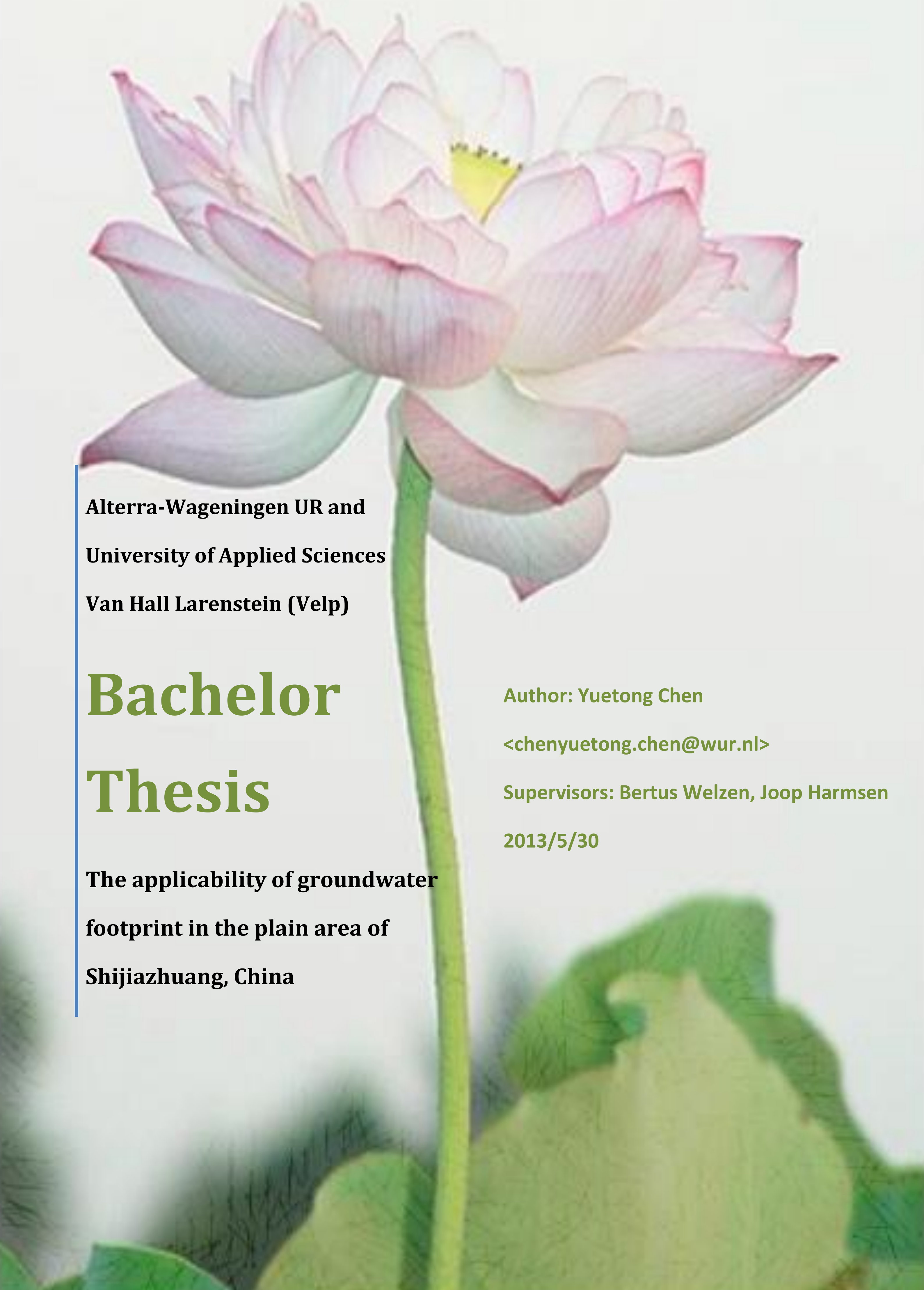

Alterra-Wageningen UR and

University of Applied Sciences

Van Hall Larenstein (Velp)

Bachelor Thesis

The applicability of groundwater footprint in the plain area of Shijiazhuang, China

Author: Yuetong Chen

<chenyuetong.chen@wur.nl>

Supervisors: Bertus Welzen, Joop Harmsen

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Preface

This bachelor thesis is for the University of Applied Sciences Van Hall Larenstein where I received my higher education. I am majoring in International Land and Water Management. For doing this thesis, I worked at Alterra, which is the research institute affiliated to the Wageningen University and Research Center. Alterra contributes to the practical and scientific researches relating to a high quality and sustainable green living environment.

My tutors are Bertus Welzen and Joop Harmsen who have been offering me many thoughtful and significant suggestions all the way and they are quite conscientious. I really appreciate their help. I also want to thank another person for his great help in collecting data necessary for writing this thesis. His name is Mingliang Li who works in the local water bureau in the research area.

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Summary

This study, supported by Alterra, aims to evaluate the applicability of a new concept—groundwater footprint (GF), in a water-deficient area. I selected my hometown, Shijiazhuang, North China, as the study area. The plain area of Shijiazhuang is a representative which is holding a dense population and increasingly suffering from water shortage. The main objectives of this study are to 1) measure the size of the current groundwater footprint in the study area, and 2) to evaluate the effectiveness of possible solutions to diminish the groundwater footprint.

In this study, I quantified GF based on both present situation and future scenario after implementing groundwater-alternating projects. GF is calculated as A[C/(R-E)]. A represents the areal extent of the study area, with the unit of km^2. Furthermore, C demonstrates the annually mean amount of extracted groundwater. R means the amount of groundwater recharge, which is also regarded as the amount of available groundwater in general. E means the amount of groundwater that is used to recharge the surface water to support the surrounding ecological services, especially during the low-flow period. C and E are outflows of the groundwater system in the study area, and R is the inflow. The unit of C, R and E is shown as million m^3 /year. In doing so, an essential step is to set the water balance by simultaneously taking both surface water and groundwater into account. For evaluating GF in the future, it is of great importance to quantify the groundwater that can be saved by implementing groundwater-alternating projects.

By comparing current GF with the areal extent of aquifer (A_A), I found that the former is 1.7 times of the later, which means there is an unsustainable over-extraction of groundwater in the study area at present. After developing and using other water resources to alternate the groundwater, the predicted ratios of GF/ A_A are still larger than 1 in 2015 and 2020. This means that even if some solutions are taken to relieve the pressure of groundwater use, there will still be a vast groundwater extraction in the study area, and this unsustainable situation will not be eliminated in the near future. Therefore, there is a need to develop more effective measures, in order to solve this problem and make groundwater resource sustainable.

1: Introduction

Compared with the southern part of China, the climate in North China is relatively dry. Owing to the fast industrial and economic development in 1980s, the amount of water consumption has rocketed dramatically. Because of the insufficient surface water, the water resource of the mostly consumed water is shallow groundwater, resulting in the ever increasingly serious problem of over-extraction. This problem may cause a decrease in the water table of groundwater, due to the fact that the ground water storage declined gradually in the last three decades. Such unsustainable condition will impact the water security for not only the contemporary generation but also future generations.

The serious groundwater over-extraction is also seen in my hometown—Shijiazhuang, the capital city of Hebei Province (See Figure 1), which is located in the alluvial plain of Hutuo River, China. In the year of 2010, the water table of the plain area of Shijiazhuang was as deep as 20 m or more below ground surface, particularly that of some counties was more than 40 m(Mingliang Li 2010). Worse still, there is a clear decrease trend in water table, compared with the same research period in 2009(Mingliang Li 2010).

Figure 1: The location of Shijiazhuang City in Hebei Province(2013)

Furthermore, it is clear that if people want to judge whether there is a problem of groundwater over-extraction and how serious the problem is, a convincing method is to be needed to make the problem and results visible and comprehensible to the public. Therefore, the method of groundwater footprint is defined as “the area required to sustain groundwater use and groundwater-dependent ecosystem services of a region of interest, such as an aquifer, watershed or community, to assess the impact of our groundwater consumption on natural stocks and flows(Gleeson, Wada et al. 2012)”.

Thus, as to this unsustainable situation in Shijiazhuang, it is important to use this method of groundwater footprint to measure the severity of its groundwater over-extraction and the efficiency of possible attempts to relieve the pressure of such groundwater consumption. People can have a direct insight of whether the solution functions well to solve this problem, based on this method. In this study, the plain area of Shijiazhuang is set as a case to be analyzed.

This research sets its focus upon the measurement of the size of the current groundwater footprint in the research area, and on the evaluation of the effectiveness of possible solutions to diminish the groundwater footprint as well. In this paper, concern and study rest on to what extent the concept of groundwater footprint can be applied in the plain area of Shijiazhuang.
Sub questions are as follows:

1. Are there enough available data to answer the main question of the research focus?
2. What is the result of the current groundwater footprint? Is the groundwater over-extracted in the concerned area?
3. What are the impacts of the existing groundwater over-extraction?
4. What are some possible solutions and subsequent results of groundwater footprint after implementation these solutions?

The main method for this research is to set a water balance to measure the groundwater footprint, by analyzing the status of both surface water and groundwater in the plain area of Shijiazhuang. From the literature review of the article ‘Water Balance of Global Aquifers Revealed by Groundwater Footprint’, the basic method of exerting this research can be defined and established. The current result of groundwater footprint in research area and the effects of solutions can be calculated by using the formula: $GF=A[C/(R-E)]$. Furthermore, the guidance knowledge about water balance setting owes the credit to my external tutor Joop Harmsen. The data needed for analyzing the situation of water resource in the research area are mainly obtained from interviews with staff of the local water bureau, and from their reports kept by the local water authorities. Data acquired from the Internet are used as well.

The structure of this report is as follows. In the second chapter, a brief introduction of the main concept of this study—groundwater footprint is given. In the third chapter, the whole catchment is described, particularly to the Hutuo River catchment and the plain area of Shijiazhuang with necessary introduction in topography, climate and societal-economic situations. Furthermore, a map of the catchment and the research area is also shown in this chapter. In the fourth chapter, an overview of the surface water status in the research area is given by introducing amounts of inflow, outflow and the total surface water resource. In the fifth chapter, the groundwater regime is mainly introduced in the variation of water table, and the amounts of recharging and discharging of groundwater are also presented in this chapter. In the sixth chapter, after setting the water balance, some calculations about the groundwater footprint are exerted to see how serious the problem of over-extraction is in the research area. In the seventh chapter, main impacts caused by groundwater over-extraction are illustrated, such as the groundwater funnel in the urban area of Shijiazhuang. In the eighth chapter, some solutions are demonstrated, which can be of help to supply water from other resources to alternate parts of the groundwater extracted. According to the concept of groundwater footprint, some calculations are also done in this chapter to evaluate the sufficiency and effectiveness of the solutions to relieve the unsustainable groundwater over-extraction. Finally, the conclusion is presented in the last chapter.

2: The concept-- groundwater footprint

Groundwater footprint (GF) is a new concept that mainly focuses on evaluating impacts resulted from groundwater extraction. It is defined as how big the area is for supporting the groundwater consumption and the groundwater-dependent ecological services in a place(Gleeson, Wada et al. 2012). To better express this concept, the following formula is needed, in which C and E are outflows of the groundwater system in the research area, and R is the inflow.

$GF=A[C/(R-E)]$

A: The areal extent of the research area (km^2).
C: The annually mean amount of extracted groundwater. (million m^3/year)
R: The amount of groundwater recharge, which is also regarded as the amount of available groundwater in general. (million m^3/year)
E: The amount of groundwater that is used to recharge the surface water to support the surrounding ecological services, especially during the low-flow period. (million m^3/year)

In addition, it is undeniable that besides quantifying the amount of extracted groundwater, this concept also quantifies amounts of available groundwater and groundwater for supporting ecological services. Therefore, groundwater footprint can be used to evaluate the impacts of groundwater extraction on groundwater reserve and groundwater-dependent ecosystems, by comparing the rate of groundwater extraction with rates of groundwater recharge and supply for ecological services.

What makes the impacts more visible is to compare the figure of groundwater footprint with the figure of aquifer area in the research area (A_A), representing as GF/A_A. If the result of this formula is far greater than one, meaning that the amount of extracted groundwater is unsustainable, and pushes the environment and the water security for the future generations under threat. If the result is smaller than one, meaning that the groundwater water consumption is sustainable. Figure 2 (Gleeson, Wada et al. 2012)presents the value of GF/A_A on world scale. The area of this study is situated in the North China Plain.

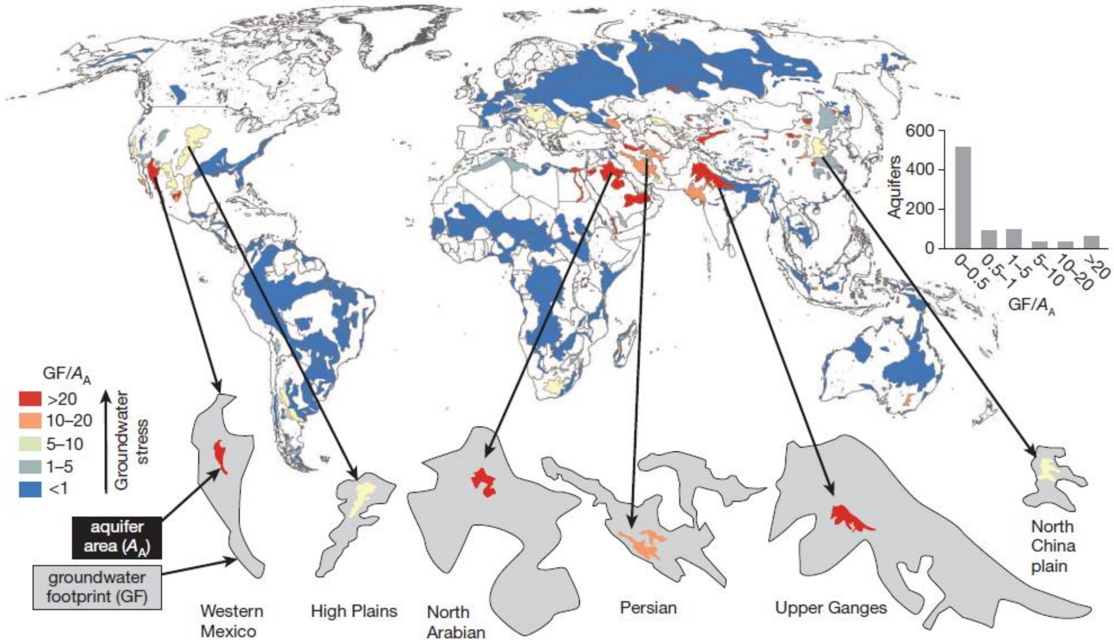


Figure 2: Comparison between the areal extent of some big aquifers in the world and their groundwater footprint (Gleeson, Wada et al. 2012)

The concept of groundwater footprint can be used not only to give a direct impression about how serious the impacts of groundwater extraction are, but also to monitor and evaluate how effective the groundwater-saving subjects are for researchers and engineers.

There is also a shortcoming of this concept. Because this concept only focuses on the quantity of groundwater rather than the quality of it, the result of the groundwater footprint could be smaller than the actual one. This situation mainly occurs when the aquifer is contaminated and the water is not suitable for the intended use.

3: The study area

3.1 Data collection

Data collection for this study was not easy. In China, the situation of collecting data is not like that in the Netherlands. In the Netherlands, the data is relatively complete, systematic and public. However, in China, there are several departments taking charge of different kinds of data, which means that if I want to collect data for a relatively big subject, I need to contact many persons from several departments. The more items to cover in the subject, the less data you can get. Furthermore, because the whole catchment is too extended, few subject covers all the data about the catchment as a whole, meaning that the proper data is not centralized. What makes collecting data more difficult is that the data base is not public in China, so people can hardly find enough data from the internet. The effective and efficient way to get data is to contact with staff working in these departments, if you know them.

At the first, because all data I want were distributed in many departments, I successively contacted many people from many departments through personal relationships. I spent much time in contacting people and waiting for proper data, before I had a relatively complete picture of the situation of my study area. In addition, because drawing the map (See Figure 3) about the research area and the three related catchments needed the professional program and a huge mass of data, it was also difficult to get this map. Thanks one of my friends who worked in the local water bureau for making this map for me, it can be shown in my report.

3.2 The river catchments

In this study, the plain area of Shijiazhuang is the most important area that is set as the research area. One part of Hutuo River which flows through the plain area of Shijiazhuang is the main stream, considerably affecting the groundwater in this area. Hence, situations of plain area of Shijiazhuang and Hutuo River catchment are emphasized in this chapter. The Figure 3 below shows the research area and the whole catchment. The shadowed area represents the part of Hutuo River catchment within the plain area of Shijiazhuang. The place-names in orange are names of the most study-relevant places. A larger version of this map is attached in the Annex.

Apart from the Hutuo River catchment that mainly affects the research area, this area is also influenced by other two river catchments. From the North to the South, these three catchments are the catchment of the Southern Tributaries of Daqing River, Hutuo River catchment and Fuyang River catchment respectively. Only two tributaries of Daqing River flow through the plain area of Shijiazhuang, the Sha River and Ci River. Similarly, there are only two tributaries of Fuyang River that flow through the plain area of Shijiazhuang, the Xiao River and Wu River. Because there are not much available data about the other two river catchments, and these two catchments do not have as much effect as Hutuo River catchment to the research area, only brief introductions of the four relevant rivers are given as follows.

Sha River

Sha River originates from Lingqiu County, Shanxi Province. Before being together with Ci River and turning to the Northeast to the Baiyang Lake, it flows through Fuping County, Quyang County and Xingtang County. In Quyang County, there is a reservoir named Wangkuai established in the main stream of Sha River.

Ci River

Ci River originates from the northwest part of mountain area in Lingshou County.

After running through Xinle County, Wuji County and Shenze County, it flows into Sha River within the boundary of Anguo City. In Lingshou County, there is a reservoir called Hengshanling established in the upper reaches of Ci River.

Xiao River

Xiao River originates from the southern mountain area of Luquan City, running through Luancheng County, Zhao County and Ningjin County. Unfortunately, there is no available data showing where this river stops. This river was the main way of pollution discharge for the urban area of Shijiazhuang, resulting in a seriously contaminated river.

Wu River

Wu River originates from the southwestern part of mountain area in Zanhuang County. After it flows through Gaoyi County and Boxiang County, it finally goes into the Ningjin Lake.

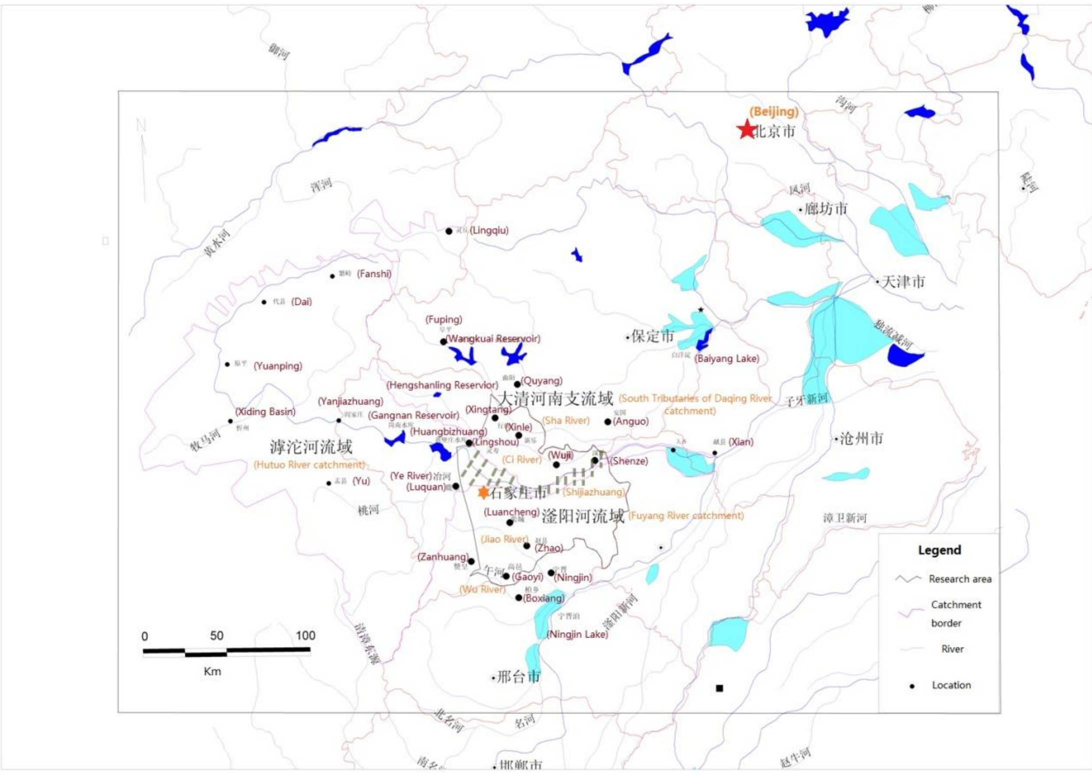


Figure 3: The research area and the different catchments. See also Annex for a larger version. (Li 2013)

3.3 Hutuo River catchment

3.3.1 Topography

The catchment of Hutuo River is the most important one to the research area, which is highlighted in this map (See Figure 3(Li 2013)). Hutuo River originates from the northern piedmont of Wutai Mountain, in a county named Fanshi, in Shanxi Province. Shanxi Province is adjacent to Hebie Province, in which the research area – the plain area of Shijiazhuang City is located, and at the meantime, Shijiazhuang city is also the capital city of Hebei Province. Hutuo River flows through Dai County, Yuanping County and the Xiding Basin, all these three places belonging to Shanxi Province. Furthermore, Hutuo River flows into Hebei Province from a village called Yanjiazhuang in Yu County, which is located in the provincial boundary of Shanxi Province and Hebei Province. After going through the Gangnan Reservoir, the largest branch of Hutuo River, which is called Ye River, flows into Hutuo River from its right-side. Before the Hutuo River running through the research area—the plain area of Shijiazhuang City, it runs through another reservoir named Huangbizhuang. Both of the two reservoirs mentioned above are mainly large water conservancy facilities constructed in the catchment of Hutuo River. Finally, after running through the Xian County where Hutuo River and another large river named Fuyang flow into one, it flows into the sea.

The length of main stream of Hutuo River is 588 km[①], and the areal extent of the whole catchment of Hutuo River is 24,774 km^2 (See Table 1). In Shanxi Province, the Hutuo River catchment is only composed of mountainous area, with the number of 18,992 km^2, occupying around 77% of the catchment as a whole. In Hebei Province, the catchment is composed of two parts: mountainous area and plain. Numbers of the areal extent of these two parts are 4616 km^2 and 1166 km^2, which take up the whole catchment with the proportions of about 18.5% and 4.5% respectively.

Table 1: The areal extent of Hutuo River catchment(Feng, Zhao et al. 2008)

	Hebei Province (km^2)			Shanxi Province (km^2)	In total (km^2)
	Mountain area	Plain area	In total	Mountain area	
Hutuo River Catchment	4616	1166	5782	18992	24774
Proportions of areal extent	18.5%	4.5%	23%	77%	100%

① All data in the chapter 3.3 are obtained from The Flood Prevention Planning Report of Ziya River System. If not, the appropriate reference is given.

From the West to the East, the topography of the catchment is in a terraced slope. The western part of the catchment is consisted of mountain land and basins that located in the eastern edge of Shanxi Plateau. There is a thick deposit layer of loess accumulated on the high topography. Furthermore, the middle part of the catchment is also the mountain land, and the East is in plain. In comparison with the area of the whole catchment, the catchment area that is in mountainous area, mountain land and hills occupies up to almost 95 per cent. Moreover, the total river drop is around 1.8km. From the water source of Hutuo River to Yaochi Lake, the width of river channel of upper reaches fluctuates from hundreds to one thousand, leading to a pretty slow flow velocity. From Yaochi Lake to Gangnan Reservoir, the middle reaches of Hutuo River, the rapid flow velocity results from two reasons. One is the V-shape river valley (See Figure 4) with a width of no more than 200 meters, and another reason is the relatively huge river drop. In addition, from the Huangbizhuang Reservoir, the left part of Hutuo River is called lower reaches, going through the plain. Due to the quite wide riverway (See Figure 5), the flow velocity is extremely slow, resulting in the large amount of silt accumulation. Because the scarcity of natural vegetation in the catchment of Hutuo River, there is also a serious water and soil loss happening.

Figure 4: The V-shape valley of Hutuo River(Li 2013)

Figure 5: The wide riverway of Hutuo River in the plain area(Li 2013)

3.3.2 Climate and hydrology

The catchment of Hutuo River is sited in the warm temperate-continental-monsoon climate zone, being characterized by the long summer and winter, and relatively short spring and autumn. With the rising elevation from the East to the West, the temperature of the whole catchment decreases gradually. The annually mean temperature fluctuates from 11.8℃ to 12.9℃. The mean temperature of July is the highest one among the whole year with the figure of more than 26℃, and the lowest monthly mean temperature shows up in January with the figure of -4℃. Additionally, the frost-free season in this area lasts about 180～220 days. Normally, the frost period starts from the beginning of October, and ends in the mid-April of next year. Because of this meteorological condition, double cropping is exerted in the Hutuo River catchment, as one of the elemental characteristics of the cultivation system in this area. The main crops cultivated there were maize and wheat. The maize would be planted in summer, at the end of June, and be harvested at the beginning of October in the same year. After the harvest of maize, the wheat would be grown in October, and be harvested at the beginning of June in the next year. Then, the next circle starts. This is the meaning of double cropping. This catchment is the major production area of grain and cotton in Hebei Province.

Furthermore, the annually mean precipitation of Hutuo River catchment changes from 400mm to 700mm. The precipitation differs in region. To illustrate, in the mountainous area of Hutuo catchment, the precipitation is 621mm, and that number is 508mm in plain of Hutuo catchment. There is also a considerable difference of precipitation between months, which means that about 80 per cent of precipitation of the whole year concentrates in three months, from July to September. In addition, the annually mean evaporation of this catchment is about 520 mm.

Moreover, the major source that supplies surface runoff in this catchment is precipitation. The mean discharge of surface water in the whole year is about 2,200 million m^3, also differing in region. For instance, the relatively high discharge is produced in the eastern slope of Taihang Mountain. Besides the difference between months, the amount of discharge also changes in years. For example, the figure of discharge in wet year can be 10 times more than that in dry year. In addition, there are 10 large reservoirs established in the whole catchment, and several small reservoirs as well, such as Gangnan Reservoir and Huangbizhuang Reservoir mentioned above.

3.3.3 Societal and economic information

The information of society and economy of Hutuo River catchment are all based on the data in 1997, which is the latest and relatively complete data I found out. Comparing with the extent of the whole Hutuo River catchment, the following figures only represent the condition of part of this catchment, which is within the extent of Hebei Province.

According to the investigation made in 1997 (See Table 2), within the boundary of Hebei Province, the total population of this part of Hutuo River catchment was around 3.6 million, which took up 5.5% of the population in Hebei Province. The land area of this part of catchment, with the number of 5,782km^2, occupied 3% of the total area of Hebei Province. To the area of cultivated land, the number of this part (1,664 km^2) occupied almost 2% of that number of the whole province. Moreover, the total agricultural output value of this part, with the number of 537.5 million€, took up about 3% of this figure in Hebei Province. In the item of total industrial output value, the figure of this part (5,775 million€) took up about 7.6% of that in the whole province.

Table 2: The societal-economic situation of part of the Hutuo River catchment within Hebei Province in 1997(Feng, Zhao et al. 2008) (Exchange rate: 1 €=8 ￥)

	Population (million)	Total area (km^2)	Area of cultivated land (km^2)	Total agricultural output value (million€)	Total industrial output value (million€)
Hutuo River catchment within Hebei Province	3.6	5,782	1,664	537.5	5,775
Hebei Province	65.4	184,960	88,000	16,850	75,825
Percentage	5.5%	3%	2%	3%	7.6%

3.4 Introduction of the plain area of Shijiazhuang

3.4.1 Topography

As the research area, the plain area of Shijiazhuang (See Figure 3(Li 2013)) is located in the inclined plain that is in front of the Taihang Mountains. The alluvial-proluvial fan of Hutuo River acts as the main part of the inclined plain, with the surface slope of 2.5‰~0.5‰(Zhao, Ran et al. 2011). The thickness of sediment is in an increasing trend from the West to the East, with the coarser particles in the upper layer and the finer ones in the lower layer(Feng, Zhang et al. 2012). Additionally, the terrain of the research area is flat, with the elevation changing from 30m② to 100m and the total

② All data in the chapter 3.4 are obtained from The Second Evaluation Report in Water Resource of Shijiazhuang. If not, the appropriate reference is given.

area of 6754.4 km^2.

3.4.2 Climate and hydrology

The plain area of Shijiazhuang is sited in the warm temperate-continental-monsoon climate zone, being characterized by the long summer and winter, and relatively short spring and autumn. Due to effects of the general atmospheric circulation, each season has its own characteristics, such as the dry and windy spring, the blazing and rainy summer, the sunny and pleasantly cool autumn and the chill winter having little snow.

The annually mean temperature of the plain area of Shijiazhuang is about 13.5℃. The annually mean precipitation of the research area is around 481mm. Precipitation in wet years is around 608 mm. That figure in normal years is 452mm and in relatively dry years is 358mm. They show in different frequencies. Furthermore, the annual precipitation distributes unevenly in seasons (See Figure 6), which means that the precipitation distributes intensively in the flood season. For instance, the mean precipitation in spring (from March to May) occupies 17% of the annually mean precipitation. In the flood season (from June to September), also being regarded as the rain season, 77% of the annually mean precipitation is concentrated in these four months. Then, the mean precipitation in winter, from October to February, only takes up approximately 6% of the annually mean precipitation. The figure of precipitation also differs in years. Normally, the figure of mean precipitation in high-flow years is two-fold of that figure in dry years. The variation of mean precipitation in each decade from 1950s to 1990s is demonstrated in the Table 3.

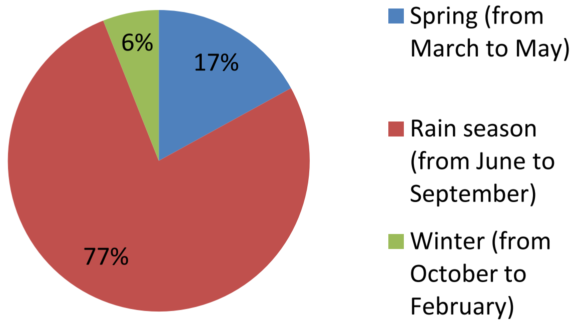


Figure 6: The distribution of annually mean precipitation in one year(Liu, Zhu et al. 2011)

Table 3: The variation of mean precipitation in each decade from 1950s to 1990s(Liu, Zhu et al. 2011)

	1950s	1960s	1970s	1980s	1990s
Mean precipitation	528mm	507mm	470mm	436mm	479mm

From this table, it is clear that figures of precipitation in 1950s and 1960s were relatively high, varying from 507mm to 528mm. Nevertheless, the 1980s witnessed a relatively dry climate in the research area, with the mean precipitation of 436mm, which was much lower than the annually mean precipitation in the plain area of Shijiazhuang (481mm). In sum, the climate became increasingly dry in these decades, and there was a decline trend in precipitation in this research area.

Furthermore, in the plain area of Shijiazhuang, the annual evaporation from water surface is about 1100mm, and the annual land evaporation is around 480mm. What is called land evaporation is the total amount of evaporation and transpiration from the water body within the urban district, soil and vegetation. The annual distribution of water-surface evaporation can be affected by many factors, such as the temperature of each month, humidity, and wind velocity. To illustrate, in this area, it is windy, dry and hot in the early summer, and the rain season normally starts from the end of June. Therefore, comparing to figures of water-surface evaporation of other months, that figure of the two months (May and June) is the highest among one year, taking up almost one third of the evaporation of the whole year. In contrast, the temperature of January and February is the lowest among one year. Hence, in comparison with figures of the water-surface evaporation of other months, that figure of these two months is also the lowest, occupying only 5% of the evaporation of the whole year. In summer, when it is during the rain season, the precipitation could be more than the evaporation, which means there will be an amount of water infiltrating into the ground to recharge the groundwater. On the contrary, in other seasons, when the evaporation is very high and the precipitation is quite low, there will be hardly any remaining water that can infiltrate to the ground.

Moreover, the shallow pore water aquifer is the major water-rich rock stratum in the plain area of Shijiazhuang, which is also the water-containing rock series being exploited and extracted currently.

3.4.3 Societal and economic information

Table 4: The societal and economic information of research area in 2010(Liu, Zhu et al. 2011) (Exchange rate: 1 €=8 ￥)

	Total population (thousands people)	GDP in total (million €)	GDP per person (€)	Cultivated area (km^2)	Total area (km^2)
The plain area of Shijiazhuang	7,463	9,514	1,275	4,220	6,754.4

From this table (See Table 4), it is undeniable that the majority of the plain area of Shijiazhuang was used for agriculture, from which the total areal extent of the research area was taken up almost 62% by the cultivated land. The main crops cultivated there were maize and wheat. The maize would be planted in summer, at the end of June, and be harvested at the beginning of October in the same year. After the harvest of maize, the wheat would be grown in October, and be harvested at the beginning of June in the next year. Then, the next circle starts. In addition, in the year of 2010, the total population of the research area was 7,463 thousands people. In the research area, the figure of gross domestic product in total and that figure in per person were 9,514 million€ and 1,275€ respectively.

4: The status of surface water resource

4.1 Inflow

In this report, the inflow is defined as the amount of surface water flowing from the outside into the plain area of Shijiazhuang, through rivers. In the research area, the long-time mean inflow is about 1200 million m^3[③], of which almost 59% is occupied by the amount of inflow of Hutuo River, with the number of 700 million m^3.

According to the statistic data about the mean inflow changing in decades (See Figure 7), the total reduction of inflow can be divided in two steps. Firstly, before 1980s, the number of inflow diminished from almost 2170 million m^3 in 1950s to about 1630 million m^3 in 1960s, and declined to about 1210 million m^3 in 1970s afterwards. Compared with the last decade for both 1960s and 1970s, the mean inflow decreased by 25% and 26% respectively. Secondly, after 1980s, due to the increasing trend of the exploitation and utilization of the surface water in upper reaches, there was a downward trend in inflow from the beginning of 1980s. In comparison with the figure of inflow in 1970s (1210 million m^3), that figure in 1980s was only 840 million m^3, decreased by 31%. In addition, the figure of inflow in 1990s was almost the same as that figure in the last decade, with the number of approximately 840 million m^3.

To sum up, the total reduction of inflow during these years was 1330 million m^3, meaning that there was a downward trend in inflow, with the decrease rate of approximately 1.5% per year. The reduction of inflow was mainly caused by two factors. Firstly, because the development in upper reaches of rivers, the surface water consumption went up. Next, because the climate became drier in general, in upper reaches, the precipitation that recharged the surface water also descended. Therefore, there was less surface water flowing into the research area from the upper reaches.

[③] All data in the chapter 4 are obtained from The Second Evaluation Report in Water Resource of Shijiazhuang. If not, the appropriate reference is given.

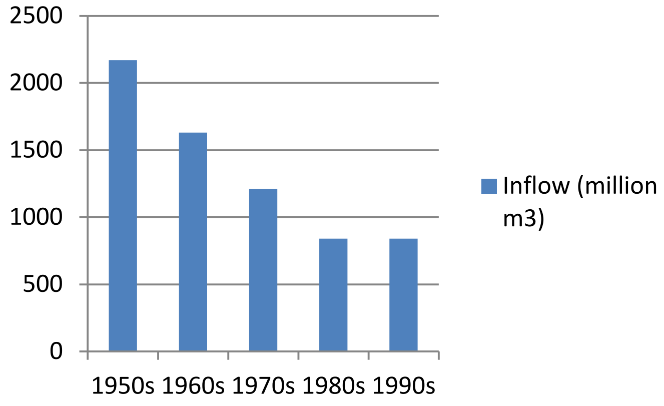


Figure 7: The mean inflow in different decades in the research area(Liu, Zhu et al. 2011)

4.2 Outflow

The outflow is defined as the amount of surface water that flows outside through rivers from the plain area of Shijiazhuang. The amount of long-time mean outflow is about 901 million m^3 in the plain area of Shijiazhuang. The mean outflow of Hutuo River is around 746 million m^3, occupying about 83% of the total outflow of the research area. Nevertheless, this figure of Hutuo River considerably differs in both months and years, mainly due to the adjustment through Huangbizhuang Reservoir. For instance, the highest figure of the annual outflow of Hutuo River is up to 666 times as much as the lowest figure of that.

There was also a dramatic decrease in outflow from 1950s to 1990s, which can be divided into two steps. On the first step, before 1960s, the number of outflow was almost 2920 million m^3 in 1950s.From 1960s to 1970s, that figure declined from 1820 million m^3 to about 740 million m^3. Compared with the last decade for both 1960s and 1970s, the mean outflow decreased by 38% and 59% respectively. On the second step, resulting from the increasing reduction in the inflow, there was also a continuing decline in outflow in 1980s, from 740 million m^3 in 1970s to 220 million m^3 in 1980s. The difference between them occupied up to 70% of that figure in 1970s. Additionally, in 1990s, the annual outflow was about 110 million m^3, reduced by 50% comparing with that figure in the last decade. The variation of mean outflow in different decades is clearly shown in the following figure (See Figure 8).

In summary, the total decrease of outflow in these years was 2810 million m^3, meaning that there was also a downward trend in outflow, with the reduction rate of approximately 2% per year. The reduction in outflow was resulted from three main factors. The first two reasons were similar to the factors affecting the inflow, such as the increasing surface water consumption in this area and the decreasing precipitation that can recharge surface water here. The third reason of the decline in outflow was the decreasing inflow. In fact, this area suffered from a dry period of precipitation, which means the climate was relatively dry and the precipitation was inadequate to form the runoff in rivers. In recent decades, there was little water in rivers in most of time. When the precipitation was not intensive, the rainwater would infiltrate into the ground immediately. The amount of outflow was mostly generated by some intensive rainfalls happening in the rain season, in which the rainwater was quickly discharged from rivers. Hence, it is obvious that the surface water resource is insufficient to be consumed in the research area.

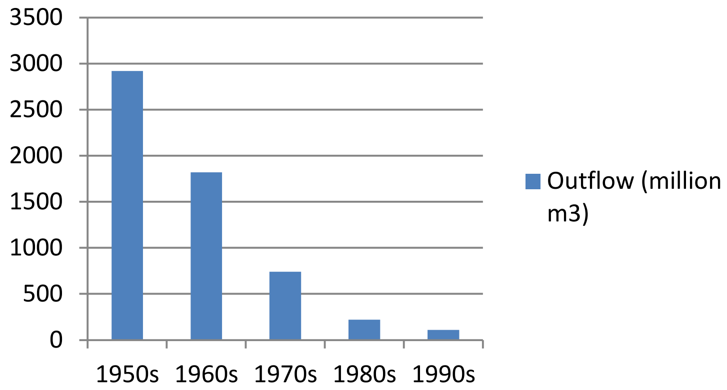


Figure 8: The mean outflow in different decades in the research area (Liu, Zhu et al. 2011)

4.3 Quantity of surface water resource

There is a lack of surface water resource in the plain area of Shijiazhuang, in which the value of precipitation is also quite low. In the research area, the long-time annually mean quantity of surface water resource is 47 million m^3. If we divide this figure by the areal extent of the research area, the annual runoff-depth can be derived, with the number of 7mm. In the plain area of Shijiazhuang, mean quantities of surface water resource in wet years, normal years and dry years are 73 million m^3, 12 million m^3 and 0 million m^3 respectively(See Table 5). The appearance frequencies of these kinds of years are different.

Table 5: The quantity of surface water resource in the plain area of Shijiazhuang(Liu, Zhu et al. 2011)

	Areal extent (km^2)	The long-time annually mean quantity		The mean quantity in wet years (million m^3)	The mean quantity in normal years (million m^3)	The mean quantity in dry years (million m^3)
		(mm)	(million m^3)			
The research area	6754.4	7	47	73	12	0

In addition, the mean quantity of surface water resource in the research area also changes in decades (See Figure 9). Figures of quantity of surface water resource in both 1950s and 1960s were higher than the average one in long time, with 52 million

m^3 and 59 million m^3 respectively. Furthermore, the 1990s witnessed a raise in the quantity of surface water resources, with the number of 54 million m^3. Before this raise, it went down from 59 million m^3 in 1960s to 39 million m^3 in 1970s, and then to 29 million m^3 in 1980s. Therefore, only in 1970s and 1980s, figures of quantity of surface water resource were fewer than the average figure in long time.

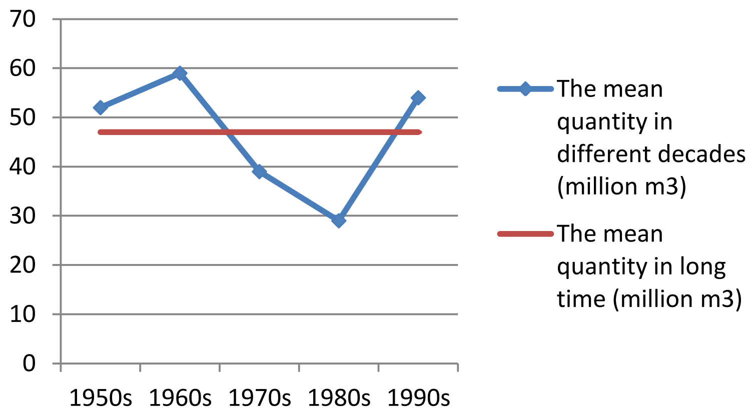


Figure 9: The comparison between the long-time annually mean quantity and mean quantities in different decades in surface water resource(Liu, Zhu et al. 2011)

4.4 Characteristics of surface runoff

The monthly distribution of the amount of surface runoff is mainly affected by the precipitation varying in months, meaning that they have the similar characteristics in distribution. In the plain area of Shijiazhuang, the total production of surface runoff of rivers is mostly contributed by several rainstorms during the rain season, from June to September.

Additionally, the amount of surface runoff in the plain area of Shijiazhuang also changes in years. Because the water table declines considerably, the unsaturated zone becomes increasingly thicker, which causes a growing amount of infiltration. Hence, only in years when the amount of precipitation is pretty large or the precipitation happens quite intensive, it is possible to generate the surface runoff. Therefore, due to these situations, it is hard to use the surface water resource.

5: The status of groundwater

In the plain area of Shijiazhuang, with the industry and agriculture developing greatly, the water demand increases swiftly. In these days, the level of surface water exploiting and utilizing is quite high, in which there is little potential to be exploited more. Hence, the water consumption of industry and agriculture mainly relies on groundwater.

The aquifer in the plain area of Shijiazhuang mostly consists of sandy loam soil, sand and gravel-cobble. Because of its bad water-resisting property, coarse-particle lithology and the relatively huge pores, it is good for the groundwater flow. Without man-made influence, the flow direction of groundwater is consistent with the slope of the topography of this area. The characteristics of hydrodynamic force in this area are phreatic water and micro-confined groundwater.

5.1 Groundwater regime

In the plain area of Shijiazhuang, the shallow groundwater is the main water resource for water consumption of industry and agriculture. The shallow groundwater is defined as the phreatic water that has direct relationships of recharging and discharging with local precipitation and surface water body, and also has the free water table. Furthermore, the micro-confined groundwater, which has the close hydraulic connection with the local phreatic water, also belongs to the shallow groundwater.

The main elements influencing recharging and discharging of groundwater are infiltration and extraction. Therefore, the regional over-extraction in recent years and the dry climate are main reasons resulting in the constant decline in water table.

5.1.1 Regulation of water table changing within the year

The variation of water table within the year is influenced by recharging from precipitation and seasonal extraction. Generally, there are two steps of increase and decrease in water table every year. Because there is no extraction of groundwater in the beginning of the year, the water table rises stably, peaking at in March. With the spring irrigation starting, the large amount of groundwater extraction causes a drop in water table, touching the bottom in almost June. After June, the rain season comes, and due to getting recharged from precipitation and the pause in groundwater extraction, the water table starts climbing.

5.1.2 Interannual variation of water table

From the beginning of 1980s to the end of 1990s, with the economy developing rapidly, the amount of extracted groundwater increased year by year. In additional, due to the dry climate in recent years, the serious scarcity of recharging resulted in an enormous and continuous reduce in water table. At the beginning of 1980s, the depth of water table in the plain area of Shijiazhuang was about 10m[4], decreasing to about 26m in the year of 2000 (See Figure10). During these two decades, the rate of

[4] All data in the chapter 5 are obtained from The Second Evaluation Report in Water Resource of Shijiazhuang. If not, the appropriate reference is given.

descend every year was about 0.8m. However, according to different rates of descent, the total two decades was divided into two stages. On the first stage, from 1980 to 1995, the mean rate of descend of water table was almost 0.9m in each year. On the second stage, from 1996 to 2000, there was a slight decrease in the rate of descent of water table, with the number of around 0.7m in each year.

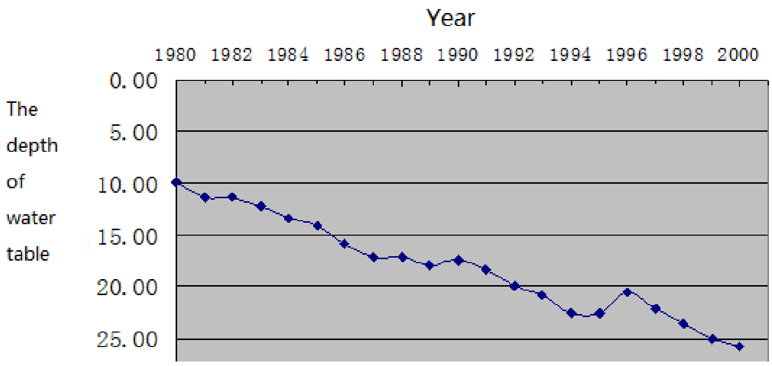


Figure 10: The variation in the depth of water table from 1980 to 2000 in the plain area of Shijiazhuang (excluding the urban district of Shijiazhuang)(Liu, Zhu et al. 2011)

5.2 Amount of water recharging to the groundwater

Water sources recharging the groundwater in the plain area of Shijiazhuang include rainfall infiltration, the lateral runoff from mountain area, infiltration from surface water body, infiltration from pollution discharging and the leakage water during well irrigation. To the amount of infiltration from surface water body, it can still be divided into several parts based on their different sources, containing the infiltration from reservoirs, infiltration from river courses, infiltration from canal system and from fields. The total amount of water recharging the groundwater consists of water from all of these sources. Figures about amounts of water sources recharging groundwater are as follows. They only represent mean numbers during the period from 1980 to 2000.

5.2.1 Amount of rainfall infiltration

The amount of rainfall infiltration means the amount of rainfall that recharges the groundwater through infiltration under the effect of gravity. The mean figure of it in the plain area of Shijiazhuang from 1980 to 2000 was 567 million m^3.

In general, the following measurement is used to calculate the amount of rainfall infiltration. Firstly, we multiply the amount of rainfall (with unit of mm) by the areal extent of the research area (with unit of km^2). Thus, the volume of rainfall (with unit of m^3) is derived. Then, we can derive the amount of rainfall infiltration (with unit of m^3) from multiplying the volume of rainfall by a coefficient varying from 0.08 to 0.25, which is based on the long-time experimental data exerted by the local water bureau.

The rest of rainfall that cannot infiltrate to the ground is evaporated and used by vegetation. This coefficient is mainly related to three factors, including the precipitation, the depth of water table and the lithology of the unsaturated zone.

5.2.2 Amount of lateral runoff from mountain area

The amount of lateral runoff from mountain area is defined as the amount of underground-runoff that comes from the mountain area to recharge the shallow groundwater in the plain area (See Figure 11). The mean figure of it in the plain area of Shijiazhuang from 1980 to 2000 was 342 million m^3.

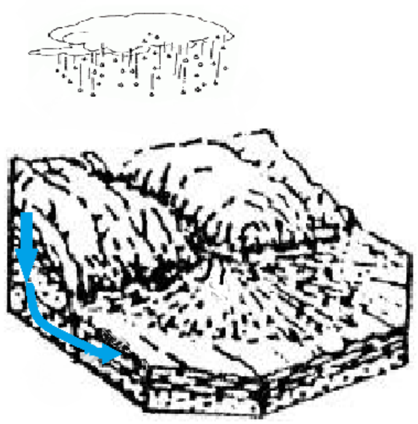


Figure 11: The lateral runoff from mountain area

5.2.3 Amount of infiltration from river courses

In the plain area of Shijiazhuang, the amount of runoff in rivers mainly recharges the groundwater. Before 1970s, there was tons of water flowing through the Hutuo River, which is located in the north part of the plain area in Shijiahzuang. It was a significant water source recharging the groundwater in research area. However, after two reservoirs named Gangnan and Huangbizhuang built up, the amount of runoff in lower reaches reduced obviously. Especially from the year of 1980, the river course almost dried up in general, so this amount of water for groundwater recharging was decreased dramatically. The mean figure of it in the plain area of Shijiazhuang from 1980 to 2000 was 120 million m^3.

5.2.4 Amount of infiltration from canal system

The amount of infiltration from canal system, recharging the groundwater in the research area, takes only main canals and lateral canals into consideration (See Figure 12). The mean figure of it in the plain area of Shijiazhuang from 1980 to 2000 was 52 million m^3.

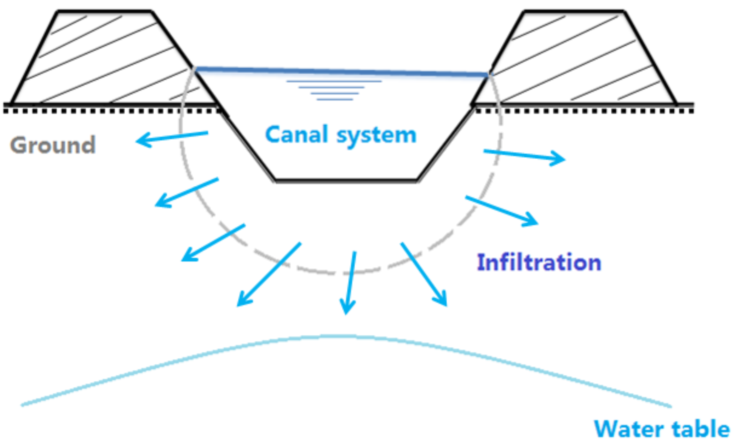


Figure 12: The profile showing the infiltration from canals in different levels

5.2.5 Amount of infiltration from fields

The water infiltrating from fields to the aquifer means the water that infiltrates from distribution canals and canals in lower levels (See also Figure 12). The mean figure of it in the plain area of Shijiazhuang from 1980 to 2000 was 11 million m^3.

It is clear that this figure is the smallest one among all these groundwater-recharging items, because farmers try to limit this amount of infiltration. Farmers want more water for irrigation rather than letting the water infiltrate into the ground, so the amount of infiltration from fields is relatively small.

5.2.6 Amount of infiltration from pollution discharging

In previous time, the main function of Xiao River, one of the rivers located in the plain area of Shijiazhuang, was to discharge the sewage from households and factories in the urban area of Shijiazhuang. In the plain area of Shijiazhuang between 1980 and 2000, the average amount of water infiltrated to the underground during pollution discharging was 75 million m^3.

5.2.7 Amount of leakage water during well irrigation

Leakage water means the infiltrated water from canals for well water conveyance. In the plain area of Shijiazhuang from 1980 to 2000, the average amount of leakage water during well irrigation was 143 million m^3.

5.2.8 Amount of infiltration from reservoirs

The Huangbizhuang Reservoir is located in where the plain area is bounded on the mountain area of Hutuo River catchment. Thanks to the anti-seepage maintenance and reinforce for this reservoir, lasting many years, the amount of infiltrated water from this reservoir has reduced considerably. Additionally, this amount of recharging water has been included into the amount of lateral runoff from mountain area. Therefore, it is not double-counted here.

5.2.9 The sum of amounts of recharging water in the plain area of Shijiazhuang

In the plain area of Shijiazhuang, according to mean figures of each water source during the period from 1980 to 2000, the total amount of recharging water was 1310 million m^3 (See Table 6 and Figure 13). It is obvious that the most significant water source for recharging groundwater was rainfall infiltration, which took up about 43% of the total amount, with the number of 567 million m^3. Furthermore, figures of lateral runoff and infiltration from surface water body also occupied relatively high percentages of the total amount of recharging water, with figures of 342 million m^3 (26%) and 182 million m^3 (14%) respectively. These three sources for recharging groundwater occupied almost 83% of the total amount. Apart from these, the amount of leakage water from well irrigation occupied about 11% of the total amount, with the number of 143 million m^3. Moreover, the amount of infiltration from pollution discharging took up approximately 6% of the total amount, with the number of 75 million m^3.

Table 6: Sources for recharging water (Liu, Zhu et al. 2011)

Sources	Rainfall infiltration	Lateral runoff from mountain area	Infiltration from pollution discharging	The leakage water during well irrigation
Quantity (million m^3)	567	342	75	143
Sources	Infiltration from surface water body			
	Infiltration from river courses	Infiltration from canal system	Infiltration from fields	Summary
Quantity (million m^3)	120	52	11	183
The total quantity (million m^3)	1310			

5.3 The amount of groundwater discharge

In the plain area of Shijiazhuang, before there was a growing number of the groundwater extraction by humans, main ways for groundwater discharge were lateral outflow, evaporation and little amount of extraction for industrial, agricultural and domestic use. Subsequently, because the intensity of groundwater extraction promoted significantly, the main way of groundwater discharge changed to artificial extraction.

The total amount of groundwater discharge in the research area includes amounts of extracted shallow groundwater, lateral outflow, transfluence and evaporation.

5.3.1 Amount of extracted shallow groundwater

Spanning from 1980 to 2000, the average amount of extracted shallow groundwater in the plain area of Shijiazhuang was 2290 million m^3.

5.3.2 Amount of lateral outflow

The amount of lateral outflow is defined as the amount of groundwater that flows outside from the research area as the undercurrent. In this area, this figure was 0 m^3 from 1980 to 2000.

5.3.3 Amount of transfluence

When the head of shallow groundwater is higher than that of deep confined water, due to the hydraulic power, the shallow groundwater will go through the aquitard to the deep water. This amount of water can be seen as the amount of discharged groundwater called transfluence. The difference between the head of shallow groundwater and that of deep confined water is not evident, so this amount of groundwater discharge can be ignored when calculating.

5.3.4 Amount of groundwater evaporation

From the year of 1980, the buried depth of groundwater in the plain area of Shijiazhuang declined from 10m to about 26m in the year of 2000 (See Figure 10). Therefore, the water table had already too deep to make it possible for groundwater evaporation. The figure of this item was 0 m^3 from 1980 to 2000.

5.3.5 The sum of amounts of groundwater discharge in the plain area of Shijiazhuang

Because of the huge amount of extracted groundwater, other ways of groundwater discharge can be ignored. Hence, the total amount of groundwater discharge can be regarded as the average amount of extracted shallow groundwater, which was 2290 million m^3 during the period from 1980 to 2000.

6: Groundwater footprint in the plain area of Shijiazhuang

6.1 Water balance

It is mentioned in the last chapter that, from 1980 to 2000, the annually total amount of recharging water was 1310 million m^3. There are seven resources that recharge the groundwater, including rainfall infiltration, lateral runoff, river infiltration, field infiltration, canals infiltration, leakage water during well irrigation and infiltration from pollution discharging. Additionally, during this period, the annually total amount of groundwater discharge almost equals to the average amount of extracted shallow groundwater, which was 2290 million m^3. Some part of the extracted groundwater is consumed, but some part of it will go back to recharge the groundwater, through leakage and infiltration from artificial constructions. The later part is called the internal input of groundwater. The external input of groundwater is from the nature rather than the extracted groundwater. The water balance is shown in the Figure 13, and figures of groundwater recharging and discharging items are also present in this figure.

Furthermore, the amount of available groundwater means the maximal amount of groundwater that can be extracted from the aquifer, meeting conditions of finance economical, technique feasible and environment friendly. To the plain area of Shijiazhuang, the amount of available groundwater equals to the total amount of water for recharging groundwater. Therefore, the average amount of available groundwater from 1980 to 2000 was 1310 million m^3.

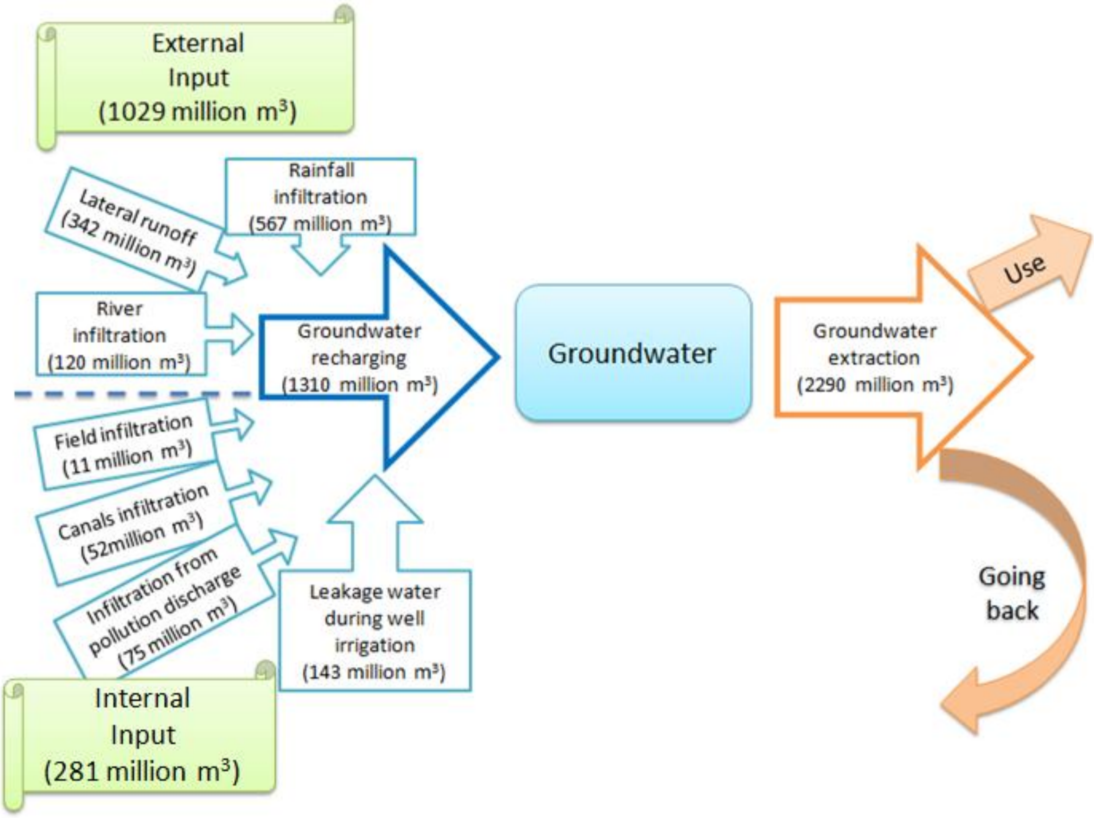


Figure 13: Recharge and discharge of groundwater in the research area

6.2 Current results of groundwater footprint

It is mentioned above that the formula of groundwater footprint is as follows: GF=A[C/(R-E)]. A defines as the areal extent of the research area. C means the amount of groundwater extraction. R and E define as the amount of available groundwater and the amount of groundwater consumed by the environment respectively. In current situation, there is no groundwater used for supporting the environment, so the figure of E is 0. Thus, the formula of groundwater footprint can be simplified to GF=A(C/R). Because in the research area, the areal extents of both the aquifer and the land are the same, the figure of land area (A) in this formula can be also regarded as the figure of the aquifer area (A_A). According to this formula, another formula (GF/ A_A =C/R) can be derived from the mathematical conversion.

It is already known that the annually mean figure of groundwater extraction during the period from 1980 to 2000 was 2290 million m^3, and the annually mean figure of available groundwater during this period was 1310 million m^3. Because there is no available data shown that figures in the recent decade, in this case, we use the annually mean figures from 1980 to 2000 to illustrate the current situation. Hence, the ratio of GF/ A_A equals the ratio of C/R, with the number of almost 1.7. According to the instruction of groundwater footprint, if this ratio is more than 1, it means that the groundwater in the research area is over-extracted and the situation is unsustainable. Fortunately, this ratio (with the figure of 1.7) is not far more than 1, meaning that though there is a water scarcity and the situation is indeed unsustainable, the situation in the research area is not quite dangerous. However, this unsustainable situation will do result in some impacts, which threats our development and cannot be ignored. To achieve the sustainability in the plain area of Shijiazhuang, there are some methods needed to be taken to improve the current situation of water supply and to solve the problems caused by groundwater over-extraction.

7: Impacts of groundwater over-extraction

7.1 Funnel area

In the plain area of Shijiazhuang, the continuous and excessive exploiting of groundwater results in a continuous decrease in the water table. It also causes a series of problems, such as a great number of abandoned wells, land subsidence and groundwater funnel (See Figure 14). In this area, the last problem listed is the most crucial one.

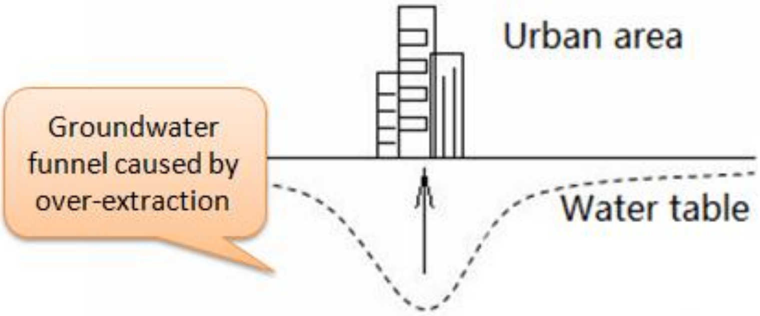


Figure 14: The groundwater funnel

In the urban area of Shijiazhuang, there is a serious shallow-groundwater funnel, located in the main shaft of the alluvial-proluvial fan of Hutuo River. In the funnel area, the depth of bottom of the first aquifer is no more than 27m underground(Zhang 2003). However, from the year of 1984, the depth of water table of the funnel center was more than 28m underground, meaning that the first aquifer in this area had been drained up (Zhang 2003).Therefore, the second aquifer in this area is mainly extracted currently, which has a close hydraulic connection with the first one, and the groundwater in this aquifer is in a good quality. The depth of bottom of the second aquifer varies from 60m to 120m underground(Zhang 2003). The second aquifer consists of medium sand, medium-coarse sand and sand gravel, and its hydraulic characteristic is determined as phreatic water.

Furthermore, the groundwater resource in the funnel area is mainly recharged by rainfall infiltration and lateral runoff from mountain area, and the main way for groundwater discharge is artificial extraction. In the funnel area, the variation of water table has the similar regulation to that in the plain area of Shijiazhuang as a whole, peaking at in the end of February and reaching the bottom in the end of June, because both of them are mostly influenced by rainfall infiltration and artificial extraction. Additionally, in the funnel area, the groundwater flows from surroundings to the center of groundwater funnel.

The northern boundary of the funnel area is consistent near to the watercourse of Hutuo River in these years, because the funnel area is affected by the runoff in Hutuo River. For instance, in 1996, the areal extent of this groundwater funnel shrank to a great degree, because the watercourse of Hutuo River was used to drain flood, meaning that a great amount of water flowed through Hutuo River intensively. In the funnel area, the part of watercourse of Hutuo River is sandy, so it is suitable for water to infiltrate.

7.2 The development of the groundwater funnel

In the urban area of Shijiazhuang, the formation of the shallow groundwater funnel initially started in 1965(See Figure 15(Li, Wu et al. 2007)). The depth of water table of the funnel center was approximately 7.6m underground in June of 1965, and the area of the funnel was 58 km^2. From 1965 to 1975, the water table in the central funnel reduced by about 7.7m, and the funnel area increased by 129 km^2. Next, from 1975 to 1985, the water table in the funnel center declined by almost 16m, accompanied by a rise in the area of funnel with the difference of 72 km^2. During the following decade, from 1985 to 1995, the water table of funnel center decreased by about 12m, and the area expanded by 112 km^2. However, from 1995 to 2000, the mean figure of depth of water table in the central funnel increased by about 1.2m, comparing with the figure of depth of water table in funnel center in 1994. During this 35years from 1965 to 2000, the total decrease of the depth of water table in the funnel center was 34.7 m, and the total expansion of the funnel area was 282 km^2.

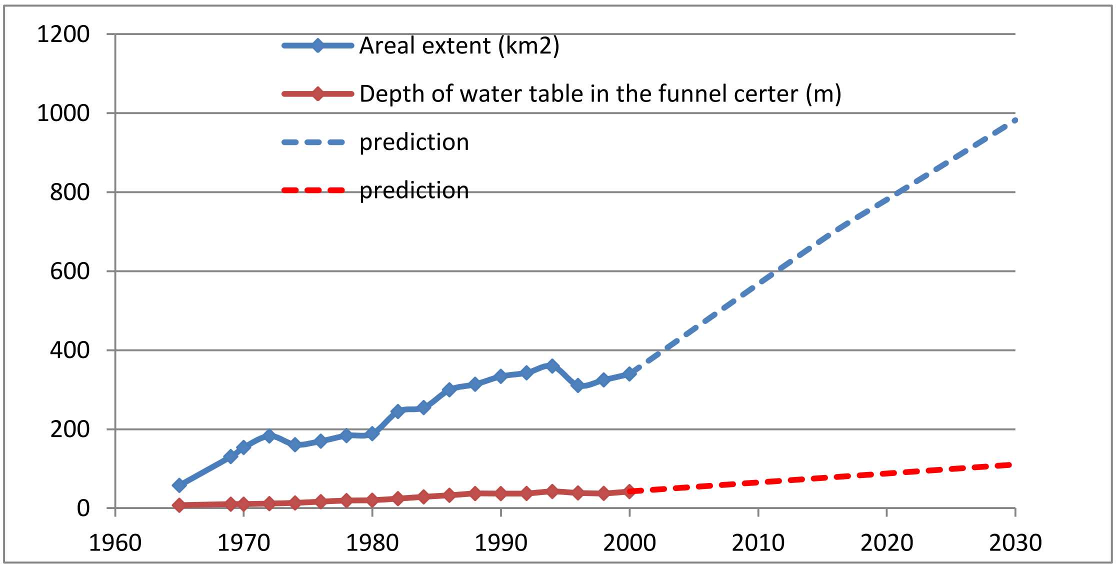
According to its development processes, it is clear that before the year of 1975, the decrease rate of water table in funnel center was relatively small, with the figure around 0.77m per year, and the expand rate of funnel area was quite fast, with the figure of 12.9 km^2 per year. Speeds of both water table of funnel center decreasing and funnel area expanding became faster from 1975, with figures of about 1.6m per year and 7.2 km^2 per year respectively. From 1985 to 1995, speeds of both water table of funnel center decreasing and funnel area expanding were still fast, , with figures of about 1.2m per year and 11.2 km^2 per year respectively. Until 2000, there was a slight increase in the water table of funnel center, and the expanding rate of the funnel area also became slower. This enhancement was owed to some preventative measures taken by the local government, such as closing part of wells, and transferring surface water from other places to local area to complement the drinking water resource.

7.3 Prediction of the development of groundwater funnel

Because of the increasing amount of extracted groundwater in surrounding places, the amount of lateral recharge for this groundwater funnel has leveled off, with the number of about 390 million m^3 per year(Liu, Lian et al. 2004). Furthermore, with the urban area of Shijiazhuang developing, there is also a growing demand of groundwater. Therefore, if the conditions of groundwater recharge and extraction remain unchanged, it is assumed that the problem of groundwater funnel in Shijiazhuang will become more seriously.

It is assumed that in the year of 2015, the depth of water table of funnel center will be 76m underground, and the funnel area will be 680 km^2. Additionally, the depth of water table of funnel center will climb at the rate of about 2.3m per year, and the funnel area will expand at the rate of almost 20.2 km^2 per year. Until the year of 2030, the funnel area will go up to 982 km^2, and the depth of water table of funnel center will be almost 110m underground, meaning that it will reach the bottom of the second aquifer in 2030 (See Figure 15(Liu, Lian et al. 2004)). This is only a warning assumption, so results of it can be a direction of groundwater management, rather than the actual situation of the development of the groundwater funnel.

Figure 15: The development and prediction about the depth of water table in funnel center, and about the funnel area(Liu, Lian et al. 2004) (Li, Wu et al. 2007)



8: Solutions of groundwater over-extraction

8.1 Prediction of water demand

It is apparent that the continuous groundwater over-extraction in recent decades severely affects the environment, and also significantly restrains the societal-economic development in the plain area of Shijiazhuang. What helps this predicament is to exploiting and using other alternative water resources to partly replace the amount of groundwater extraction.

There are several other water resources developed to alternate the groundwater, such as the water transferred by the South-to-North Water Diversion Project, reclaimed water, surface water and brackish water. Among these resources, what takes the priority for water consumption is the water transferred by the South-to-North Water Diversion Project. Meanwhile, it is also greatly encouraged to use the reclaimed water. Then the surface water and brackish water are used. Groundwater is extracted to compensate for the remaining amount of water supply.

In the plain area of Shijiazhuang, due to the fact that the majority of these groundwater-alternating projects have not come into service until the year of 2015⑤, in this case, we only exert some predictions in water demand and consumption from 2015.

In this chapter, because those groundwater-alternating resources will be used to meet the water demand, if we use the amount of water demand minus the amount of supplied water by other resources, we can get the amount of groundwater that will be extracted after implementing those groundwater-alternating projects. In order to do this, the first thing is to know the amount of water demand. With the economy developing in the plain area of Shijiazhuang, there is a growing trend in water demand. According to the prediction, the amount of water demand in the year of 2015 will be 2663 million m^3, and that figure in the year of 2020 will be 2718 million m^3.

⑤ All data of chapter 8 are from The Investigation and Extraction-reducing Target of Groundwater in the Intake Area of the South-to-North Water Diversion Project in Hebei Province. If not, the appropriate reference is given.

8.2 Amount of water supplied by other water resources

8.2.1 Water transferred by the South-to-North Water Diversion Project

There is a surplus of surface water resource in the South of China. On the contrary, in the northern part of China, the climate is dry and the water resource is scarce. The serious scarcity of water in the North severely restrains the economic development and even threatens the public security. Therefore, the aim of South-to-North Water Diversion Project is to transfer the surplus water resource from the South to the North.

The main work of this project consists of three water-transferring routes. These three routes transfer water from the upper reaches, middle reaches and lower reaches of the Yangtze River respectively, going across four rivers besides the Yangtze River, such as the Yellow River, the Huai River and the Hai River (See Figure 16). The flow direction of these three water-transferring routes is from the South to the North, and that of four rivers is from the West to the East. Hebei Province in which the research area is located in benefits from the route that starts from the middle reaches of the Yangtze River. It is planned that from 2014, the main canal of this route will be coming into service and will be used to transfer water from the southern part of China.

The main object of this project is to relieve the water shortage in urban area. Water transferred by this project will be used for industrial and domestic consumption in urban area. Resulting from this, the surface water that was previously occupied by the urban development will be replaced, so that it can be used for agriculture in the rural area in the immediate future. Thus, part of the groundwater used to support agriculture will be replaced, and the amount of extracted groundwater will decrease. In the plain area of Shijiazhuang, after taking the amount of water loss into account, the amount of transferred water that can be actually used will amount to 526 million m^3 in 2015, and that figure in 2020 will be 672 million m^3.

Figure 16: Four related rivers and three main routes of the South-to-North Water Diversion Project(2013)

8.2.2 The surface water previously consumed by urban area

After the urban use of the water transferred by the South-to-North Water Diversion Project, the amount of surface water used to support the urban development will be returned to agriculture in rural area. Then, because this amount of surface water will be used for agriculture, the same amount of groundwater previously consumed by agriculture can be saved. Thus, the amount of surface water returned from urban area equals to the amount of groundwater that can be saved, with figures of 153 million m^3 in 2015 and 147million m^3 in 2020. The 'surface water' mentioned in this chapter, which will be returned from urban area, is only regarded as a groundwater-alternating resource. It has no relationship with 'the surface water resource' mentioned in previous chapters.

8.2.3 Reclaimed water

The reclaimed water means the water treated and discharged from the water treatment plant. It is treated according to a lower level, so that it cannot meet the drinking water standard, but still can be used for industry and irrigation. It is a kind of water resource that can alternate the extracted groundwater, and it cannot be regarded as the waste water. In the plain area of Shijiazhuang, the reclaimed water is mainly used for both urban ecologic development and agricultural irrigation. Except for the amount of reclaimed water being used for cooling in industry, urban landscaping, sanitation and recharging the surface water bodies, the amount of reclaimed water that can be used for agriculture to replace groundwater will be 157 million m^3 in 2015 and 207 million m^3 in 2020.

8.2.4 Brackish water

The brackish water will be used for irrigation by mixing the saline water with the fresh water. In the research area, the amount of groundwater that can be alternated will be 5 million m^3 in both 2015 and 2020.

8.2.5 Total amount of water supplied by other water resources

After adding all amounts of groundwater-alternating resources, it is clearly shown that in the year of 2015, the total amount of these water resources will be 841 million m^3, and this figure will increase to 1031 million m^3 in the year of 2020 (See Table 7). These figures also demonstrate the amount of groundwater that can be saved by consuming other water resources.

Table 7: The total amount of water supplied by other water resources in the research area(Tian, Deng et al. 2011)

	The amount of water supply (million m^3)				
	Water transferred by the South-to-North Water Diversion Project	Local surface water	Reclaimed water	Brackish water	In total
In 2015	526	153	157	5	841
In 2020	672	147	207	5	1031

8.3 Complement by groundwater

At least from the year of 2015, other water resources mentioned above will be used initially to support the water demand in the plain area of Shijiazhuang. It is really true that only this amount of water will not be enough. Hence, the remaining amount of demanded water will be supplied by extracting groundwater. In 2015, the amount of extracted groundwater will be 1822 million m^3. With the amount of water that can be supplied by other resources increasing, there will be a decline in the amount of groundwater extraction, with the number of 1687 million m^3 in the year of 2020 (See Table 8).

Although, the use of other groundwater-alternating resources will relieve some constrains, in comparison with the mean amount of groundwater extraction during the period from 1980 to 2000, with the number of 2290 million m^3. It is undoubted that the amount of extracted groundwater will be still huge in the future seven years, and problems that caused by groundwater over-extraction will not be solved immediately. There is still a water shortage in the plain area in Shijiazhuang, so the groundwater consumption will still be quite huge. At least before the year of 2020, the amount of water that can be supplied by other water resources is not sufficient to achieve the groundwater sustainability in this area.

Table 8: The amount of groundwater extraction in 2015 and 2020 in the research area(Tian, Deng et al. 2011)

	Water demand - Water supply by other resources = The amount of groundwater extraction （ million m^3 ）		
	Water demand	Water supply by other resources	The amount of groundwater extraction
In 2015	2663	841	1822
In 2020	2718	1031	1687

8.4 Result of groundwater footprint in 2015 and 2020

In this prediction, we use the same formula GF/ A_A =C/R as converted in the previous chapter. We assume that the conditions of groundwater recharge in the plain area of Shijiazhuang have not changed during these years, so in this chapter, we also use the annually mean figure of available groundwater (R) from 1980 to 2000 to calculate, with the figure of 1310 million m^3 . In addition, the expected amounts of groundwater extraction in the year of 2015 and 2020 are 1822 million m^3 and 1687 million m^3 respectively. Hence, the ratio of GF/ A_A can be derived, with the figure of around 1.4 and 1.3 in 2015 and 2020 respectively (See Table 9). It is shown that though some solutions are taken to reduce the amount of groundwater extraction and to relieve problems caused by groundwater over-extraction, in the research area, there is still an unsustainable water shortage and more improvements needed to be taken to achieve the sustainability.

Table 9: The result of groundwater footprint in 2015 and 2020

	The amount of groundwater extraction (C) （ million m^3 ）	The amount of available groundwater (R) （ million m^3 ）	The ratio of GF/ A_A =the ratio of C/R	Results
In 2015	1822	1310	1.4	Over-extraction and not sufficient to achieve sustainability
In 2020	1687	1310	1.3	Over-extraction and not sufficient to achieve sustainability

9: Conclusion

To sum up, after doing this study, we find that this concept of groundwater footprint is almost totally applicable in the plain area of Shijiazhuang. Because the needed data are hold by government and not public in China, though it took much time to collect data, the necessary data of this study are all available.

Under the current situation, the ratio of GF/ A_A is almost 1.7, which means the area of groundwater footprint is 1.7 times of the area of actual aquifer. Because this ratio is more than 1, it is sure that the groundwater is over-extracted in the research area and the situation is unsustainable.

Though it is not yet extremely dangerous at least so far, people need to be aware of it, because this groundwater over-extraction can bring some impacts and threaten our water security and development. For instance, due to the continuous and intensive groundwater extraction in the urban area of Shijiazhuang, a groundwater funnel generated and developed at a high speed. During this 35years from 1965 to 2000, the total decrease of the depth of water table in the funnel center was 34.7 m, and the total expansion of the funnel area was 282 km^2. If no control were taken, the situation would only deteriorate. According to a warning prediction, until the year of 2030, the funnel area will go up to 982 km^2, and the depth of water table of funnel center will be almost 110m underground, meaning that it will reach the bottom of the second aquifer in 2030. This means if no attention is paid and nothing is done to the groundwater over-extraction, the impact of groundwater over-extraction will become more serious, and this unsustainable situation will threaten our life.

To achieve the groundwater sustainability in the plain area of Shijiazhuang, there are some other water resources developed to alternate the used groundwater, such as the water transferred by the South-to-North Water Diversion Project, reclaimed water, surface water and brackish water. It is expected that the ratio of GF/ A_A will be around 1.4 and 1.3 in 2015 and 2020 respectively, both of which are smaller than this figure of the current status, but still greater than 1. This means that although there may be some solutions to lessening the pressure of groundwater consumption, there will be still a vast groundwater extraction, and the groundwater footprint will not decline much in recent years. Hence, in order to make the groundwater situation become sustainable as soon as possible, people need to develop more measures to solve this problem.

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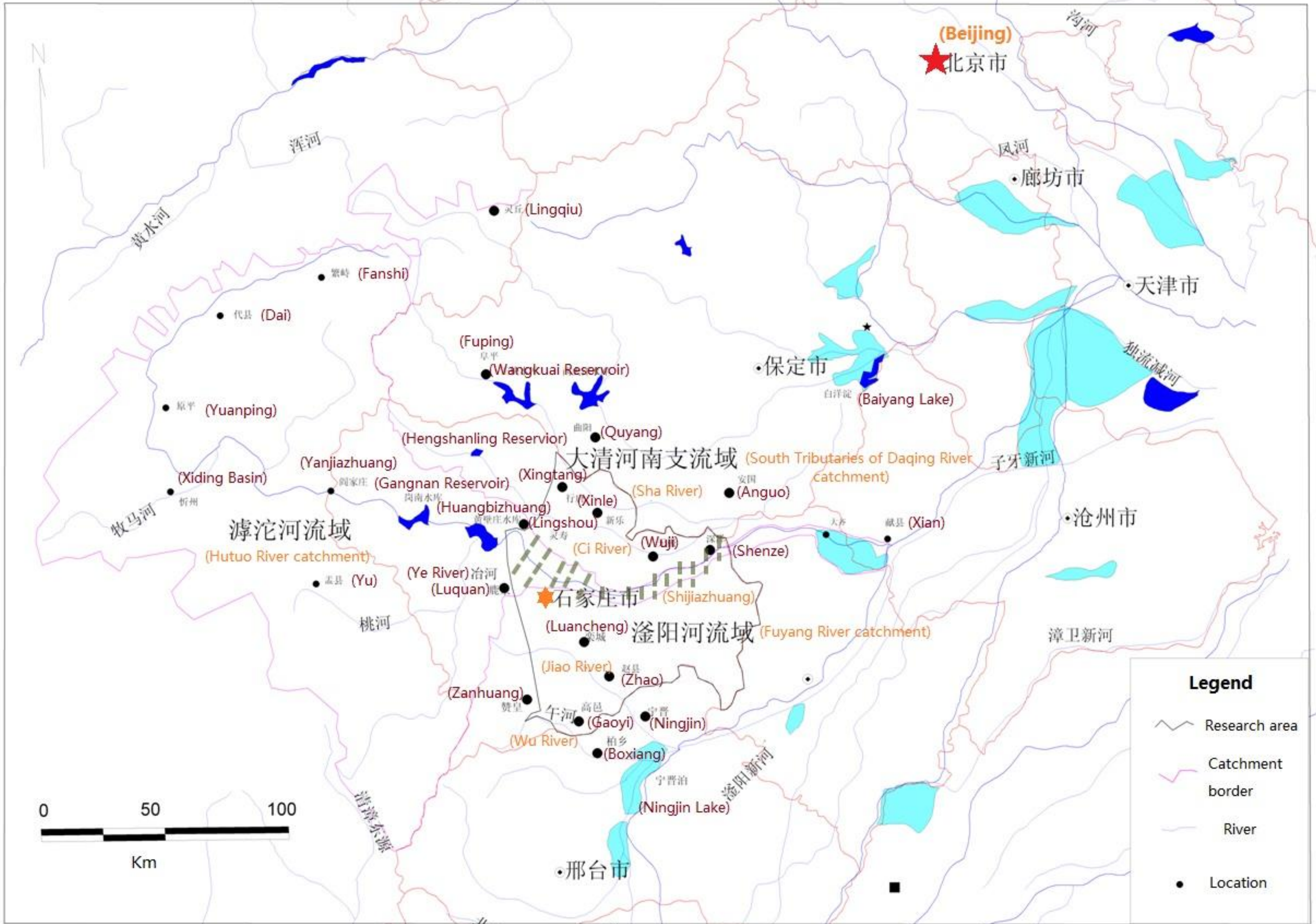
Annex



(Beijing)
北京市
廊坊市
天津市
保定市
(Lingqiu)
(Fanshi)
(Dai)
(Fuping)
(Wangkuai Reservoir)
(Yuanping)
(Baiyang Lake)
(Hengshanling Reservior)
(Quyang)
大清河南支流域
(South Tributaries of Daqing River catchment)
(Yanjiazhuang)
(Xiding Basin)
(Gangnan Reservoir)
(Xingtang)
(Sha River)
(Anguo)
(Xinle)
(Huangbizhuang)
(Lingshou)
(Xian)
沧州市
滹沱河流域
(Hutuo River catchment)
(Ci River)
(Wuji)
(Shenze)
(Yu)
(Ye River)冶河
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石家庄市
(Shijiazhuang)
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滏阳河流域
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(Zhao)
(Zanhuang)
(Gaoyi)
(Ningjin)
(Wu River)
(Boxiang)
(Ningjin Lake)
邢台市
子牙新河
独流减河
漳卫新河
滏阳新河
浑河
黄水河
牧马河
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Legend
Research area
Catchment border
River
Location