declined from 10-12 billion m^3 in 1994 to about 4 billion m^3 in 2007. Regardless Wei et al. (2010) and Zhang et al. (2011d) estimated different number of the river runoff, reduction of water discharge to the Yellow Sea is tremendously large in both case, and in addition Hai River has continuously been influenced by human for more than 1500 years, thus it is not a surprise that the natural original vegetation has disappeared.

Physical water scarcity is not the only problem in Hai River basin, the river is also the most polluted basin in China as it was indicated in the previous chart 3.1 and by Vörösmarty et al. threat maps. Based on data from the website 'Circle of Blue', only 37.1% of Hai River's total water resources is considered to be consumable for human use, 40.3% is not suitable for any use at all and the rest 22.6% is only suitable for industrial or agricultural use. The main polluters in this area are paper and pulp mills, chemical factories, and petroleum coking (China Statistical Yearbook, 2011; Wang, Ji, & Lei, 2012), moreover, both Wang et al. (2012) and the World Bank (2009) claim there are many water intensive industries which are mostly located in the upper reach of the basins and discharge untreated industrial wastewater into the rivers and deteriorates water quality for the lower reach.

3.2.2   Yellow River

Yellow River is China's second longest river and is sometimes called "the cradle of Chinese civilization" and used to be the most prosperous region in early Chinese history (Zhang, et al., 2011b; Feng, Siu, Guan, & Hubacek, 2012), but it is also called "China's sorrow" because of its catastrophic floods (Zhu, Giordano, Cai, & Molden, 2003). Flood control has always been the primary issue through history, ironically, due to human activities and reduced rainfall water scarcity has emerged as number one issue and the river is now repeatedly experiencing droughts (Zhu, Giordano, Cai, & Molden, 2003). For instance, in 1972 the lower reach of Yellow River ceased to reach the sea for the first time, in 1997 the lower reach was dry for more than 226 days, and in 1999 the river also dried up in the upper reach (Chen, Zong, Zhang, Xu, & Li, 2001).

Yellow River flows through eight provinces; it originates in Qinghai province, enter the very northwest of Sichuan and back to Qinghai, and then flows through Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong before emptying into the Yellow Sea (figure 3.15). The river's length and drainage area is 5464 km long respective 752,443 km^2, the total water resource is 65.5 billion m^3 (575 m^3/capita) and is home for 114 million people (China Statistical Yearbook, 2011; Aquastat, 2010; Feng, Siu, Guan, & Hubacek, 2012). The river is commonly split into three parts: upper reach, middle reach and lower reach (Zhang, et al., 2011b; Giordano, et al., 2004; Feng, Siu, Guan, & Hubacek, 2012). Each part shows different characteristics in terms of climate, water resources, consumption pattern and economic structure (Feng, Siu, Guan, & Hubacek, 2012)
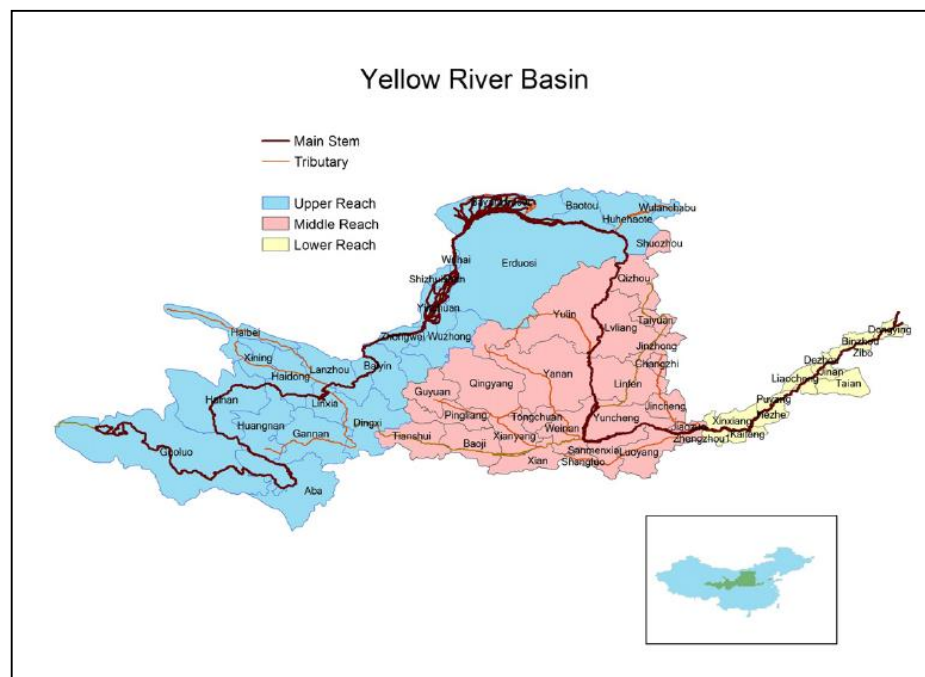
Figure 3.15. Location of Yellow River and its three divided reaches. Source: Feng K. et al. (2012)

Based on findings from Feng K. et al. (2012), the upper and middle reaches of Yellow River is the main provider of the river's total runoff. The upper reach covers about 51% of the total basin area (Zhang, et al., 2011b) and begins in the Qinghai-Tibetan plateau, stretches all way to northwest of Sichuan, middle of Gansu and Ningxia, and south part of Inner Mongolia. Continuing on Feng K. et al. (2012) findings, Yellow River's upper reach provides 54% of the river's total runoff with a total water resources of 35,3

billion m^3 (1176 m^3/capita) and a population of 30 million inhabitants (70 persons/km^2). The upper reach has the largest water share of the river's total water resource due to the high precipitation and low evaporation in Qinghai-Tibetan plateau, but while the river moves northwards into Ningxia, Inner Mongolia and Gobi desert, the climate becomes more arid with low precipitation and high evaporation. Per capita water consumption in the upper reach is not large, 461 m^3/capita, but the total amount of the total consumed water is 13,8 billion m^3, and accounts almost a third of Yellow River's total water resource. Data from 2007 in Feng K. et al. (2012) article shows the upper reach water use intensity is 39% (table 3.2) of the reach's total water resource and data from China's Ministry of Water Resources' (MWR) 2011 bulletin shows the upper reach has the largest share of the total water withdrawals of Yellow River's, 53% (chart 3.2). Note, chart 3.2 only represent the provinces' water withdrawals share of the total water withdrawal from the river and is not a ratio to the river's total water resource. The high water use intensity in upper reach is mainly due to the hyper-irrigation and large hydroelectric projects, and the high water withdrawal has great influence of the river runoff for the lower reaches (Miao, Ni, Borthwick, & Yang, 2011).

The middle reach covers about 45.7% of the total basin area and supplies about 35% of the total water resources in the area of 22.9 billion m^3 (328 m^3/capita) water to about 72 million inhabitants (210 persons/km^2) and the water consumption is about 10.6 billion m^3 (148 m^3/capita) (Zhang, et al., 2011b; Aquastat, 2010; Feng, Siu, Guan, & Hubacek, 2012). The reach lies between west and central China and covers large area of Shaanxi province and Shanxi province and a small part of Henan province. Zhang et al. (2011b), explain the climate in the middle reach as semi-arid and the precipitation is low in average in this area. The researchers also point out this part of the Yellow River has also the highest discharge of mud and sand in the river in the world - about 92% of sediments are derived from the middle reach. Moreover, Inner Mongolia, Shaanxi, Shanxi and Henan are the largest fossil fuel producer (coal, natural gas and crude oil) in the country (HSBC, 2010). Fossil fuel production is one of the top water intensive industries in China and this explains partly why upper reach and middle reach has such high water consumption (Water Resources Group, 2009). Continuing Feng K., et al. (2012) findings, the runoff of Yellow River after the middle reach has reduced with 46%, and upper reach and middle reach have together withdrawn 37% of the river's total water resource. This mean only 3% of the river's total water resources is left for the lower reach to use, if following the international standard of maximum 40% river water withdrawal for keeping a healthy and sustainable river.

Moving further down to the lower reach, Feng K. et al. (2012) estimated this part of Yellow River has the smallest basin area, 3%, and covers a large part of Henan province and whole Shandong province and faces serious water scarcity, which is also indicated by the map above (figure 3.6). It has the highest population density with a total 18 million inhabitants (750 person/km^2) in the area and the basin's total water resources is 7.4 billion m^3 (409 m^3/capita), but the total water consumption in the area is 9.4 billion m^3 (525 m^3/capita). This implies the water consumption exceeds the total local water resources with about 28% (Feng, Siu, Guan, & Hubacek, 2012). The high water use per capita could be explained by the area is a large agriculture producer. Both Henan and Shandong are the largest producer provinces of agricultural products in China and the agriculture sector is a large water consumer (HSBC, 2010). Moreover, water recharge from precipitation in this area are also very low; despite the average

precipitation is the highest among the three reaches. The reason is because of the 2000 years of levee constructions with the purpose to hold the river and prevent floods, due to high loads of sediments from the middle reaches and aggrades the riverbed (Zhang, et al., 2011b). The walls prevent rainfall from surrounding land drain into the river and neither can any tributaries enter it, and thus, this make the lower reach dependent on the runoff from the upstream (Zhu, et al., 2003). In overall has the runoff in whole Yellow River and the precipitation declined since 1956 (table 3.3).

The fact that both the middle and lower reach of Yellow River are country's largest fossil fuel and agricultural product producer, there is no surprise the area is under high threats of pollutions as it is shown in the fourth WA method 'Threats to human water security and river biodiversity' in figure 3.8-3.12. Especially when many industries discharge untreated industrial wastewater into the rivers as mentioned earlier (The World Bank, 2009). Yellow River is the third most polluted river in China, 20.5% of the river's total water resources is graded to be +V and is unusable, 6.8% is graded as V and is only usable for agriculture and landscape design, 4.5% is graded to be IV and is suitable for industrial production, and 68.2% is potable for human, animals and water species as long as it is treated first (chart 3.2). Main polluters are the fossil fuel producers (coal, natural gas and oil) and agriculture (Economy, 2010; The World Bank, 2009). It may seem odd that Vörösmarty et al. threat maps indicate the threatened areas are concentrated near the coastal area and the most water intensive industries (fossil fuel producer and agriculture) mainly located in the upper and middle reach, but it is because all the discharged untreated industrial wastewater from the upstream is accumulated in the lower reach and in the river mouth (The World Bank, 2006). The detailed information about Yellow River's reaches' water resource, water use, rainfall, and river runoff is shown in table 3.2 and 3.3

	Upper reach[a]	Middle reach[b]	Lower reach[c]	Total[d]
Drainage area (thousand km2)[1]	428	343	24	794
Population (10^6)[2]	30	72	18	114
Population density (persons/km2)[3]=[2]/[1]	70	210	750	230
Total water resources (a) (10^9 m3)[4]	35.3	22.9	7.4	65.5
Water resources per capita (m3/c)[5]=[4]/[2]	1176	318	409	575
Total water consumption (10^9 m3)[10]=[6]+[7]+[8]+[9]	13.8	10.6	9.4	33.9
(Irrigation, 10^9 m3)[6]	(10.7)	(7.4)	(8.0)	(26.0)
(Livestock, forestry, fishery, 10^9 m3)[7]	(1.6)	(0.8)	(0.6)	(3.0)
(Industry, 10^9 m3)[8]	(1.4)	(2.0)	(0.7)	(4.2)
(Services, 10^9 m3)[9]	(0.2)	(0.4)	(0.1)	(0.7)
Water consumption per capita (m3/c)[11]=[10]/[2]	461	148	525	297
Water use intensity in the reaches[12]=[10]/[4]	39%	46%	-28%	52%

(a) Water resources consist of surface and ground water from local precipitation and excludes inflows from other regions, and therefore, it is not the total water resources of the Yellow River.
Due to the many uncertainties and lots of assumptions have been made in the data, the total may be smaller than the sum

Table 3.2. Water supply and demand in the three reaches in Yellow River. Source: Feng K. et al., 2012.

		Time period				1990s change from 1956
		1956-70	1971-80	1981-90	1991-00	
Upper	Rain (mm)	380	374	373	360	-6%
	Runoff (10^6 m3)	35	34	37	28	-25%
Middle	Rain (mm)	570	515	529	456	-25%
	Runoff (10^6 m3)	29	21	23	15	-93%
Lower	Rain (mm)	733	689	616	614	-19%
	Runoff (10^6 m3)	1.5	1.1	0.6	0	-100%

Table 3.3. Average rainfall and runoff in Yellow River's three reaches. Source: Giordano M. et al, 2004.
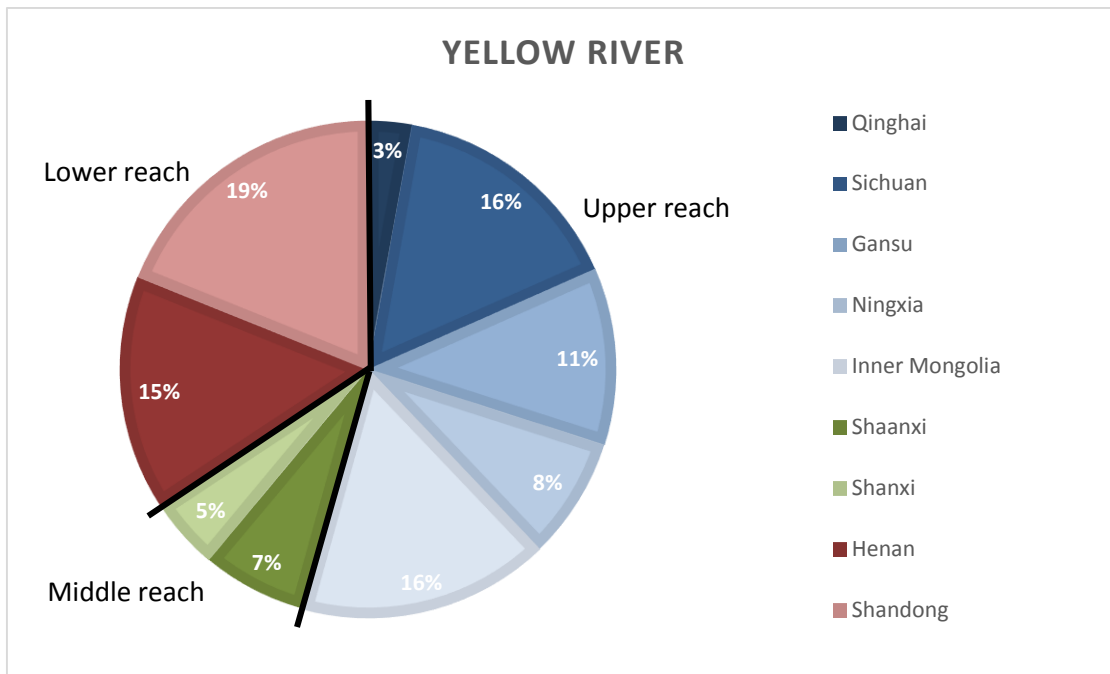
Chart 3.2 Provinces water withdrawals share of Yellow River. The chart only represent the provinces' water withdrawals share of the total water withdrawal from the river and is not a ratio to the river's total water resource. Source: Ministry of Water Resources' (MWR) 2011 bulletin, 2012

3.2.3 Huai River

Among the three major rivers in north China (Yellow, Hai and Huai), Huai River is most abundant in surface water and groundwater (Fang, et al., 2010). However, the river do faces both drought and flood problems, especially in the lower reach (Zhang, Xia, Liang, & Shao, 2010c). The river flows through five provinces, it begins in Hubei and flows through Henan, Anhui, and Jiangsu, and it has some tributaries which starts in Shandong and connects to the river in the lower reach and finally discharge into the Yangtze River (figure 3.16). Ju et al. (2012) explains this region's climate as temperate monsoon climate with hot and rainy summer, and winter is cold and dry. About 60% of the total annual rainfall is concentrated between June

48

and August, and during this period a large amount of rainfall falls in a short period which causes severe floods.

Data from the statistical yearbook 2011 shows the river length is 1000 km, drainage area is 269,283 km^2 and its water resource is 96.1 billion m^3. The river basin is home for more than 217 million people (807 persons/km^2), making it the most densely populated river basin area with the water availability per capita of 442 m^3 (Zhang, Xia, Liang, & Shao, 2010c; China Statistical Yearbook, 2011). Huai river basin is also the densest reservoir and floodgates river basin, and according to Bai and Shi (2010), there are more than 5,600 reservoirs that are mainly located in the upper reach and 4,300 floodgates that are mainly located in the middle reach to lower reach.
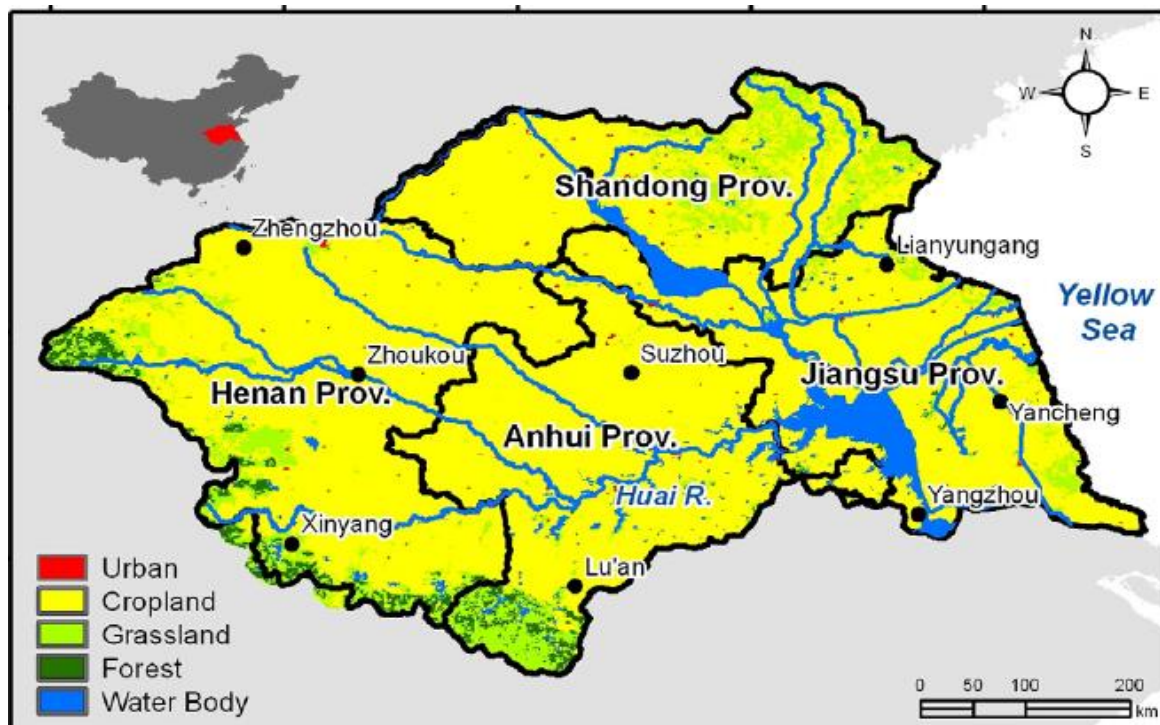
Figure 3.16. Map of Huai River's river network. Huai River originates in Hubei province, which is not illustrated in this picture, but is located to the west of Henan. The river's flow path continues through Henan, Anhui and Jiangsu before it discharge into Yangtze River. Huai River also has some tributaries which starts in Shandong and connects to Huai River in Jiangsu. Source: Zhang H. & Huang G.H., 2011.

In Zhang et al. (2011e) investigation, it was found that at present there are 36 large reservoirs, which control one-third of the entire river's runoff. There are 600 large and middle size dams and this implies there is one dam in every 50 km^2, and as it is not enough, there are on average ten floodgates in each tributaries. The excessive constructions of reservoirs, dams and floodgates, and intensive human activities have of course great deterioration effect on the river's runoff, water quality and ecology.

As mentioned earlier, most of the reservoirs and dams are constructed in the upper reach and data from Zhang et al. (2011e) article indicate most of the dams and reservoirs are constructed in provinces - Hebei and Henan. Data from China's statistical yearbook indicates the provinces in the upper reach of Huai River

are important for China's economy – Henan is one of the largest fossil fuel producer, Henan and Shandong are the largest producers of agricultural products, and lastly Shandong and Hebei are large producer of copper, iron and steel. All those activities are both water intensive and large water polluters and this in combination of uneven seasonal distribution of precipitation, and water detention in the upper reach lead to much less water is available for the province Jiangxi, which is located in the end of Huai River, and therefore drought occurs frequently in this area and this is also indicated by Falkenmark Water Scarcity Index map (figure 3.1).

However, the major water problem in Huai River is water pollution which is also indicated in Vörösmarty et al (2010b) threat maps of pollutions (figure 3.8-3.12). According to Zhang et al. (2010c) in 2004, 83% of Huai River's total water resource's water quality was worse than grade V and based on more updated data from 'Circle of Blue', Huai River is the fourth most polluted river at present and 16.3% of the total water resource's water quality is considered to be worse than V (i.e. unusable) (chart 3.2). The major polluters in Huai River basin are paper and pulp mills, brewing industry, food industry, and chemical industry, and the major pollutants are organic compound which produces COD (chemical organic compound), BOD (biochemical organic compound) and ammonia nitrogen (Bai & Shi, 2006). Some parts of the river have higher pollution rates of heavy metals, especially in downstream that accumulates all pollutions from the upstream (Bai & Shi, 2006). The many dams in the basin have also large impact on water quality. During the time when gate sluices are closed, large amount of pollutants are accumulated within the dams and when the gate sluices opens, all the accumulated pollutants are discharged to the downstream and killing fishes and other water species and additionally making the water unusable for human (Economy, 2010).

3.2.4 Tarim River

Tarim River is the longest inland river in China and is located in Xinjiang (figure 3.17). The river is 1324 km long, has a drainage area of 1.02×10^6 km^2, 58 million m^3 in water resources (7022 m^3/capita) and inhabited by 8.26 million people (Zhang Q. et al., 2009; Zhengbin & Ping, 2007, and Thevs N., 2011). Few studies have been done on Tarim River basin and as Zhang et al (2009) point out, little is known about the decadal changes of hydrological characteristics of the basin because of that. In Thevs (2011) research, Tarim River receives water from its tributaries - Aksu River, Yarkant River and Hotan River; however, Hotan River and Yarkant River discharge into the river only during high floods. Headwaters within Tarim River basin are supplied from surrounding mountains' snow melt, glacier melt and summer rainfall. The upper reach of Tarim River basin can be considered to be the area where tributaries Aksu and Yarkant flows, the middle is area between Aksu Rive and Yanqi River and lower reach from Yanqi River to the inland lake Lop Nur.

Qi et al (2005) described Tarim River basin as one of the most arid zone in China and due to sparse precipitation, Tarim River is the only water resource that supports and maintains the ecosystem in the basin area. Annual precipitation is quite large, it ranges from 200-800 mm/area, however, most of it occurs in the mountainous areas and cannot be used directly unless the rainfall can be converted to runoff and flow into foothills. Due to the arid climate, the evaporation rate is also very high, it is estimated to be 800 mm/area annually. The climate in the middle and lower reaches are extremely arid with precipitation as

low as 50-70 mm/area annually, and high potential evaporation ranges from 2100-3000 mm/area annually.

Due to the scarcity water resource, there is high competition between the agricultural, industrial and domestic sectors. Xinjiang province is the largest cotton producer in China and irrigated agriculture is the largest water consumer (China Statistical Yearbook, 2011; Qi, et al., 2005). Since water is more available in the upper reaches, cotton production is located in this area (Qi, et al., 2005). According to Xu et al., (2007), the consumed water in the upper reaches increased from 27.6% of the total water supply in 1950s to 45.7% in 1990s. This resulted the lower reach's water availability shrank and its water consumption declined from 24.2% to 5.7% of the total water supply and groundwater is overexploited in the lower reach. This severe water scarcity is aggravating by the continuously expanding flood irrigated agriculture and expanding oil industry (Thevs, 2011).

Figure 3.17. Tarim River basin in Xinjiang province. Upper reach can be considered to be the area where tributaries Aksu and Yarkant flows, the middle is area between Aksu Rive and Yanqi River and lower reach from Yanqi River to the inland lake Lop Nur. Source: Wikipedia, 2012.

3.2.5   Heihe River

Heihe River is the second largest inland river in northwest China after Tarim River and flows through Qinghai province, Gansu province, Inner Mongolia province and eventually discharge into two terminal lakes in the desert, the Ejina oases (figure 3.18) (Chen, Zhang, Sun, Liu, & Wang, 2005). According to the data from Chen et al. (2005) article, the drainage area and length of the river is 116,000 km^2 respective 821 km with a total water resource of 2,8 billion^3 (2314 m^3/capita) and total population of 1.21 million inhabitants. As Tarim River basin, the climate in Heihe River basin is extreme arid and majority of the precipitation occurs in mountainous area and declines moving downwards - annual average precipitation is 400 mm/area in the upper reach; 164 mm/area in the middle reach; and 55 mm/area in the lower reach. The potential evaporation is also high in this arid region, in the middle reach is the annual potential evaporation 1900 mm/area and 2300 mm/area in the lower reach, and due to the high evaporation the basin cannot rely to be recharged by rainfall.

According to Shan et al. (2005) Heihe River was once considered to be abundant in water resources and was an important base for grain production in northwest China. However, the intensive water consumption have led to severe water scarcity with degraded environment, salinization of river water due to reduced river flow and desertification of land in the whole basin. The severity of water scarcity is mainly due to anthropogenic factors, such as rapid population growth, excessive irrigation development in the middle reaches and lack of integrated river basin management. Chen et al. (2005) estimated the middle reach is the most populated area in Heihe River basin, 90% of the basins total population and is still an important agricultural area in northwestern China. Due to the low precipitation and high evaporation, the middle reach is dependent on irrigation and as consequence the lower reach's water resource is reduced significantly.

Figure 3.18. Heihe River basin's geographic location and its reaches. Source: Wu, 2011.

3.2.6 Yangtze River

Yangtze River is the largest river in China and world's third largest river and originates in Qinghai province and flows through 10 provinces (Tibet, Yunnan, Sichuan, Chongqing, Hubei, Jiangxi, Anhui, Jiangsu and Shanghai (Müller, et al., 2008). The river is home to more than 400 million inhabitants and the river's total catchment area is 1,808,500 km^2 (Yang & Zhang, Impacts of dams on Yangtze River sediment supply to the sea and delta intertidal wetland response, 2005). Water supply to the river is mainly from rainfall, groundwater and meltwater from snow and glaciers (Chen, Zong, Zhang, Xu, & Li, 2001). Data from Yang et al. (2010) article says Yangtze River basin is influenced by a moonsoon climate with wet summer och dry winters. Precipitation within the basin area are lower in the uppear reach and higher in the lower reach – about 400 mm/year in the upper reach and 1600 mm/year in the lower reach, and 85% of the total preciptation occurs during April and October. Yangtze River is often divided into three reaches – upper reach covers from Tuotuohe in Qinghai to Yichang in Hubei; middle reach covers from Yichang in Hubei to Hukou in Jiangxi; and lower reach covers from Hukou in Jiangxi until the river discharges into East China Sea (figure 3.19).

Figure 3.19. Map of the river network of Yangtze River and its flow path. The upper reach extends from Yuotuohe in Qinghai to Yichang in Hubei, middle reach extends from Yichang in Hubei to Hukou in Jiangxi, and lower reach extends from Hukou in Jiangxi to the discharge into East China Sea. Source: Yang et al., 2011.

It is known that floods have always been the major issue in Yangtze River basin for decades and a large number of dams were constructed along the river for flood management (Müller, et al., 2008; Xu, Milliman, Yang, & Xu, 2008). Yangtze River has more than 50 000 dams, which makes it to one of the most highly impacted rivers in China (Xu, Milliman, Yang, & Xu, 2008). Yang and Zhang (2005) estimated there are more than 5000 dams in the upper reach and the reach has the largest dams in the entire basin area (figure 3.20). However, dam construction has large impacts on the environment since it interferes the balance of the ecological system, such as interuption of river flow and sediments discharge, restriction of animal migration which reduces species population size due to restricted moving area (Vörösmarty, et al., 2010b; Yang & Zhang, 2005).

In Yang et al (2011) investigation about human impatcs on Yangtze River, it was found the annual water discharge to East China Sea has a decreasing trend of 11% and is mainly due to increased water consumption and the many dams. According to Xu et al. (2008) measurements, sediments discharge in the lower reach during 2003-2005 has decreased with about 38% to the average discharge volume during 1950s-1960s. As Yang and Zhang (2005) and Xu et al. (2008) point out, reduced discharge of sediments to the sea means more sediments will accumulate in the river and degrade the quality of the water, since Yangtze River's sediments are nutrient rich and increases the risks for eutrophication. Reduced water and sediment discharge have also increased saltwater intrusion and the duration length in the estuary of the river, since there is not enough water and sediments that can hold back the salt seawater. In addition to the increased salinity, water temperature of the river water has also increased and the blooming of jellyfish, which endanger the coastal fishing resources since jellyfishes feeds on fish eggs and larvae. Furthermore, accumulated sediment will also aggrade the river bed and increases the risks for flooding, as in the lower reach of Yellow River.
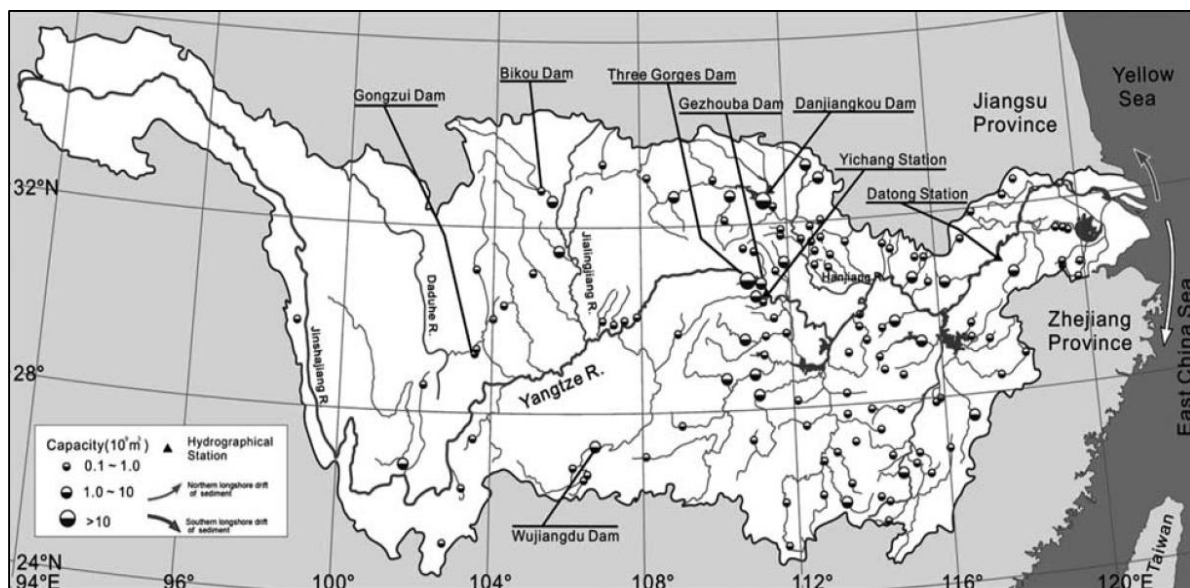
Figure 3.20. Yangtze River map with distribution of large dams and hydrological gauging stations at Yichang and Datong.
The storage capacity is in 10^8 m^3. The map shows three sizes of the dams - largest dams have with capacity which are greater than $10 \cdot 10^8$ m^3, the middle size dams have $1.0 \cdot 10^8$ m^3-$10 \cdot 10^8$ m^3. Source: Yang et al., 2005.

Most of the researchs about Yangtze River are about the changed water and sediments discharge to the sea and few are about the quality of the river water (Chen, Zong, Zhang, Xu, & Li, 2001; Xu, Milliman, Yang, & Xu, 2008; Yang & Zhang, 2005; Luo, Yang, & Zhang, 2012; Müller, et al., 2008). However, Müller et al. (2008) investigated how polluted the river is due to anthropogenic factors and it was found that despite the amount of disposed pollutions from industries, agriculture, and domestic sectors are large, the concentration of the anthropogenic compounds are not that high. The reason is mainly due to the abundance of water in the river and therefore there is high dilution potential in Yangtze River and its water quality is still meeting the national standards, according to Müller et al. (2008). However, the researchs emphasizes the extinction of the famous Yangtze River Dolphin is an alarming sign of deterioration of the

ecosystem in Yangtze River and further research and countermeasurements have to be initiated in order to stop further deterioration of the ecosystem and further extinction of more water species.

3.3 Water pollution and its connection to economic activities

The practice approach of EKC: 'grow (pollute) first, clean up later'; and have long time been dominating the mind of the leaders in China (Lee, 2012), however, the existence of EKC has been questioned by several researchers, e.g. Stern (2004); Yong, H. et al., (2010); Bartz & Kelly (2008); Dinda (2004).

As mentioned earlier, this analysis focuses on gross industrial output and discharge of COD, ammonia and nitrogen due to data limitation and industries indicates a regions' economic activities, but also because of the economic growth in China during the second industrial adjustment (late 1970's until now) is mainly based on expansion of the secondary industry (Dong, Song, & Zhu, 2011; Woo, 1997). From now on, water pollutants in this analysis is only referred to COD, ammonia and nitrogen. Furthermore, as explained in chapter 2.1 the author intend to use two approaches for analyzing if there is a connection between industrial economic activities and discharge of water pollutants – the first approach is to study the economic activities in the seven major river basins, industrial discharges of water pollutants from the provinces within the basin areas, and the seven major rivers' water quality; the second is to divide China into four regions and study the regions' gross industrial output and industrial discharge of water pollutants. The reason this analysis is not focusing on provinces' gross industrial output and discharges of industrial water pollutants is because the author does not really see any signs that there could be a connection between provinces' economic activities and discharge of water pollutants. Data from China's statistical yearbooks (2004-2011) shows provinces' gross industrial output has increased every year, but the discharge of water pollutants varies between the provinces and due to there are too many missing variables it is difficult to find the signs if there could be a connection between provinces' economic activities and discharge of water pollutants.

3.3.1 River basins' economic activities, water pollutants and river water quality

In this approach, river basins' gross industrial output is the sum of the provinces' gross industrial output and total amount discharge of industrial water pollutants which are located within the basins. The analyzed river basins are: Hai River, Huai River, Yellow River, Liao River, Songhua River, Pearl River and Yangtze River; and it is due to the data availability of rivers' water quality is limited to only these seven rivers..

Based on the Chinese statistical data, the top five river basins with highest gross industrial output value per capita (chart 3.3) with their respective discharge of water pollutants in gram per yuen (chart 3.4 and 3.5) among the seven major river basins are:

1. Liao River basin with gross industrial output valued to 71,874 yuen per capita, 0.22 g/yuen in COD discharge and 0.01 g/yuen in ammonia and nitrogen discharge.

2. Huai River basin with gross industrial output valued to 65,695 yuen per capita, 0.29 g/yuen in COD discharge and 0.02 g/yuen in ammonia and nitrogen discharge.
3. Hai River basin with gross industrial output valued to 57,697 yuen per capita, 0.38 g/yuen in COD discharge and 0.03 g/yuen in ammonia and nitrogen discharge.
4. Yangtze River basin with gross industrial output valued to 50,215 yuen per capita, 1.18 g/yuen in COD discharge and 0.07 g/yuen in ammonia and nitrogen discharge.
5. Pearl River basin with gross industrial output valued to 45,301 yuen per capita, 0.90 g/yuen in COD discharge and 0.04 g/yuen in ammonia and nitrogen discharge.

Although Yangtze River and Pearl River have the largest discharge of water pollutants, their water quality is still the best among the seven major river basin. 95% of Yangtze River's water resources is suitable for human use and in Pearl River is 85% suitable for human use (chart 3.1) (Circle of blue, 2011). These two rivers' good water quality may be explained by abundance of water in that region and have good dilution potential of water pollutants.

Based on data from the website 'Circle of Blue', the top five river with the worse water quality at present are (see previous chart 3.1):

1. Hai River – 37% is graded as I-III, 11.3% is graded as IV, 11.3% is graded as V, and 40.3% as V+.
2. Liao River – 40% is graded as I-III, 16% is graded as IV, 19% is graded as V, and 24% as V+.
3. Huai River – 42% is graded as I-III, 32% is graded as IV, 9% is graded as V, and 16% as V+.
4. Songhua River – 48% is graded as I-III, 36% is graded as IV, 5% is graded as V, and 12% as V+.
5. Yellow River – 68% is graded as I-III, 4% is graded as IV, 7% is graded as V, and 20% as V+.

From the same data source, it was also found the top five rivers with the best improvements of rivers' water quality between years 2003-2010 are (annex, chart 7.1-7.7):

1. Songhua River – grade I-III increased with 40%, grade IV reduced with 28.4%, grade V reduced with 6%, and grade V+ reduced with 6%,
2. Yellow River – grade I-III increased with 36%, grade IV reduced with 50%, grade V reduced with 0.2%, and grade V+ increased with 7%.
3. Huai River – grade I-III increased with 23%, grade IV reduced with 9%, grade V reduced with 4%, and grade V+ reduced with 23%.
4. Hai River – grade I-III increased with 16%, grade IV reduced with 13%, grade V increased with 5%, and grade V+ reduced with 14%.
5. Liao River – grade I-III increased with 11%, grade IV reduced with 13%, grade V increased with 11%, and grade V+ reduced with 16%.

Based on these data, there are not any clear signs that there could be a connection between the river basins' economic activities and improvements of rivers' water quality. Songhua River basin and Yellow River basin are two of the river basins with lowest gross industrial output, and yet, these two basins have the highest percentage improvements of rivers' water quality compare to Liao River basin and Huai River basin which have the lowest percentage of improvements of rivers' water and highest gross industrial output.

Gross Industrial Output Value Per Capita

Yuen/Capita

- Hai River Basin: 57697
- Yellow River Basin: 39972
- Huai River Basin: 65695
- Yangtze River Basin: 50215
- Pearl River Basin: 45301
- Liao River Basin: 71874
- Songhua River Basin: 30892

Legend: 2004, 2005, 2006, 2007, 2008, 2009, 2010
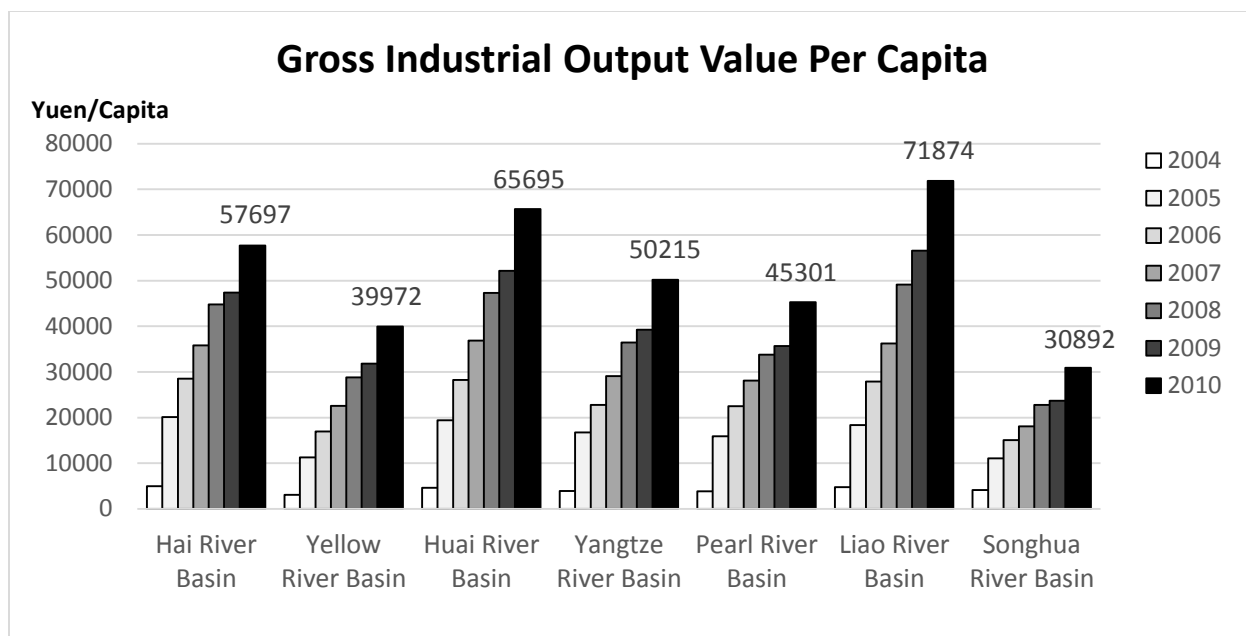
Chart 3.3. Gross Industrial Output Value for the seven major river basins. This barchart present the economic development for the industries in each river basin during the period 2004-2010. The data label presents the output value for year 2010. Source: China Statistical Yearbook 2004-2010, Chapter: *Main Indicators of Industrial Enterprises above Designated Size by Region*

Industrial COD Discharge, g/yuen

COD, g/yuen

Data labels (2010 total COD discharge):
- Hai River Basin: 0,38
- Yellow River Basin: 1,39
- Huai River Basin: 0,29
- Yangtze River Basin: 1,18
- Pearl River Basin: 0,90
- Liao River Basin: 0,22
- Songhua River Basin: 0,22

Legend: 2004, 2005, 2006, 2007, 2008, 2009, 2010

-94%	-89%	-94%	-91%	-95%	-94%	-90%	Reduction in %
-6g/yuen	-12g/yuen	-4g/yuen	-12g/yuen	-17g/yuen	-4g/yuen	-2g/yuen	Reduction in gram/yuen

Chart 3.4. COD Discharge in 9 major river basins during period 2004-2010. The data label present 2010 total COD discharge. The tables presents the reduction of the discharges in percentage and g/yuen from year 2004 to 2010 for each river basin and is ranged after the order as in the barchart. Source: China Statistical Yearbook 2004-2010, Chapter: *Discharge and Treatment of Industrial Waste Water by Region*

Industrial Ammonia and Nitrogen Discharge, g/yuen

-95%	-90%	-96%	-94%	-97%	-95%	-88%	-96%	-77%	Reduction in %
-0.6 g/yuen	-1.1 g/yuen	-0.6 g/yuen	-1.1 g/yuen	-1.3 g/yuen	-0.2 g/yuen	-0.1 g/yuen	-0.1 g/yuen	-0.01 g/yuen	Reduction in gram/yuen
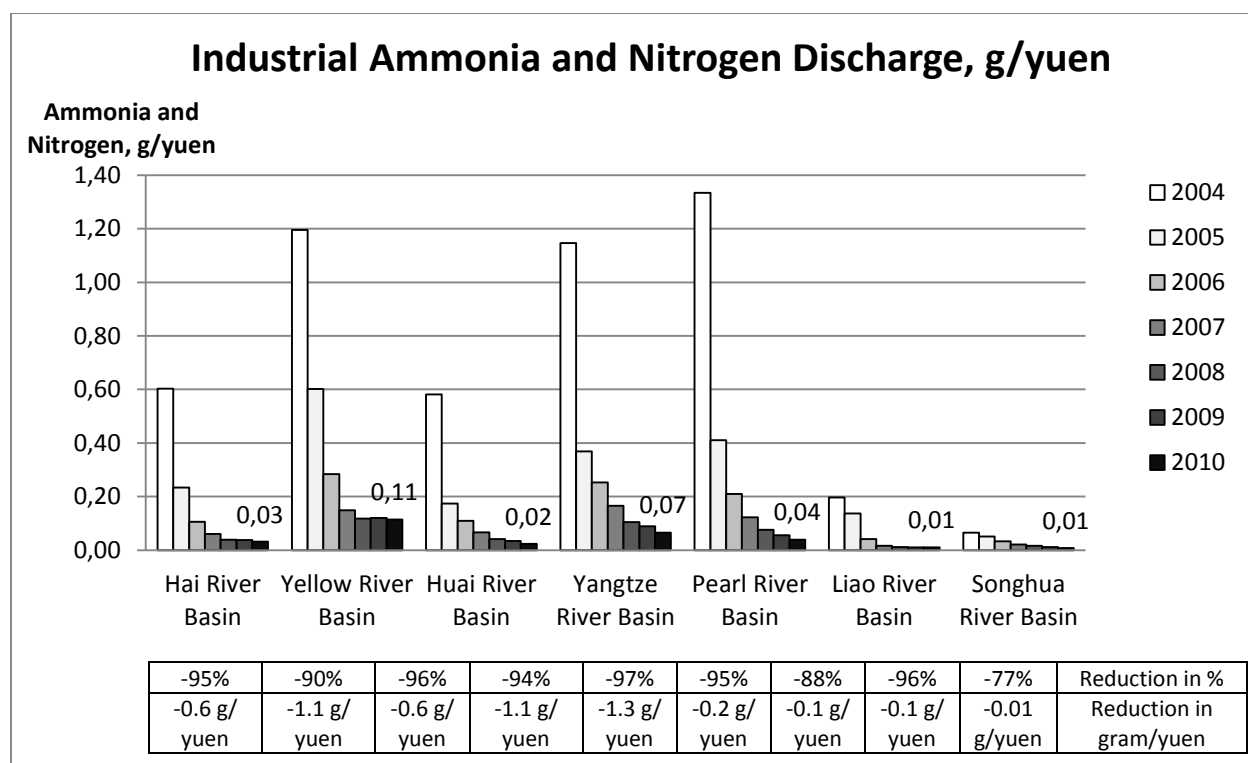
Chart 3.5, Ammonia and Nitrogen Discharge in 9 major river basins during period 2004-2010. The data label present 2010 total ammonia and nitrogen discharges. The tables presents the reduction of the discharges in percentage and g/yuen from year 2004 to 2010 for each river basin and is ranged after the order as in the barchart. Source: China Statistical Yearbook 2004-2010, Chapter: *Discharge and Treatment of Industrial Waste Water by Region*
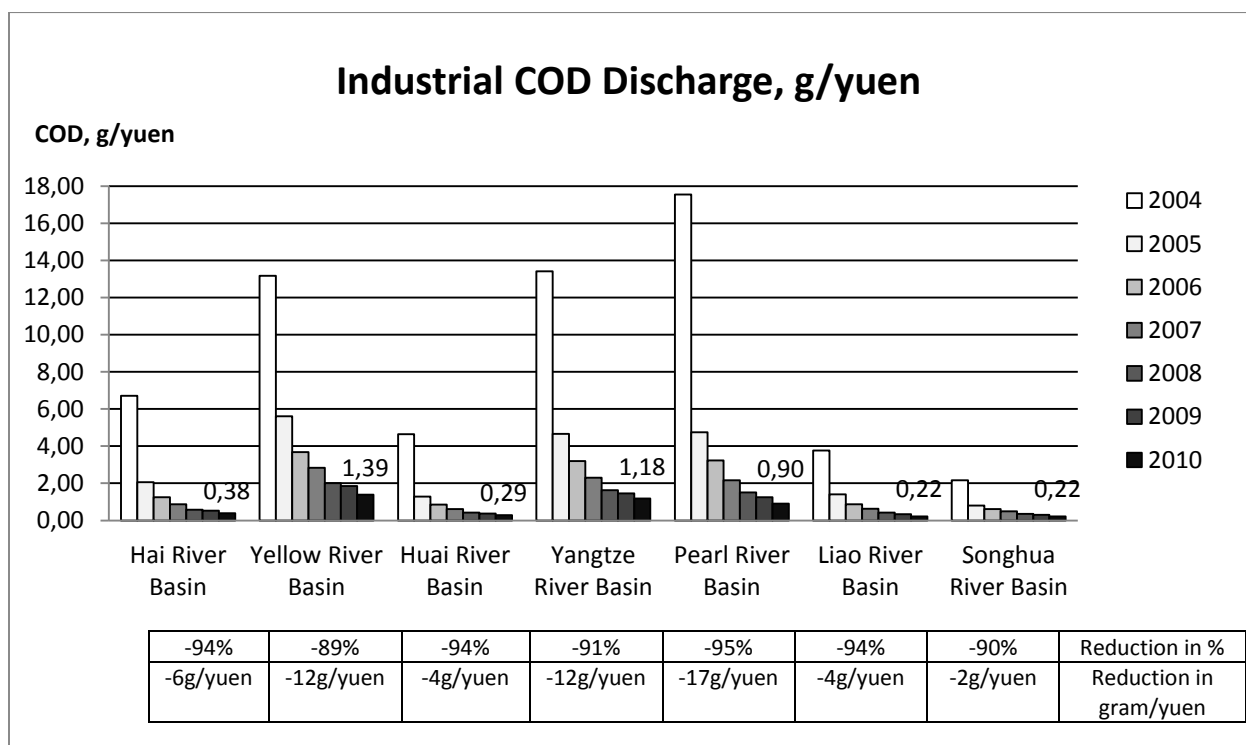
3.3.2 Regions' economic activities and discharge of water pollutants

In this second approach, China is divided into four regions according to the Chinese government's convention and the division is based on provinces' economic structure and economic development (HSBC, 2010). The four regions' economic activities are analyzed to find out if regions' geographic location could have any connection to industries discharge of water pollutants.

The Chinese government divides China in four regions (figure 3.21) with respective provinces:

- East China: Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shandong, Tianjin, and Zhejiang.
- Northeast China: Heilongjiang, Jilin, and Liaoning.
- Central China: Anhui, Henan, Hubei, Hunan, Jiangxi, and Shanxi.

- West China: Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Tibet, Xinjiang, and Yunnan.

-

Figure 3.21. China divided into four regions according to the Chinese government's convention. Source: HSBC, 2010.

Data from the Chinese statistical yearbook indicates the region with highest gross industrial output value (chart 3.7) and lowest discharge of water pollution per yuen (chart 3.8 and 3.9) at present are:

1. Eastern China – 85,699 yuen per capita in gross industrial output value, 0.02 gram discharge of COD per yuen, and 0.002 gram discharge of ammonia and nitrogen per yuen.
2. Northeastern China – 53,723 yuen per capita in gross industrial output value, 0.08 gram discharge of COD per yuen, and 0.003 gram discharge of ammonia and nitrogen per yuen.
3. Central China – 33,817 per capita in gross industrial output value, 0.08 gram discharge of COD per yuen, and 0.007 gram discharge of ammonia and nitrogen per yuen.
4. Western China – 25,203 per capita in gross industrial output value, 0.16 gram discharge of COD per yuen, and 0.009 gram discharge of ammonia and nitrogen per yuen.

Gross Industrial Output Value per capita

Yuen/capita
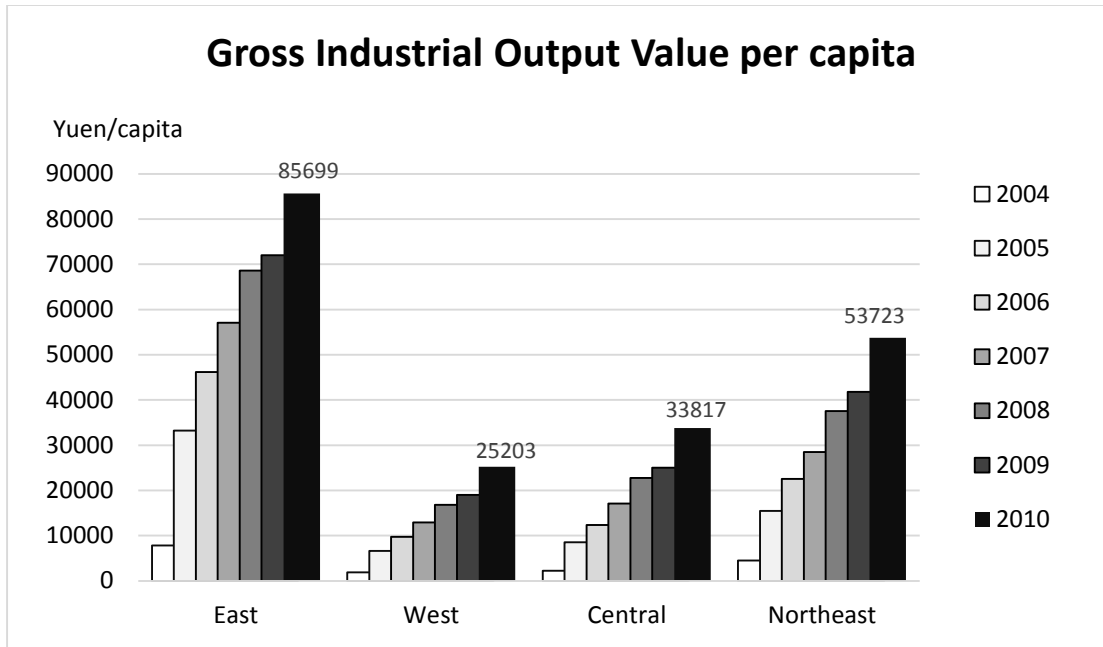
Chart 3.7 Gross industrial output value per capita. The chart present the four regions industrial economic development for the period 2004-2010. The output value is in yuen per capita and the labels present the output value per capita for year 2010 in each region. Source: China statistical yearbooks 2003-2011, chapter: *'Main Indicators of Industrial Enterprises above Designated Size by Region'*.

Industrial COD Discharge, g/yuen

g/yuen
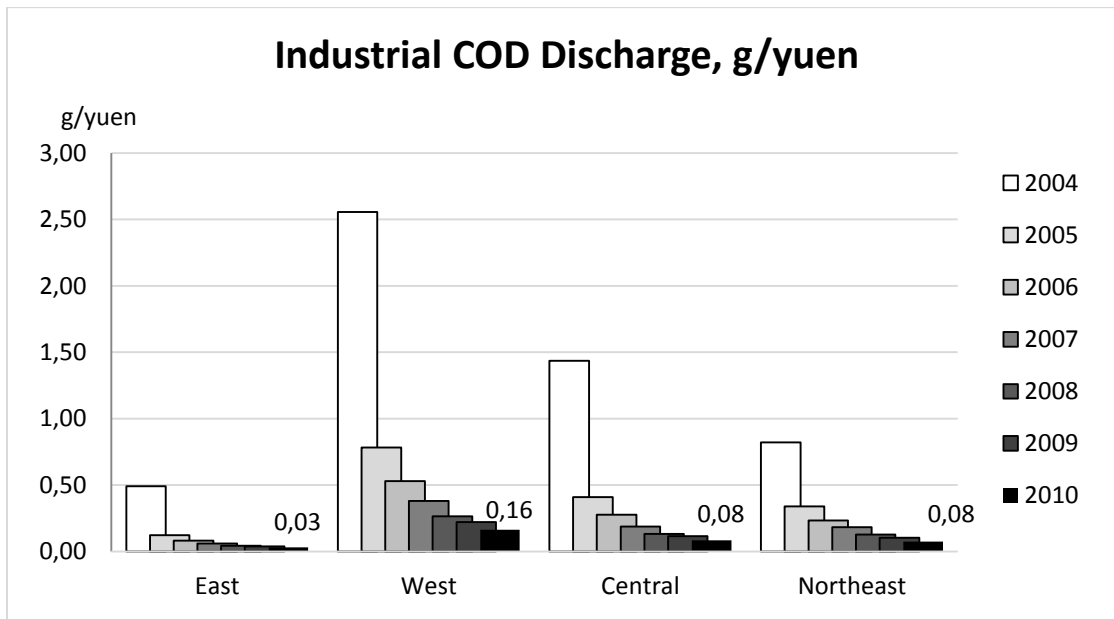
Chart 3.8 Industrial discharge of COD. The chart present the amount industrial discharge of COD in grams per yuen during the period 2004-2010. The label present the total industrial COD discharge for year 2010 in each region. Source: China's statistical yearbook 2003-2011, chapter: '*Discharge and Treatment of Industrial Waste Water by Region'*.
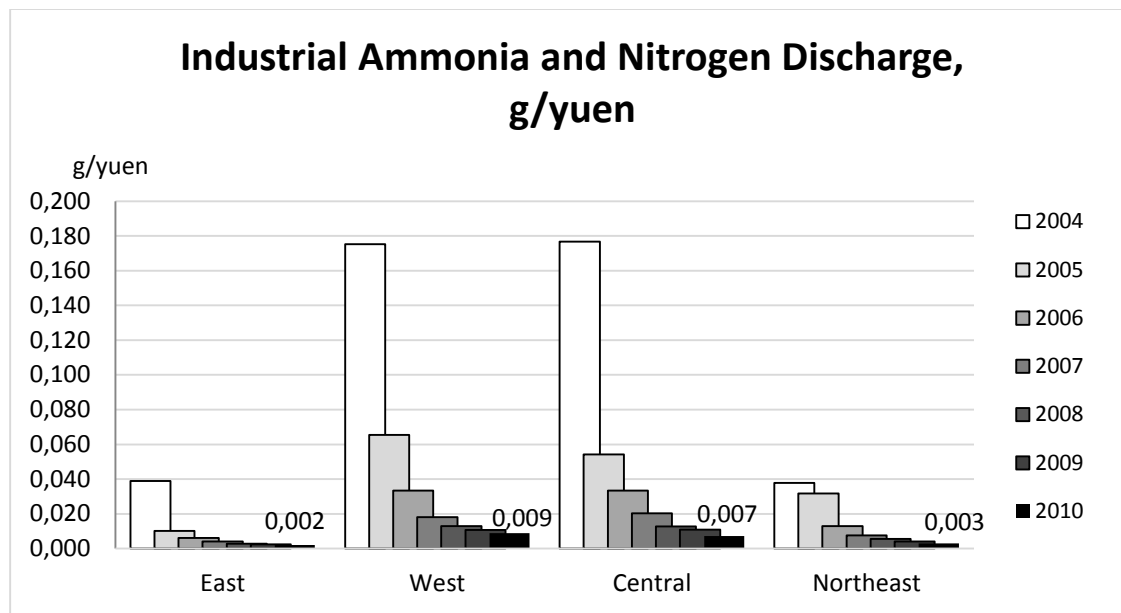
Chart 3.9 Industrial discharge of ammonia, and nitrogen. The chart present the amount industrial discharge of ammonia and nitrogen in grams per yuen during the period 2004-2010. The label present the total discharge for year 2010 in each region. Source: China's statistical yearbook 2003-2011, chapter: '*Discharge and Treatment of Industrial Waste Water by Region'*.

Unlike the result of the previous approach, there seems to be signs that there could be a connection between region's economic activities and discharge of the three industrial water pollutants. The higher industrial output value per capita, the lower is the region's discharge of water pollutants. The coastal regions are more developed with a secondary sector, and also a tertiary sector in the east region, and a service dominated economy pollutes less compare to the inland regions which are more agriculture and industry dominated economy. The further inland the provinces are located, the less developed the provinces seem to be with mainly primary sector dominated economy and higher amount of water pollutants. In HSBC (2010) report, the four regions different economic development was mapped out:

- Eastern China is the richest region and thanks to its coast location. It was the first region to open and develop a trade-economy with the rest of the world and today it is the top leader in primary, secondary and tertiary industry[2] of China's economy. The region accounts for 54% of the country's GDP, 60% of the secondary sector, 86% of the country's total import, and 89% of the total export.
- Northeastern China is the smallest region with only three provinces, however it is the second richest region in China and it is due to the region is rich in reserves of natural resources. The region is a heavy industrial base since mid-1900's and leads in production of organic foods and milk, oil refining, iron, and steel industry. The region has 24% of the country's total iron reserve.

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[2] Primary sector is a term used to describe industries within production and development of raw materials, such as agriculture, mining, and forestry.
Secondary sector is referred to industries involved in manufacturing of goods, such as chemicals, food, electronics, beverage, clothing etc.
Tertiary sector is referred to industries involved in the service sector, such as finance, transportation, health care, education etc.

- Central China is an important agriculture base and food processing centre, and it is mainly thanks to its natural condition - fertile soil, temperate climate, and abundance of precipitation. The region is also rich in reserves of natural resources, such as coal, copper, gold, and iron. Being in the middle between east and west China, gives also benefits for this region's economic growth. Many low-end manufacturing plants are moving to this region from the east due to rising labour and manufacturing costs in east. Central has low costs in both labour and manufacturing, and convenient location with good transportation system.
- Western China is the least developed and poorest region in China. However, the region hold an important energy position. It is estimated this region has about two-thirds of the proven coal reserves in China, more than 60% of the proven natural gas, and about 40% of the proven crude oil. Due to the natural condition west has become the base for renewable energy in the country, northwest have the best environment conditions for wind and solar power, and 77% of the total estimated usable hydropower capacity is located in the west.

Although there are signs that indicates there could be a connection between China's economic activities and discharge of water pollutants, it is difficult to conclude an increased economic activities will result to reduction of water pollution and improvements of river water quality due to too many missing variables in this analysis. Rivers' water quality is not only degraded by COD, ammonia and nitrogen, but also from heavy metals, dissolved oxygen, BOD (biochemical oxygen demand), fluoride, arsenic etc., which could not be analyzed due to data limitation. Moreover, improvements of rivers' water quality depends on several factors, such as political decisions, pressure from a global market or non-governmental organizations since China has opened the country for the world and a global market, thus, the water quality improvements of Songhua River and Yellow River could also be related to political decisions, such as improved regulations and laws. Another important note is the study of discharged COD, ammonia and nitrogen are in gram per yuen which does not necessarily mean the total amount of the three pollutants have reduced, but rather the number of industries have increased and the industries have reduced their discharges of water pollutants and that will then lead to amount of discharged water pollutants are reduced per yuen.

3.4 Summary of findings

To summarize the findings of all water scarcity indices and water assessment methods, the most water scarce threatened area is concentrated to north central China and includes the provinces: Xinjiang, Gansu, Qinghai, Inner Mongolia, Ningxia, Shaanxi, Shanxi, Henan, Hebei, Beijing, Tianjin, Shandong and a small part of Liaoning. The region has five major river basins, Tarim River basin, Yellow River basin, Huai River basin, Hai River basin and Liao River basin, and all basins are experiencing either little water scarcity and severe water pollutions (Huai River basin and Liao River basin) or both severe water scarcity and severe water pollutions (Tarim River basin, Yellow River basin and Hai River basin) caused by humans.

Among these five rivers basins, Hai River and the lower reach of Yellow River are the most water scarce river basins and are frequently experiencing droughts due to anthropogenic factors, such as mismanagement and over withdrawal of river water. The total water withdrawals in Hai River basin have

exceeded the river's total water resources with about 26% according to Cheng and Hu (2012), and Liu and Xia (2004) discussed the large water usage in the basins is mainly because of agriculture is dependent on irrigation since precipitation has reduced to such degree that it would not be possible to produce such large amount food that could support China's large population if the crops were only rainfed. Yellow River basin has a more complicated water problem than Hai River basin because of its length and flows through provinces which have different water demands. The upper reach has the highest water usage due to the arid climate and agriculture is entirely dependent on irrigation which causes the river's water resource is reduced for the middle and lower reaches, and the middle and lower reaches have the highest water demand due to these two regions are much more densely populated and industrialized than the upper reach. Thus, after upper and middle reaches Yellow river's water resource has reduced to such low level that the water utilization in lower reach exceeds 27% of the lower reach's total water resource. Thus, during the annual dry season Yellow River cease to the sea and Hai River cease to sea during dry years, and when rivers cease to the sea the estuary of the rivers will have an increase intrusion of salt seawater since there is no or not enough river water that can hold back the salt seawater and groundwater is also overexploited due to it is the only water source during drought and causing ground subsidence.

Overall, the three basins - Hai River, Huai River and Yellow River; have the highest water demand among all the basins in north China and it is due to the region is the largest provider of grain based products, coal and large producer of oil, natural gas and metals (such as steel, iron and copper) (HSBC, 2010; China Statistical Yearbook, 2011). Moreover, many other water intensive industries are established in this region, such as paper and pulp mills, chemical production (sulfuric acid, caustic soda, soda ash, ethylene, chemical fertilizer, and chemical pesticide) and electricity production (mainly coal based) (China Statistical Yearbook, 2011). According to Zhu et al., 2003, these three basins is the core area of China's political, economic and social development, and based on the yield data from China's statistical yearbook 2011 the region in 2010 accounted for about: 85% of the total national production of wheat and 51% of the total national production of maize; 69% of the total output from the coal production, 62% of the steel production, 47% of the paper and paper product productions, 47% of the chemical production, and 49% of the electricity production (annex, table 7.2 and 7.3).

Moving on to the inland, Tarim River basin is a severe water scarce inland river basin in northwest China and Tarim River is the most important water resource in the cotton producing Xinjiang province, since the river is the major water resource provider in Xinjiang (Qi, et al., 2005). Xinjiang accounts for 42% of the total national cotton production (annex, table 7.2) and due to the desert climate, the agriculture in this region is dependent on irrigation. However, if only studying the statistical data of total water resources in the Xinjiang, the province is abundant in water; 111 billion m^3 in total water resources and 5125 m^3 in average per capita. Yet, the province is known for being water scarce area, which was also indicated by Falkenmark water scarcity index, Physical and economic water scarcity, and WSI taking EWR into account. Xinjiang province is indeed rich of water resources and has many rivers, but many of the small rivers disappears into desert regions after flowing out from the mountains, and therefore, large part of the total water resources is not directly available for human use and it may be misleading by only studying the statistical data.

One thing the four river basins, Hai, Huai, Yellow and Tarim, have in common is the large water usage in agriculture which accounts together accounts for 70% of these fours basins' total water usage (chart 3.10) because of the arid climate and is irrigation dependent. These four basins have 48% of the total national cultivated land and 58% of the land is irrigated, but looking at the provincial level some provinces irrigates 70%-90% of their total arable land, e.g. Beijing, Tianjin, Hebei and Xinjiang (annex, table 7.4) (China Statistical Yearbook, 2011). However, the high water demand in agriculture is mainly because of high inefficiency, and according to Deng et al. (2006), water use efficiency in the agriculture in north China is about 40% and 60% of the water is wasted in either leakage or evaporated. The researchers continues, the inefficiency is mainly characterized by old-fashioned irrigation technologies, such as flood irrigation and canal irrigation, which allows large amount of water to be lost through evaporation and often is the infrastructure for water distribution also old with lots of leakage. This high water demand in all provinces and sectors have resulted conflicts are emerged between upstream and downstream and between sectors (i.e. agriculture, industry and domestic) (Cai, 2008).
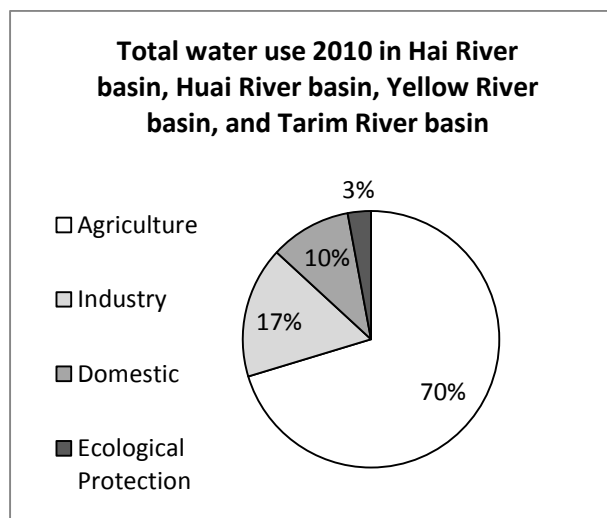
Figure 3.10, Total water use in Hai River basin, Huai River basin, Yellow River basin, and Tarim River basin. The figure shows the different sectors water use share and water use change for year 2010. Source: China Statistical Yearbook 2004 resp. 2011, Chapter: '*Water Resources*' and '*Water use and Water supply*'.

All these water intensive industries aggravate the water scarcity, and in addition, more and more people from the rural areas are moving into the urban areas which increase the domestic water demand (China Statistical Yearbook, 2011). So too high population in some certain regions is also be an important factor which is contributing to China's water scarcity and water pollution. For instance, Hai River basin, Huai River basin and Yellow River basin is the most populated regions in the water scarce north China. Based on data from the statistical yearbooks for years 2004-2011, the surface water and ground water resources declined with 18% respective 9% from year 2003 to 2010 (chart 3.11). The population in the area also increased with 5% during that period, which put additionally more pressure on the scarce water resources. The total water resources in these three basins in 2010 were estimated to be 335.2 billion m^3 and is home for a population of about 509 million people. If the threshold for water scarcity from Falkenmark Water

Scarcity Index is used (min. 1700 m^3/capita before considering water stress) to estimate the basins' water support capacity and do not consider environments water requirements, the basins' total water resources only supports about 197 million people. This mean the areas have about two and half times more than the basins are capable to provide water to the people (annex, table 7.5) and if the environment's water requirement is considered (40% of the total water resources), the actual number of people the basins can support is only 118 million people.
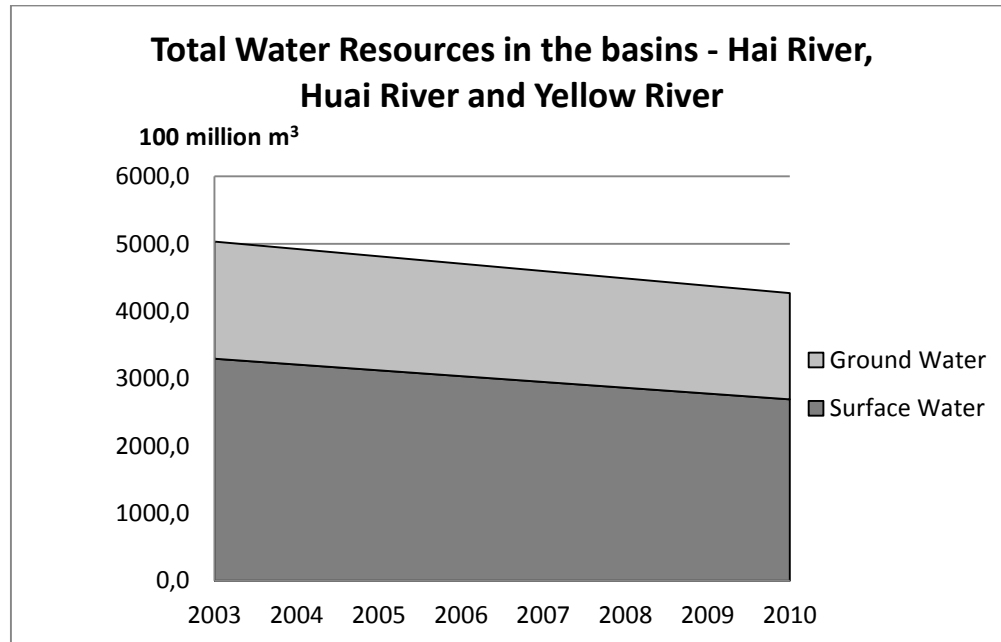

Total Water Resources in the basins - Hai River, Huai River and Yellow River

100 million m^3

Chart 3.11. Total water resources in the basins – Hai River, Huai River and Yellow River. The total water resources of the three basins during the period 2003-2010, ground water and surface water have declined with 9% respective 18%. Source: China Statistical Yearbook 2004 and 2011.

According to the World Bank (2009), a large amount of the untreated industrial waste water is discharged into the rivers, especially in the upper reaches and deteriorates the water quality for the lower reaches. The water quality is further deteriorated by more untreated industrial waste water in the lower reach is discharged into the rivers. About 25 billion m^3 water is withheld due to pollution and leads to unmet water demand and ground water exploitation. As Vörösmarty's et al. global threat maps indicates, Hai River, Huai River, Yellow River, and Liao River's water are highly threatened and especially in provinces along the coast, i.e. Beijing, Tianjin, Hebei, Shandong, Jiangsu, Anhui, Henan and Liaoning. Hai River and Liao River are the two most polluted major rivers (Circle of blue, 2011) and have many industries within coal mining, paper and pulp mills, steel mills, and oil refining, which are water intensive industries and large water polluters and thus are the major contributors to deterioration of the rivers' water (Wang, Ji, & Lei, 2012). In addition, both river basins are also large agricultural products producer and agriculture is a large non-point source water polluter; non-point source water pollution is referred to indirectly water pollution from surface water runoff, precipitation, drainage, atmopheric deposition etc., and unlike industries is the used water in agriculture difficult to collect for treatment and recycling.

However, the water scarcity is also due to the climate change which has increased the average temperature in northern China and that in turn has increased the potential evaporation rate and reduced precipitation. For instance, in Hai River precipitation has declined with 7.6% from 1956 to 2000 and in Yellow River the precipitation has declined with 6% in upper reach, 25% in middle reach and 19% in lower reach from 1956 to 1990s (Zhang , et al., 2011d; Giordano, et al., 2004). As mentioned earlier, rivers' water resource is recharged from precipitation and with a declining precipitation trend comes a declining water resource. In addition, the agriculture will become even more dependent on irrigation since the crops are less rainfed and this will further increase the competition of water between sectors.

4 China's water future

4.1 The climate change and its impacts

There are many researches about countries emissions of greenhouse gases and its influence on the climate change and the global warming, but less investigation about the impacts of climate change on a country's water resources (Piao, et al., 2010). As mentioned earlier, water is a complex resource and is interconnected with climate in complex ways and anthropogenic climate change will put additionally pressure on freshwater system.

According to Piao et al. (2010), the temperature in China has increased by 1.2 $^{\circ}$C since 1960 and northern China is getting warmer than southern China. Based on observations from IPCC:

- temperature has increased the last 50 years in China, especially during the winters;
- over the past four decades, glaciers in China has shrunken by 7% due to increased temperature;
- annual precipitation has increased in western and southern China, with increased floods in Yangtze River as consequence;
- and precipitation has declined in northeast and north China, with increased droughts as consequence, and it is projected this warming trend will continue in the near future (Cruz, et al., 2007).

In IPCC's Fourth Assessment Report (2007), several scenarios were projected, but only two scenarios (A1F1 and B1) were used to project how the climate change will affect Asia. Explanations to why these two scenarios were chosen were not given.

- Scenario A1F1 is a projection of a future with high population growth and slow economic development, and is a future scenario with highest future emission. The scenario projects there will be an average temperature increase of 1.61-1.82 $^{\circ}$C during the spring and summer, and an increase with about 1.31-1.35 $^{\circ}$C during autumn and winter in average in whole China.
- Scenario B1 is a more optimistic future projection with focus on global solutions to economic, social and environmental sustainability, and is a future scenario with lowest future emission trajectory. This scenario projects there will be an average temperature increase of 1.5 $^{\circ}$C during spring and summer, and 1.24-1.31 $^{\circ}$C during autumn and winter.

Considering the worse scenario will occur in the future, A1F1, with the highest temperature increase in China. It will result to accelerate glacier melt and reduce the glacial volume in Western China. Furthermore, according to Kundzewicz, Z.W. (2007), higher temperatures means the atmosphere will have increased capacity to keep water and in northern China which is already water scarce will experience more severe droughts due to warmer air will increase the evaporation capacity and reduce the precipitation, which in turn reduces river's runoff and eventually dry up. In southern China where water is abundant, increased temperature and influence from the humid monsoonal climate will increase the precipitation, which in turn leads to increased risks for floods from rivers.

4.2 Future water demand

According to the Water Resource Group's report "Charting Our Water Future" (2009), China's water demand will grow with 1.6% from year 2005 till 2030. The largest drivers of water demands comes from the industrial and domestic sector, with 2.7% respective 2.9% growth, the agriculture's water demand will only grow with 0.6% during those 25 years. The highest water demand within the industrial sector comes from thermal power cooling due to increased energy use both in the industry and domestic sector. This high energy demand lies in the growing population and mostly in the growing middle class from 4% of the total population in 2005 to 56% of the population in 2030. With a large population going from living low standard to a higher, results large consumption and larger energy use. More people will also move from the rural area to the urban area, which means more potable water will have to be delivered for municipal and industrial systems. In addition, the water treatment is very energy intensive, which means additionally increased energy use.

According to the report, based on the water supply data from year 2005 there will be a huge gap of 201 billion m^3 between water supply and water demand in China 2030. The Hai Basin will face the largest percentage gap at 39% (23 billion m^3) and Yangtze Basin will face the largest size gap at 70 billion m^3 (25%). An estimation made by Cruz, R.V. et al. (2007), only 70% of the water demand for irrigation in north China can be met in the future due to the climate change and increased demand. This will have further negative impact on China's food supply, since northern China is major provider of agricultural products.

It is always difficult to forecast any future demands. If China wants to maintain their economic growth, the power consumption will also increase. With increasing power consumption comes increasing water consumptions due to large amount of water is needed for cooling, but also for coal mining and preparation since China's power generation is mainly coal based and will most likely remain like that in the near coming future. In order to keep the economic growth, a reform is needed for China's water conservancy.

4.3 Future water resources

The future projections of climate change are very uncertain, since it is challenging to forecast future weather and is affected by many factors (both anthropogenic and natural) (Kundzewicz, et al., 2007). For the same reason, it is also difficult to estimate future water resources since there are so many factors that

affects the water availability. However, assuming the worst case scenario, northern China's water scarcity will become even more severe with the risk that rivers and lakes will shrink or dry up, declining of groundwater table due to over exploitation of both surface water and groundwater, and the recharge for groundwater will also decline. In addition, reduced river runoff and river discharge to the sea will degrade the water quality since pollution are not diluted by any new water recharge. Increased frequency of droughts will also lead to more serious salt-water intrusion in the estuary of the river's and deteriorate both surface water and groundwater (Cruz, et al., 2007).

The future water demand and water resources will also depends on the future economic development. According to HSBC's report, eastern China will focus to become more energy efficient and meet carbon intensity target, grow in the service sector, R&D development and high-tech manufacturing. Due to higher labour costs, manufacturing costs and energy efficiency reasons, many manufacturing industries have to move from eastern China to central China which is a region with cheap labour and good transportation system. Western China is an important area for development of renewable energy and many provinces in this region will focus to expand in developing renewable energy and become the new energy base. Moreover, as this region is one of the poorer region among the four regions but rich in resources, in the coming future this region aim to become an industrial base and develop their major industrial sectors, such as coal, steel, non-ferrous metal materials, aluminium, petrochemicals, pharmaceuticals, and food processing. Northeastern China will focus in the coming future to expand their industrial sectors with focus on energy, petrochemicals, textiles and food processing, but also in service sector, such as radio and television, digital transmission, network services, and journalism.

Analyzing China's development structure at provincial level, the richest and most developed region in China is the eastern part and moving towards inland the provinces are less developed and poorer. Thus, due to the different development stage between the regions, eastern China will become the more modernized economy which is more service oriented and moving towards inland the economy goes back to be industrialized based economy. Looking at water use pattern and water pollutions, eastern China's water consumption will reduce and so as for the water pollution since the service sector discharges less pollutions compared to industries, but the consumption and water pollutions will increase while moving towards inland due to industry sectors are more water intensive compared to service sectors and discharge more waste water with higher rate of water pollutants. This in turn means water withdrawal and discharge of industrial waste water in the upper reaches of the rivers' will keep increasing and the lower reaches scarce water resources will get even scarce and accumulate more pollutions. In combination with warming air and reduced precipitation in northern China, the water resources will shrink and degrade additionally.

4.4 Water-savings measures

Better water management has to be implemented in all sectors and all water consumption activities in order to mitigate the water scarcity. Water consumption in some of the water intensive activities have been studied and the author has estimated roughly how much water may be saved if water management is improved in those activities. The top eight water intensive industries in China are thermal power, textile, steel, paper, oil refining, food and beverage, coal mining, and chemical (Water Resources Group, 2009), and based on available data these water activities was studied: coal power production, paper production, steel production, agriculture, waste water recycling.

Power production from coal-fired power plants
Power production from fossil fuels is always water intensive due to large amount of water are needed for extraction, washing and cooling. Power production from coal accounts for 70% of China's total power production (EIA, 2012), and according to Pan L. et al. (2012), the average water consumption in coal-fired power plants is approximately 3.1 m^3/kWh, compared to the average water consumption in developed countries which is 2.52 m^3/kWh. Large part of the water consumption in coal-fired power plants is used for cooling, ash removal, boiler feed, human consumption and fire extinguishing. In 2010, the power production was 4207 billion kWh based on China's statistical yearbook 2011 and if 70% of the power production is coal based, it means about 2945 billion kWh is generated from coal-fired power plants. If water management in the coal-fired power plants were improved to developed countries standard, about 1708 billion m^3 water could be saved.

Paper production
In the report, 'Addressing China's Water Scarcity', published by the World Bank in 2009 it was estimated that the paper industry in China uses about 400-500 m^3 water per ton of produced paper, while water use in OECD countries is less than 200 m^3 water per ton of produced paper. If the Chinese paper industry reduced their water intensity to OECD countries' level, the water usage can be reduced with at least 50%. In 2010, about 98 million tons paper and paper board was produced according to China's statistical yearbook (2001) and if OECD countries water management standard is implemented, then at least 29 billion m^3 of water could be saved.

Steel production
From the same report, 'Addressing China's Water Scarcity', it is estimated the largest steel mills in China use about 60% more water to produce one ton of steel than the combined average of the U.S., Japan and Germany, and the smaller mills use about five times more water. Since the author could not find data of total water usage from steel industry, average national water footprint was used for ferrous metal smelting and products in order to estimate roughly how much water could be saved in steel industry. Zhao X. et al. (2008), estimated the national water footprint in China for metal smelting and products is 21.5 million m^3/billion yuen and from China's statistical yearbook 2011, the total industrial output value for ferrous metal smelting and products was about 1370 billion yuen. If water management is improved to developed countries standard, at least 18 billion m^3 of water could be saved.

Water waste in agriculture

In the report, 'Addressing China's Water Scarcity', it was estimated that only 40% of the water that is withdrawn for agricultural use is actually used on crops and it is mainly due to poor water management. If water use efficiency within agriculture sector is improved to 100%, then about 184 billion m^3 of water could be saved.

Waste water recycling

As the agriculture, the Chinese industries water use efficiency is low. The Chinese industries only recycle 40% of their industrial waste water, while developed countries' industries recycles 75-85% of its waste water (The World Bank, 2009). If the industrial waste water recycling is improved to 75%, then the industrial freshwater withdrawal could be reduced with at least 109 million m^3 water based on the statistics of industrial water use during year 2010.

If all these measurements are applied, theoretically, about 2,777 billion m^3 could be saved or water for 1,633 million people (1700 m^3/capita). This large amount of savable water should not be mixed up with 94% of the total water resource could remain unused, because water is reused. Discharged water in the upper stream is reused by the lower stream and the difference is water quality in downstream is deteriorated.

See table 4.1 below for more detailed information about the water-saving measurements.

	Total water consumption, 10^9 m3	Estimated saved water, 10^9 m3	Measures
Domestic	77	14	Improvement of utility distribution network by reducing leakages, which accounts for 18% of the water losses.
Agriculture	369	184	Improve water management in agriculture by improving water use efficiency to 100% through reducing water waste in leakages and lost by evaporation.
Industry	145	109	Improve the water recycling rate to 75%.
Paper	12	12	Improve water management in paper industry and reduce water usage with at least 50%.
Ferrous metal smelting and products	29	18	Improve water management in ferrous metal industry and reduce water usage with at least 60%.
Coal-fired power productio	13042	2440	Improve water management to developed countries standard and reduce water usage with 23%.
Total saved water		2777	

Table 4.1. Suggested water-savings measures in three top water intensive industries: paper and pulp mills; ferrous metal smelting and products; and power production, and in the sectors: domestic; agriculture; and industry. Data source: China's statistical yearbook 2011.

Another conservancy measure is to change water cooling power units to air cooling power units, which could save up to 60% water use (The World Bank, 2009). No calculations have been made for this measurement due to lack of data. There are a few coal-fired power plants in upper north China that have implemented air cooling, but the author could not find total amount produced power with air-cooling adoption.

5   Discussion

Main reasons to China's water stress and water scarcity
The main factors to China's declining ground water table and rivers runoff are intensive human activities, excessive water withdrawals from rivers, water detention in dams and reservoirs, and water pollutions that makes the water unusable. Most of the times are the lower reaches that experiences the worse water scarcity due to the upper reaches have large water withdrawals, discharge of untreated waste water and large number of dams that detents the water. As it was estimated in chapter *4.4 Water-savings measures*, about 2,777 billion m^3 water could be saved if water management is improved in only a few industry sectors, in agriculture, and in domestic sector. How large would the amount be if China managed to improve its water management in all three sectors (domestic, agriculture and industry)?

Although the key factor to the water scarcity is human activities, the natural climate contribute also some influence on the water resources by the water resources are uneven distributed both geographical and seasonal. If the projected climate change turns out to be correct with increased temperature, northern China will become warmer and more arid. A more arid climate will increase the potential evaporation and this means the volume of water resources will shrink additionally for this part of China. Since southern China has tropical monsoon climate, which means air flow in winter will change direction and move from inland towards the sea, the evaporated water will then move to southern China as rainfall. The region will become ever more abundant in water and have more extremes rainfalls and floods.

Scarcity of physical water and clean water
According to the World Bank (2006), 25 billion m^3 of water is held back due to water pollution in China and another 47 billion m^3 of water does not meet the water quality standard, but is nevertheless supplied to households, industry and agriculture. Because of that, many regions with heavily polluted water usually have higher rates of cancer, cholera, typhoid and other water borne diseases. 70-90% of hepatitis A cases are transmitted by water and 9 million cases of diarrhea are due to water pollution (The World Bank, 2006). Rivers' lower reach is the most exposed areas because it is dependent of the water use in upstream, which characterize of large water withdrawals and discharge of untreated waste water into the rivers. There are also more water treatments facilities located in rivers' downstream than in the upstream due to it is often in the coast, which are the more developed and wealthiest region in China and is able to invest into more cleaner technology. However, most of the water treatments are in the cities, the rural areas which are less developed are often supplied with contaminated water (Economy, 2010). So having

water does not mean having safe and potable water and as an example is the Huai River, which have been indicated as the most water abundant river in the north but also the most polluted river.

Future water demand and impacts from the climate change on future water resources
Considering China's five-year plan, both the national and the provincial, whole China will become more industrialized, especially in provinces located inlands, and the power demand will therefore increase. This in turn will increase both water demand and withdrawals from the rivers even more, and results additional reduction of water resources for the coast provinces, which are located in the lower reaches of the rivers'.

If the climate change projection turns out to be true, water scarcity in China will aggravates further, but there are also other issues that comes along with a warmer climate. Many of China's rivers and lakes are suffering from eutrophication and bloom of algae due to high loads of nitrogen and phosphorus from non-point sources. A warmer climate will exacerbate the conditions and also increase the risks for development of pests and waterborne diseases, especially in the rural areas. For the agriculture sector, contaminated water will damage crops and reduce the harvests. This implies water treatment will become even more important in the future, and increased water treatment will increase power demand, which in turn goes back to increased water demand. This is why China's water situation is so complex, since it seem to be a vicious circle.

Water crisis or business as usual?
It is challenging to identify if a country is experiencing water crisis due to water is such complex system. Only studying a country's total annual water resources is not enough, because it would give a misleading picture of a country's water situation and which also was proven with Falkenmark water scarcity index. The simple indicator shows there are only few provinces that are experiencing water scarcity and it seems that China does not to have a water crisis at all, however, when more sophisticated indicator is used with more variables that are taken into accounts then the result will also become more accurate and certain. The summarized result from all four WSIs shows clearly that China has a water crisis and the north is experiencing severe water scarcity since there is imbalance between water demand and supply in the entire country, but also economic losses due to droughts and water pollution. Northern China's water crisis is mainly due to physical water scarcity and water pollution, which leads to droughts and economic losses in terms of left out industrial and agricultural outputs. Southern China do not experience water crisis as the north does, but the region is facing high threats to their water security both for human and environment due to massive dams and floodgates along the rivers.

Furthermore, having water does not mean having available and usable water. Huai River is quite abundant in water compared to many other rivers in the north and Liao River did not even appeared to be water scarce in the WSI. However, these two rivers are the most polluted rivers in China and large percentage of the rivers' water resources are considered to be not suitable for anything. Moreover, during the dry periods the water pollution problem will become worse since rivers' dilution potential is reduced.

Nevertheless, the result about China's water situation is not any news, but what is interesting to discuss is if China can keep their rapid growth and if industries can keep doing their business as usual? China is abundant in water, but not in useable clean water. There are mixed results regarding the existence of the EKC and as discussed in chapter 3.2 Water pollution and its connection to economic growth, there seem to be a relationship between these two factors. However, some regions environmental quality at present is deteriorated to such degree that the consequences from the severe water pollutions and over-exploitation of groundwater will be everlasting, for instance the extinction of Yangtze River's dolphin. So, it is not sustainable and most likely not possible for China to follow the EKC influenced approach, *'Grow (pollute) first, clean later',* combined with the present poor water management and a continuously increasing water demand. Because water is primary inputs (directly or indirectly) in all goods and services, and water shortage will influence all sectors negatively. Regardless the existence of EKC, as Hong et al. (2010) remark: *'Whatever the shapes of the income-pollution relations, one can be sure that the environmental quality will not improve automatically with income increases, but require appropriate policies to generate enabling capacities and incentives to reduce the pollution.'* (Hong, Zhou, & Abbaspour, 2010). Therefore, the leaders of China cannot take for granted that the environmental quality will improve in a few years when the economic growth have reached to a certain points. Stronger enforcements of water laws and regulations are needed in order to reduce pollutions of both air and water.

China's water crisis is also much more complex than just left out outputs from industries and agriculture, and degraded water quality. China's rapid economic growth has contributed to about 14% annual growths in energy demand and it will keep growing in the near future during the country's transition time from a rural, agricultural-based economy to urban, industry-based economy (Kahrl & Roland-Holst, 2008). Water is mainly used as coolant and driving steam turbines in power plants, and thus, water shortage will become a major constraint for the power production. Moreover, China's government targets to increase the rate of reuse of waste water and reduce water pollutions, but collection and treatment of waste water is very energy intensive and will put additionally pressure on power production and indirectly on water resources, especially when China is already experiencing shortages of both water and power. This is one of the main key to complexity of China's water issue, since either way water resources seem to be put under additionally pressure in the end.

Coping water scarcity
In order to cope with the water scarcity, the Chinese government has to improve their water management in whole China in all sectors, such as:

- infrastructure has to be improved in order to reduce the leakages;
- irrigation techniques has to be optimized and reduce the water wastage;
- industries have to improve their water management and reduce the water use to developed countries level;
- and waste water has to be treated and recycled.

The Chinese government has set several goals in their 12th five-year plan to improve their water management and laws and regulations. However, due to policy failure the enforcement of the laws and regulations are weak. Although China has become one of the largest economy in the world, country's political system is unique as being both centralized and have a market dominated economy simultaneously. As Economy (2010) point out, there are still a lot of corruptions within the country and it is one of the reasons to many policy failures and uncertainties among the statistical data: many water pollution incidents and groundwater exploitations are not reported; and data on water consumption, treated waste water, and discharge of waste water is often manipulated in ways that will not give local regions or provinces bad image. Local industries and regions only pay attention to short-term interest and their own area, and disregards harms done to others.

Several researchers (Jiang, Y., 2009; Xia, J., 2009; World Bank, 2006; Yi, L. et al., 2011) have suggested similar measurements that can help to mitigate water scarcity, such as:

- Regulations and laws have to be better enforced;
- The price of the water should be more fairly priced and reflect the value of the water availability, since water is at the moment very low priced and does not reflect the market price;
- Recycling of waste water would increase available water supply by 56%;
- Increase punishment fees for industries if discharged water does not meet the discharge standard and etc.

Except better enforcement of regulations and laws, more clear definitions are also important. Many environment laws and regulations are vague stated, and because of that local officials and departments interpret them in ways which favorable themselves. Water rights should also be better defined and registered for each province or region. Because unlike land use, one region's water use will affect another region's water resource, since same water resource flows through several provinces and this is clearly proven by river's downstream often experiences the worse water problems.

As mentioned, water is heavily underpriced and due to it is not market-based there are no incentives for development of improvements on water management and water-saving measurements. Also, because of the Chinese government has set the food security as one of the major top priorities, agriculture will be primarily prioritized for water use despite industries' water use has more value than agricultures' water use. This combination of non-market based approach and scarce resources restrict China's economic growth. If China was a more market-based economy the water would be more fairly priced and water demand will be restricted and provide incentives to save water.

The water expert Peter Gleick refers all above mentioned measurements as the hard path. In 2002, Gleick introduced the terms soft path and hard path in his article "*Soft path for water*". The terms refer to the usage of water and technologies in ways which conserves water. Hard path relies on centralized infrastructure and decisions making, such as water conservancy by dams and reservoirs, pipelines and water treatment, water departments and agencies. The soft path complement centralized infrastructure with decentralized facilities, efficient technologies and human capital.

China has good environment laws and regulations, however, the author believes the soft paths is as important as the hard paths as Gleick point out. The Chinese government realizes the country is suffering of severe water scarcity and is making great efforts to mitigate the problems, but efforts have to come from the other side too. In the end, the major water consumers are not the government; it is the agriculture and industries. If the largest water consumers do not to pay more attentions to long-terms solutions and concerns harm done to others, China will never be able to cope with their water crisis. Many times are the inefficient water use among farmers and industries due to lack of knowledge about sustainable water use and environmental impacts. By education and giving people more enlightenment about the long-term consequences with the present unsustainable water consumption and the benefits with improvements of water management, people attitudes towards water use can be changed. In some cases it might increase the motivation to find own solutions for better water savings measurements. However, the soft paths will take time to implement because unlike implementing punishment fees, changed water price, laws and regulations; educating people and changing their attitude towards sustainable water use is a social-cultural change. China's environmental tradition is highly influenced by Confucianism, Taoism and Legalism, which basically implies the human should use the environment for its own benefits and the environment is impersonal and purposeless (Economy, 2010). Because if this irrational philosophy is permeated in the whole nation since thousands years back, changing people's attitudes and philosophy will take more than just a five-year plan.

Large part of China is experiencing water scarcity and with existing five-year plan, water demand will for sure increase in the coming future. Based on the author's findings, the main factors to China's water shortage are human activities and if better water management is implemented in all sectors, the water crisis would be manageable. For example, Israel is known for its scarce water resources and is world leading in water management (Mincer, 2012). The average annual water availability per capita in Israel is about 265 m^3 and yet Israel managed to use the same amount of water resources to increase their food output with 9% over the past 16 years (FAO, 2009; IANS, 2012). Although, it is difficult to compare Israel's water situation to China's water situation, since the circumstances for these two countries are different – economic structure, climate, number of people, political structure etc; the author believes it could help China to mitigate their water issue by study and learn from other water scarce countries and their water management, and implement suitable water technologies and management into the Chinese industry and agriculture sectors.

Another way to tackle China's water issue would be importing more virtual water. The concept 'virtual water' means water embedded in water intensive products, which are then traded outside the producing region (Guan & Hubacek, 2007). Northern China is the main producer of agricultural products, which are dependent of irrigation, and export large amount of it to southern China. With other words, Northern China which is water scarce region export large amount of virtual water to the water abundant Southern China. Some researchers suggest water scarce regions should increase their water use efficiency by reducing their export of virtual water and increase the import of it. In China's case, it would be that the north should produce less agriculture products and import it from the south and vice versa for the south. However, cultivable land is already maximized in entire China and cultivated crop types and crop rotations for specific region are also optimized – rice and tropical fruits are mainly cultivated in south due to the

abundance of water and the more humid and tropical climate, while north has more wheat and maize based agriculture due to the more appropriate climate condition. So, it is difficult to increase the agricultural output in the south or reallocate some specific crops, especially wheat and maize, due to land limit but also because of climate condition the crops requires.

To end this discussion, the water crisis in China is very complex due to the integration of so many systems; climate change, ecosystem's water demand, human's water demand and etc., but also because the water problem appears in different form in the country simultaneously: "too much water – floods, too little water – droughts, and too dirty water – water pollution" (Jun & Chen, 2001). China's water crisis is a huge challenge, because improvement of water quality requires increased water treatment, which in turn increases power demand and indirectly water demand. Nevertheless, if China wants to keep their economic growth, more measurements have to be implemented and followed up in order to reduce the corruption and ignorance of laws and regulations.

For future work, in order to make as accurate and certain assessment of China as possible more accurate water data is needed. Moreover, language may be an obstacle since more data is available in Chinese than English and it is an advantage to know how to read Chinese, e.g. when the author wanted to analyze how much water was withdrawn from the rivers, there were no data in the Chinese statistical yearbooks. However, with some help from an external source, more information was collected from MWR's Chinese website. As mentioned earlier, due to many water pollution incidents and discharges of untreated waste water are not reported, data of total amount of waste water discharge and pollutions incidents in the statistical yearbooks are not certain. A suggestion is to gather the data by field studies in order to mitigate as much uncertainties as possible.

6 Conclusion

There is a water crisis in China and several provinces in northern China are experiencing physical water scarcity due to human activities and the shortage of water is further aggravated by deteriorated water quality, reduced precipitation and increased temperature. The water crisis is becoming a bottleneck for China's economic growth and with the five-year plan, where the provinces in inland China are going from being agriculture intensive to industrial intensive, water demand will increase additionally. Because with economic growth comes also increased power demand and water demand. Especially since the power generation in China is mainly coal based, large amount of water is required for coal mining, production and cooling in the power plants. If there is not enough water, power generation will be restricted and that will in turn restrict China's economic development. Therefore, it is no longer "business as usual" if China wants to keep their economic growth. Large efforts have to be made by both the government and the people. There need to be an attitude change among the Chinese leaders and realize it is not sustainable to use the EKC influenced approach, '*Grow (pollute) first, clean later*'. Because some areas have been suffering from severe water scarcity for a long time and if the situation is not improved in those areas the consequences might be permanent, such as extinction of water species, soil might become too salinized and uncultivable, rivers might dry up and disappear. It is also important that more effort are made in educating and encouraging people about the water situation and what is sustainable use and why it is important. Industries and farmers also need to be more aware about their own impacts on the water resources and harms done to others and what measurements can be implemented without being too costly.

The climate change will also have impacts China's water resources. According to IPCC's projected climate change, China will in average become 1-2 °C warmer, precipitation in northern China will decline additionally and southern will experience more extreme precipitations. Reduced precipitation means reduced water recharge for the rivers, since 98% of the rivers' water resource is recharged by the rain, but also, the agriculture will become more dependent on irrigation since crops are less rainfed.

Despite the water situation in China is crucial, the water scarcity is still manageable. As mentioned earlier China is abundant in water but due to poor water management large amount of water is wasted - the coal-fired power plants use about 23% more water than developed countries; the paper and pulp industry in China use at least double amount of water compared to the developed countries to produce one ton of paper; the largest steel mills use about 60% more water in China to produce one ton of steel than the developed countries; 18% water is lost through leakages when distributed to cities; water use efficiency in agriculture is only 60% due to leakages and poor water management; and industrial waste water recycling rate is only 40%. If better water management is implemented, i.e. increase the water use efficiency, increase cleaning of waste water and water recycling, improve the infrastructure for water transportation, more than half of the present water use could be reduced and could mitigate the water competition among the sectors.

However, the greatest challenge is to improve the water situation without having too much negative impact on the economic growth, since these two factors are integrated with each other. So a remaining question is how can China improve their water situation and keeping their economic growth

simultaneously? Recommendation for future water studies are more accurate and certain data need to be collected in order to make a fully covered water study about China. Since water use and power production is integrated with each other, it would be interesting to study how much water could be saved from the industry sector if energy consumption is reduced by implementing energy efficiency measurements. Field trip to some of the water scarce regions might also give better understanding to the wasteful water use pattern.

7 Annex

7.1 Tables

Table 7.1. Weighting sets for themes and drivers used to assess threat to Human Water Security and River Biodiversity. The table presents the 23 drivers which Vörösmarty et al. consider are the main drivers to threat human water security and river biodiversity. The drivers are organized into four themes. The two weighting sets indicates when human water security and river biodiverisyt are threatened. Source: Vörösmarty et al., 2010b.

Theme	Relative weight	
Driver	Human water security	Biodiversity
Catchment disturbance (Captures the impacts of land-use change and insufficient stewardship within catchment at local-scale)	**0.18**	**0.22**
1. Cropland	0.38	0.31
2. Impervious surface	0.28	0.25
3. Livestock density	0.20	0.18
4. Wetland disconnectivity	0.14	0.26
Pollution (Cover a broad range of pollutants direct or indirect negative impacts on water resources and biodiversity)	**0.35**	**0.28**
5. Soil salinisation	0.13	0.08
6. Nitrogen loading	0.14	0.12
7. Phosporus loading	0.13	0.13
8. Mercury deposition	0.13	0.05
9. Pesticide loading	0.15	0.10
10. Sediment loading	0.07	0.17
11. Organic loading	0.18	0.15
12. Potential acidification	0.05	0.09
13. Thermal alteration	0.02	0.11
Water resource development (Cover the various way to alter the quantity of available water for human-use)	**0.41**	**0.30**
14. Dam density	0.09	0.25
15. River fragmentation	0.03	0.30
16. Consumptive water loss	0.34	0.22
17. Human water stress	0.26	0.04
18. Agricultural water stress	0.19	0.07
19. Flow disruption	0.09	0.12

Biotic factors (Capture the local and spatially-distributed impacts of changing the biota of river ecosystems)	0.06	0.20
20. Non-native fishes (%)	0.13	0.26
21. Non-native fishes (#)	0.14	0.21
22. Fishing pressure	0.27	0.34
23. Aquaculture pressure	0.46	0.19

Table 7.2. Total output of wheat, maize and cotton production in the basins Hai River, Huai River, Yellow River and Tarim Basin. Total output of wheat and maize and cotton during year 2010 from provinces within Huai River basin, Hai River basin, Yellow River basin and Tarim River basin. Source: China Statistical Yearbook 2011, Chapter 13-15 Output from major farm products.

Huai, Hai and Yellow River basin	Wheat, 10 000 tons	Maize, 10 000 tons
Beijing	28.4	84.2
Tianjin	53.2	92.7
Hebei	1230.6	1508.7
Shanxi	232.2	766.0
Inner Mongolia	165.2	1465.7
Jiangsu	1008.1	218.5
Shandong	2058.6	1932.1
Henan	3082.2	1634.8
Shaanxi	403.8	532.2
Gansu	250.9	390.4
Qinghai	37.3	10.7
Ningxia	70.3	165.8
Anhui	1206.7	312.7
Total	**9827.6**	**9114.5**
Total National	**11518.1**	**17724.5**
Ratio of total	**85%**	**51%**

Tarim River Basin	Cotton, 10 000 tons
Xinjiang	247.9
Total National	**596.1**
Ratio of total	**42%**

Table 7.3. Total output from coal production, chemicals production, steel production, paper and pulp mills, and electricity production in the basins Hai River, Huai River and Yellow River. Total output from coal, chemicals, steel, paper and pulp mills, eleclтricity industries from provinces within Huai River basin, Hai River basin and Yellow River basin. Source: China Statistical Yearbook 2011, Chapter 14-23 Output from industrial products by region.

Provinces in Hai River, Huai River and Yellow River basins	Coal (10 000 tons)	Chemicals (10 000 tons)	Steel(10 000 tons)	Paper and pulp mills (10 000 tons)	Electricity, (100 million kwh)
Beijing	160.6	103.1	1633.6	10.6	269.0
Tianjin	238.4	312.3	8582.7	88.9	589.1
Hebei	5045.7	558.3	44951.8	412.6	1993.1
Shanxi	8504.8	422.4	9317.6	21.0	2151.0
Inner Mongolia	2034.3	610.9	3933.2	28.8	2489.3
Jiangsu	1393.6	1422.9	20594.0	1088.2	3359.2
Anhui	874.9	781.2	6155.4	208.9	1443.9
Shandong	3429.0	2485.8	18187.9	1638.6	3042.7
Henan	2572.1	1012.9	7691.3	967.8	2191.8
Shaanxi	1570.9	277.1	2116.1	86.6	1112.3
Gansu	244.3	442.2	1986.9	11.6	791.5
Qinghai	129.8	411.0	387.0		468.3
Ningxia	424.0	196.2	72.2	78.9	587.2
Total	**26622.3**	**9036.4**	**125609.6**	**4642.4**	**20488.2**
National total	**38864.0**	**19336.4**	**203732.9**	**9832.6**	**42071.6**
Ratio of total	**69%**	**47%**	**62%**	**47%**	**49%**

Table 7.4. Share of Cultivated land and irrigated land in the four basins Hai River, Huai River, Yellow River and Tarim River. Total area of cultivated land and total area of irrigated land of the cultivated land in provinces within Huai River basin, Hai River basin, Yellow River basin and Tarim River basin. Source: China Statistical Yearbook 2011, Chapter 13-3 Area of Cultivated Land at Year-end by Region, and Chapter 13-6 Irrigated Area, consumption of chemical fertilizers and rural hydropower stations and electricity consumption in rural areas.

Hai River, Huai River, Yellow River and Tarim River Basin	Area of cultivated land, 10 000 hectares	Area of irrigated area, 10 000 hectares	Ratio of irrigated area
Beijing	231.7	211.4	91%
Tianjin	441.1	344.6	78%
Hebei	6317.3	4548.0	72%
Shanxi	4055.8	1274.2	31%
Inner Mongolia	7147.2	3027.5	42%
Jiangsu	4763.8	3819.7	80%
Shandong	7515.3	4955.3	66%
Henan	7926.4	5081.0	64%
Shaanxi	4050.3	1284.9	32%
Gansu	4658.8	1278.4	27%
Qinghai	542.7	251.7	46%
Ningxia	1107.1	464.6	42%
Anhui	5730.2	3519.8	61%
Xinjiang	4124.6	3721.6	90%
Total	**58612.3**	**33782.7**	**58%**
Total National	**121715.9**		
Ratio of total	**48%**		

Table 7.5. Water resource capacity in Hai River, Huai River and Yellow River basins. Comparison between the three river basins' (Huai, Hai and Yellow) support capacity based on the sum of three rivers' total water resources (based on human's basin water needs is 1700 m³/capita per year) and the actual total population in the three river basins. Source: China Statistical Yearbook 2011, Chapter 3-4 Total population and birth rate, death rate, natural growth rate by region and 12-17 Total water resources.

| Water capacity in Hai River, Huai River and Yellow River basins	
Total water resources, m3	$335.2 \cdot 10^9$
Basic water needs, m3/capita/year	1700
Capacity, number of people	$335 \cdot 10^6$
Total population in the basins	$509 \cdot 10^6$
Overpopulation	52%

7.2 Charts

Chart 7.1 – 7.7. The water quality improvements of the seven major rivers in China during 2003-2010. Historical development (2001-2010) of rivers' water quality in the seven major rivers, Huai River, Hai River, Yellow River, Yangtze River, Pearl River, Liao River and Songhua River. Source: Circle of blue, 2011.
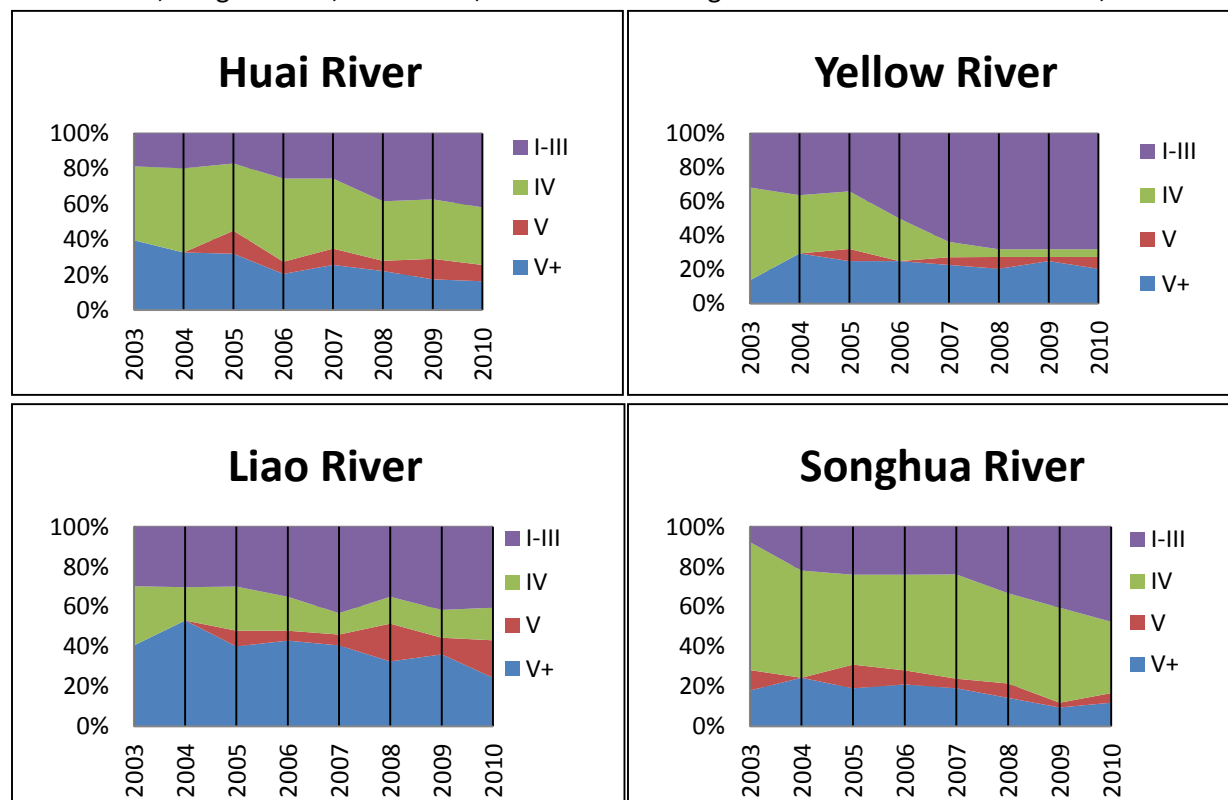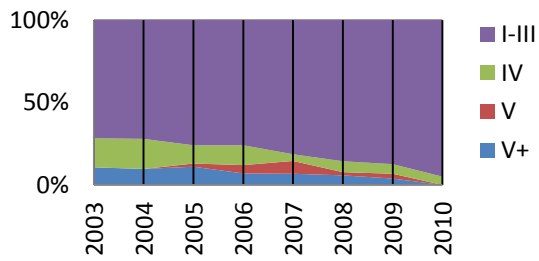
Pearl River
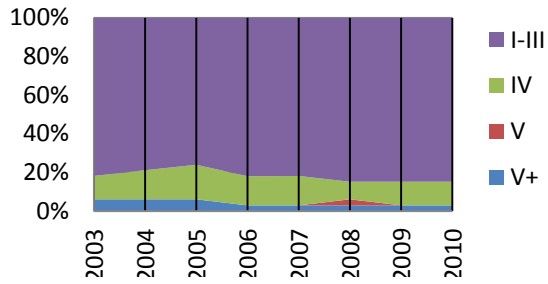
Hai River
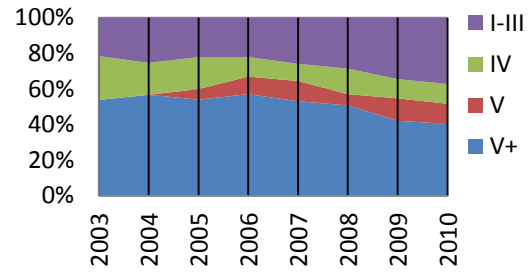
Yangtze River

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