Transboundary Aquifers in Asia With Special Emphasis to China

United Nations
Educational, Scientific and
Cultural Organization

October 2006

Contents

Foreword……………………………………………………………………3
Preface 4
1 UNESCO in the management of transboundary aquifers 5
2 Groundwater Resources and Transboundary aquifers in Asia 6
2.1 Geography...6
2.2 Characters of Aquifers and Groundwater Resources 8
2.3 Problems of Groundwater in Asia 12
2.4 Transboundary aquifers in Asia 16
2.5 Challenges for Hydrogeologists...19
3 Groundwater Resources and Transboundary aquifers of China 20
3.1 Geography and Water Resources 20
3.2 Characters of Aquifers and Groundwater Resources 22
3.3. Issues in Groundwater Development...23
3.4 International Transboundary Aquifers of China..................................25
3.5 Pilot study of Provinces Transboundary Aquifers in China..................29
4 Case study - Transboundary Aquifer between China and Russia 31
4.1 Geography and Hydrology of Middle Heilongjiang-Amur river Basin..31
4.2 Hydrogeological Conditions 35
4.3 Groundwater Resources...37
4.4 Groundwater Quality...38
4.5 Groundwater Usage 40
4.6 Cooperation between China and Russian Federation 41

By
Prof. Han Zaisheng[1, 2], Mr. Wang Hao[2], Miss Chai Rui [2]
[1]China Geological Survey, [2]China University of Geosciences

Associated with
Dr. R. Jayakumar[3], Mr. Liu Ke[3], Ms. Wang Jin[3]
Natural Sciences Sector
UNESCO Office Beijing

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Foreword

Approximately 40 per cent of the world's population lives in river basins and aquifer systems that cross the political boundaries of two or more countries. Transboundary aquifers, as transboundary rivers, are another important component of global water resource system. World's largest aquifers contain substantial amount of water, including the Rum-Saq, the Nubian, and the North Sahara Aquifer. The aquifers, apart from its environmental function as vital natural resources, are also endowed with crucial social function, constituting solution for preventing conflicts on water in regions such as the Mid-East.

Nevertheless, through the mid-1980s and late 1990s, issues concerning the management of transboundary aquifers were hardly in the forefront of scientific and political discussions. Transboundary aquifers thus received scant attention from policymakers. Moreover, existing international conventions and agreements barely address aquifers and their resources, and there are neither global policies nor appropriate legal instruments to govern this natural resource.

To remedy the deficiency, the International Association of Hydrogeologists (IAH) established a commission on Transboundary Aquifer Resource Management (TARM) to promote their study and joint international cooperation. The initiative of IAH coincided with the Commencement of the UNESCO International Hydrological Program (IHP), which after joint efforts with Food and Agriculture Organization (FAO) and the United Nations Economic Commission for Europe (UN ECE) gives rise to the framework document of ISARM (Internationally Shared Aquifer Resource Management).

With the goal of promoting sound use of transboundary aquifers, ISARM has led to several regional initiatives, including ISARM-Americas Programme, ISARM-Europe Programme, and ISARM-Balkans. Moreover, studies financed through GEF (Global Environmental Facilities) have also commenced in Africa and the Caribbean. The report on "Transboundary Aquifers in Asia With Special Emphasis to China" represents the advance of research on transboundary aquifers in the Asia-Pacific region, where research in this terms, comparatively, is in need of further promotion. More importantly, through this report, UNESCO, as major coordinator of ISARM, is expecting to promote awareness on transboundary aquifers as vital natural resources, especially among the policymakers, and also to enhance collaboration of countries with shared aquifers on management of such resources in a sustainable manner.

Dr. Yasuyuki Aoshima

Director and Representative
UNESCO Office Beijing

Preface

Transboundary Aquifers， as an important part of global groundwater resource system, are important for building a society where all civilizations coexist harmoniously and accommodate each other. The UNESCO's Intergovernmental Programme for the "International Hydrological Programme IHP-VI activities work out the International Shared Aquifer Resource Management (ISARM). The Transboundary Aquifers would be summarized and demarcated. Countries with shared groundwarer resources would be encouraged to set up further cooperation. The sustainable usage of transboundary aquifers would be thus promoted. The pilot case study on “Transboundary Aquifers in Asia with special emphasis to China” is with in the frame work. It is jointly undertaken to implement within close cooperation between relevant ministries, departments and commissions responsible for development and management of groundwater water and transboundary issues. The authors coordinate, supervise and develop regional preliminary data on selected shared aquifers in Asia and develop a pilot case with Heilongjiang-Amur River of China and Russian Federation under ISARM-Asia. The study includes topics of Groundwater Resources and Transboundary Aquifers in Asia, Groundwater Resources and Transboundary Aquifers in China, Case Study - The aquifers of the Heilongjiang-Amur River basin.
The purpose of the pilot case study is to contribute to the ISRAM-Asia as first contribution and to promote the ISRAM-Asia Network headed by China.

Acknowledgement

Special thanks to Dr. Alice Aureli and Dr. R. Jayakumar of UNESCO who offer kind advices and support to this studies. Appreciation would also send to Mr. Liu Ke and, Ms. Wang Jin UNESCO Office Beijing, for their contributions.

Dr. Han Zaisheng

China Geological Survey

1 UNESCO in the management of transboundary aquifers

Transboundary aquifers have long been recognized. However, their significance and function in environmental and human development have not received due attention. In an effort to remedy the gap, UNESCO, through its IHP programme, (International Hydrological Programme), carries out the ISARM initiative, jointly with IAH (International Association of Hydrogeologists) and other international agencies.

The success of the International Hydrological Decade (1965-1974), which aimed to find solutions to the specific water resources problems of countries with different geographical conditions at different levels of technical and economic development, led to the founding of the International Hydrological Programme (IHP) in 1975. Realizing that water resources are often one of the primary factors limiting harmonious development in many regions and countries of the world, governments and the international scientific community saw the need for an internationally coordinated scientific programme focusing on water. The first three phases of the Programme (IHP-I: 1975-1980; IHP-II: 1981-1983; IHP-III: 1984-1989) implemented over 70 projects of scientific and practical interest, guided by a number of international conferences.

Specifically, the 5th phase of IHP (1996—2001) was set to stimulate a stronger interrelation between scientific research, application and education, and identified groundwater and arid and semi-arid zone hydrology as priority areas. The emphasis was on environmentally sound integrated water resources management and planning, supported by a scientifically proven methodology within its overall theme. Its results continue to influence research and practice. The 5th phase of IHP also coincides with the TARM (Transboundary Aquifer Resource Management) initiative developed by IAH. On the 14th Session of the Inter Governmental Council of UNESCO, in 2000, joint activities were approved between TARM and UNESCO. In addition, these activities had also been carried out through cooperation with the Food and Agriculture Organization (FAO) and the United Nations Economic Commission for Europe (UN ECE). Such interagency action was defined in a framework document of ISARM (Internationally Shared Aquifer Resource Management).

Since its inception in 2000, ISARM, through collaboration of multiple agencies, has developed several regional initiatives, including ISARM-Americas Programme, the ISARM-Europe Programme and ISARM—Balkans programme, In addition, studies financed through the Global Environmental Facility (GEF) have also commenced in Africa and the Caribbean. Efforts made under the ISARM framework also led to the draft Convention of the Use of Transboundary Aquifers advanced by the International Law Commissions.

Moreover, the initiative of transboundary aquifers management was further developed within the IHP programme of UNESCO. In the 6th phase of IHP (2002 to 2007) entitled “System at Risk and Social Challenges”, five themes were developed, among which theme 2 is particularly devoted to Integrated Watershed and Aquifer Dynamics. The rationale behind such development is “The basin scale is appropriate for comparing water resources and water use or demand. It is the natural scale for hydrogeolgical process but it is also a relevant approach for landscape and land use mapping because of the topographically-driven organization of the watershed. The evaluation of water resources at the basin scale needs to combine data from various sources. However, the problem is more complicated for the water demand which is often evaluated at administrative scales. Mechanisms that govern water demand are not well outlined and relevant parameters are yet to be suggested”. Taking note of the rationale of this focal area, and recognizing the wider value of transboundary aquifers, UNESCO’s Scientific Panel concluded that a major international initiative was justified. As a result, a resolution, adopted on the 14th session of the Inter Governmental Council of UNESCO IHP, was adopted by a vote of 143 countries, which authorizes UNESCO IHP’s component on ISARM.

2 Groundwater Resources and Transboundary aquifers in Asia

2.1 Geography

Asia is located in the east hemisphere. Fig.1-1 The east, north, south and west of Asia border on the Pacific Ocean, Arctic Ocean, Indian Ocean and Mediterranean Sea respectively. The area is 44 million square kilometer. The population of Asia is 3.5 billion. It is the largest continent both in area and population in the world. There are 48 countries and regions in Asia. Geographically, it could be divided into East Asia, Southeast Asia, South Asia, West Asia, Central Asia and North Asia . Countries with a population of more than 100 million are China, India, Indonesia, Japan, Bangladesh and Pakistan. The length of coastal line of Asia is 69900 km. There are many islands and peninsulas. Kalimantan is the third largest island in the world. The characteristics of topography Asia are the big gurgitation of earth’s surface, high in the central and low around, alternate with apophysis and depressed. The mountains, highlands and hills count for three fourths of the total area. Another one fourth is plain whose area is 10 million square kilometers. Pamirs as the epicenter, series of mountains eradiate and extend to the fringe of continent. The Qinghai-Tibet altiplano whose average altitude is 4500 m is named as fastigium of the world. Everest, as the highest mountain in the world, is wit an altitude of 8844.43 m. The plains are situated in the outboard of mountains and tableland. These are North China plain, Northeast China plain,

Middle and lower reaches of Yangtze River plain, Hindustan river plain, Ganges river plain, Mesopotamia plain and west Siberian Plain, etc. The Dead Sea is the lowest depression in the world with altitude 400 m under sea level.
There are many rivers in Asia. Most of those are sources from central mountains and radial flow to every direction. The major rivers flows into Pacific Ocean are Heilongjiang-Amur River, Yellow River, Yangtze River, Pearl River and Mekong River etc. The major rivers flows into Indian Ocean are Indian River, Ganges River, Salween River, Ayeyarwady River, Tigris River and Euphrates River etc. The major rivers flows into Arctic Ocean are Ob River, Yenisei River, and Lena River etc. The inland Rivers are situated in central and west arid area of Asia. The majors are Sill River, Amu River, Ili River, Talimu River and Jordan River etc. The lakes in Asia are not in a large number compared to other continent. They could be posteriori to 5 groups, North Asia, Central Asia, West Asia, Qinghai-Tibet tableland and Middle-lowest Yangtze River. Some lakes are famous for their peculiar characteristics . The Caspian is the biggest salt lake in the world. Lake Baikal is the deepest lake in the world and biggest fresh lake in Asia. The Dead Lake is the lowest depression. Lake Balkhash is an inland lake with both fresh water and salt water.

The three climate zones are frigid zone, temperate zone and torrid zone which across the continent of Asia. The climatic types are various and complex. The Southeast Asia, South Asia and southeast part of East Asia are in the humid monsoon torrid zone. Central Asia, West Asia and the inland part of East Asia are in the arid zone. The area between both zones and the most part of north Asia are in the semi humid semiarid zone. Precipitations are various in different areas in Asia. The main direction of rainfall is descending from the humid southeast to the northwest part. There are abound rain fall near the equator zone. The annual rainfall is more than 2000 mm. There are rainless all over the year in the southwest and central Asia. The precipitation is less than 150 mm in a large area.

Fig. 1-1 Map of Asia

2.2 Characters of Aquifers and Groundwater Resources

Groundwater resources in Asia are various. Some regions are underlined by aquifers extending over large areas, while the floodplain alluvial deposits usually accompanying the largest rivers. The sedimentary rocks, especially Quaternary loose sediments are very thick with good storage space. The deep fissure water is relatively abundant in confined aquifers. In mountainous regions, groundwater generally occurs in complexes of joint hard rocks. There is small rainfall and strong evaporation in inland arid area of central Asia. However the thawing of glaciers and snow from high mountains is favorable to recharge groundwater. The loess plateau in central Asia has specific topography. Continuous aquifers are only distributed in loess tableland. The carbonate rocks are widely distributed in Southeast Asia. In south China and Indochina peninsula, there are stratified limestone of late Paleozoic and Mesozoic in which karst is considerable developed. The reef karst could be found in coastal island. A lot of Quaternary volcanic rock is extensively distributed on the circum-Pacific islands, which forms asymmetrical rings aquifers. The piedmonts of volcanoes mostly occurs spring water with good water quality.

Groundwater resources assessments have been taken in most countries of Asia. Evaluation and mapping of Groundwater recharge and runoff of individual basins and regions are in progress. The hydrogeological survey on a medium scale has performed regional quantitative assessment of natural groundwater resources in most countries of Asia. Groundwater runoff is an important component of the hydrological cycle. Local hydrogeological conditions of different regions left effects on the distribution of groundwater runoff/precipitation ratios. Those ratios are less than 10% in the arid area in central Asia, and more than 40% in the karstic area in Southeast Asia. Groundwater monitoring networks have operated at national, regional and local levels in some parts of Asia. Groundwater levels constitute the most observed parameter, continuous water quality and natural groundwater discharge and abstraction networks are operational in urban area. However groundwater assessment, monitoring, and data management activities are operated regularly in China, India, Japan, Korea, and Thailand etc. But it is taken for less time in other Asian developing Countries.

UNESCO has presented an overview of the available water resources and population of Asian countries as Table 1-1. (Middle East exclusion) The total Groundwater recharge inside of Asia is 2500 km^3/year.

The development of groundwater has been increased in the passed 30 years. The degree of groundwater development is shown in Fig.1-2. The ratio of groundwater abstraction with mean recharge is upon the country. There are more areas where groundwater is over-abstraction upon the province in a country. In some arid region of Asian countries, where sufficient renewable groundwater resources are not available, non-renewable groundwater is being exploited to support development, such as the coastal area of north China plain.

Groundwater is crucial for human drinking and food security, especially in the developing countries. The impact of groundwater use is positive and included benefits such as increased productivity, food security, job creation, livelihood diversification and general economic and social improvement. In the long run, the impact of groundwater extraction might be negative especially in overexploitation situation, such as permanent lowing of the water table, deterioration of water quality, saline intrusion in coastal area, etc. The social and economic dimensions of groundwater use as well as its benefits are important for the development in Asia. Some of these benefits are linked to the inherent characteristics of groundwater as resources. For instance, most aquifers provide large natural storage space and help stabilize water supply during peak drought seasons. The sluggish flow of groundwater through small void helps purify water used as drinking water. Almost ubiquitous availability of groundwater makes it as resources easy to access. In areas with extensive aquifers endowed with good permeability and storage properties, groundwater exploitation could increase recharge and also decrease flood intensity. Groundwater irrigation has also ensured security and helps alleviate poverty.

For example, in India, the population increased quickly in the last 20 years, and it has a burgeoning grain reserve of over 60 million tons and annual grain production touched a record high 0f 210 million tons in 2002-2003. Similarly, Bangladesh, dependent on foreign aid for a long time, emerged as food sufficient in 1999-2000, all related to groundwater irrigation. That groundwater irrigation, especially in water abundant area such as eastern part of India, Bangladesh and Nepal can be an effective way to alleviate poverty.

Since the 1970s, groundwater extraction has increased greatly in China, India, Republic of Korea and some other countries in South Asia. For example, In India, large groundwater irrigated areas witnessed a spectacular increase from around 11.9 million hectare in 1970-1971 to 33.1 million hectare in 1998-1999, an increase of over 178%. The number of groundwater extraction mechanism rose from less than 1million in 1960 to almost 26-28 million in 2002. In Pakistan Punjab, the number of mechanized wells and tube wells increased from barely a few Thousand in 1960 to 500 thousands in 2000. Bangladesh saw an increase in the number of tube wells, from 93000 in 1982-83 to almost 800000 in 1999-2000. The groundwater extraction in China is 111 km^3 in the end of last century. Those are 57 km^3 in 1970s and 75km^3 in 1980s, which doubled in the last 30years. It is estimated that there are 3500 thousands tube wells for agricultures, withdrawing 68 km^3 of water in 1999, constituting 61% of the total groundwater withdrawing. But it has decreased since 1980s when the groundwater for agriculture usage is 88% of the total. In North china plain, groundwater irrigation has supported the development of agriculture in the passed 30 years.

Table 1-1 Water availability per person per year of Asian countries

Country		Water Resources						Population	
0		1	2	3	4	5	6	7	8
18	Laos	190.42	37.9	190.42	37.9	333.55	63,184	5,279	23
26	Bhutan	95	–	95	–	95	45,564	2,085	44
30	Cambodia	120.57	17.6	115.97	13	476.11	36,333	13,104	74
37	Malaysia	580	64	566	50	580	26,105	22,218	68
38	Brunei Darussalam	8.5	0.1	8.5	0.1	8.5	25,915	328	62
44	Myanmar	880.6	156	874.6	150	1,045.60	21,898	47,749	73
56	Mongolia	34.8	6.1	32.7	4	34.8	13,739	2,533	2
58	Indonesia	2,838.00	455	2,793.00	410	2,838.00	13,381	212,092	117
62	Viet Nam	366.5	48	353.5	35	891.21	11,406	78,137	240
74	Nepal	198.2	20	198.2	20	210.2	9,122	23,043	161
76	Bangladesh	105	21.09	83.91	0	1,210.64	8,809	137,439	1,056
83	Kazakhstan	75.42	6.1	69.32	0	109.61	6,778	16,172	6
85	Thailand	210	41.9	198.79	30.69	409.94	6,527	62,806	123
86	Philippines	479	180	444	145	479	6,332	75,653	254
91	Turkmenistan	1.36	0.36	1	0	24.72	5,218	4,737	10
97	Kyrgyzstan	46.45	13.6	44.05	11.2	20.58	4,182	4,921	26
102	Korea Dem. People's	67	13	66	12	77.14	3,464	22,268	185
106	Japan	430	27	420	17	430	3,383	127,096	349
112	Afghanistan	55	–	–	–	65	2,986	21,765	33
114	Pakistan	248	55	243	50	418.27	2,961	141,256	183
122	Sri Lanka	50	7.8	49.2	7	50	2,642	18,924	293
123	Tajikistan	66.3	6	63.3	3	15.98	2,625	6,087	43
128	China	2,879.40	891.8	2,715.50	727.9	2,896.57	2,259	1,282,437	137
130	Uzbekistan	16.34	8.8	9.54	2	50.41	2,026	24,881	60
133	India	1,260.54	418.54	1,222.00	380	1,896.66	1,880	1,008,937	339
146	Korea Republic of	64.85	13.3	62.25	10.7	69.7	1,491	46,740	473
171	Singapore	0.6				0.6	149	4,018	6,587
175	Maldives	0.03	0.03	0	0	0.03	103	291	970
Total		11313	2509	10920	2116			3412996	

Sources: UNESCO: Water for People Water for Life

0 Ranking in the world

1 Total internal renewable water Resources (km^3/year)

2 Groundwater produced internally (km^3/year)

3 Surface water produced internally (km^3/year)

4 Overlap: Surface and groundwater renewable (km^3/year)

5 Water resources: total renewable (km^3/year)
6 Water resources: total renewable per capita (m^3/capita year)
7 Populations in 2000 (1000 Inh)
8 Population densities in 2000 (inh//km^2)
2+3-4* Aggregation of data can only be done for internal renewable water resources and not the total renewable water resources, which would result in double counting of shared water resources.
(–) No data available

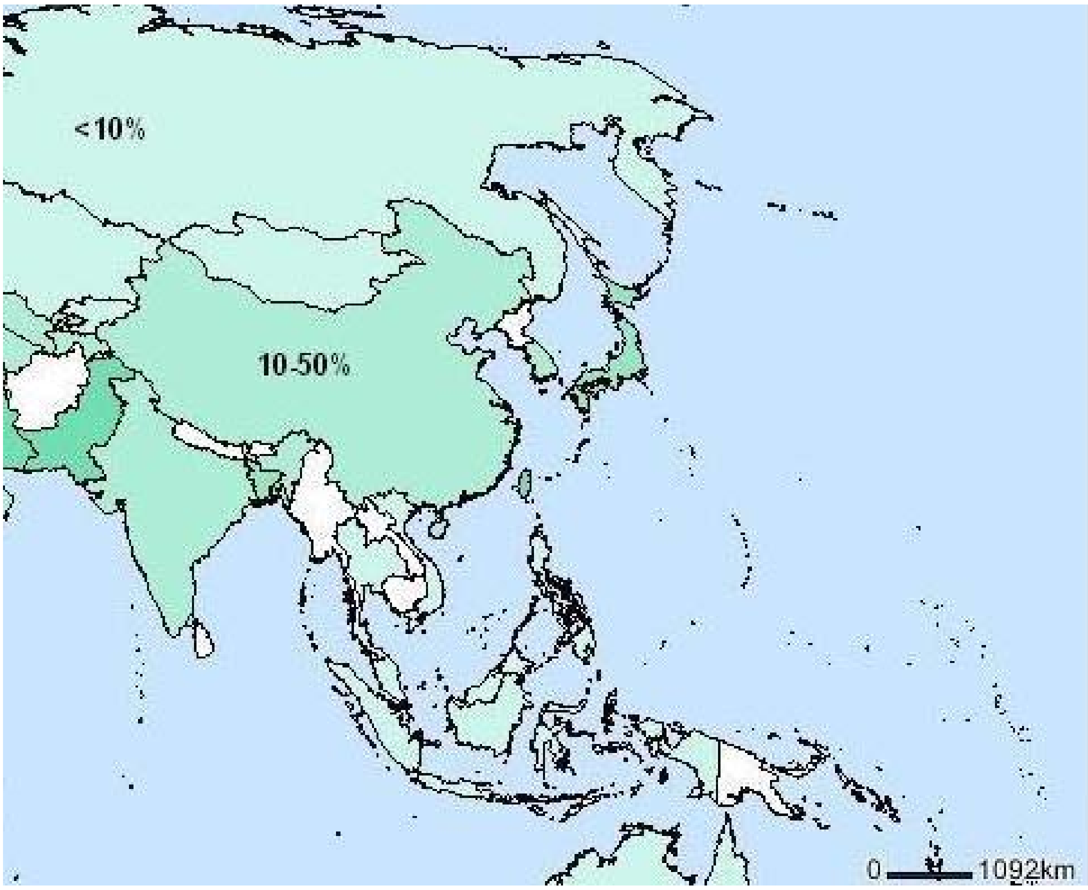

Fig.1-2 Degree of groundwater Development in Asia (From IGRAC 2004)

2.3 Problems of Groundwater in Asia

Problems of groundwater could be caused by nature issues and human action. The main problems caused by nature issues are quality of groundwater in the arid and semi-arid areas especially in the central part of Asia. Global climate change made the hydrogological condition diversified in both inland and coastal area of Asia. Problems caused by human action are groundwater overexploitation and related land subsidence, seawater intrusion to inland and groundwater contaminated occurred in many regions. Those problems have increased rapidly during the last 20 years.

1.3.1. Groundwater quality. Most renewable groundwater is of high quality for domestic use and does not require treatment. But the resort groundwater is naturally unacceptable for drinking. In the arid and semi-arid areas, the salt contained in shallow groundwater is high.

High content of arsenic and fluorine of groundwater are in many regions of Asia. In Bangladesh and the neighboring Indian states of west Bengal, the high level of arsenic in the groundwater used for drinking has made a time bomb for public health. Groundwater sources of 61 out of Bangladesh's 64 districts were found with arsenic. An estimated 35 million people are under the risk of being exposed to arsenic poisoning though drinking water. In China groundwater with high content of arsenic were found in Inner Mongolia and other areas. (Fig.1-3) However, with proper management, these problems could be solved by alternative water sources or renders unviable by mitigating arsenic poisoning. Fluoride is a common constituent of groundwater. Natural sources are connected to various types of rocks and to volcanic activity. Agricultural (use of phosphate fertilizers) and industrial activities (clays used in ceramic industries or burning of coals) also contribute to high fluoride concentrations in groundwater. High Fluoride of groundwater has emerged as an important environmental problem in India, Pakistan, Viet Nam and Indonesia. The high Fluoride content of groundwater has caused endemic problems in some areas of northern part of China. Drinking water supply must be treated with advisable methods. (Fig 1-4)

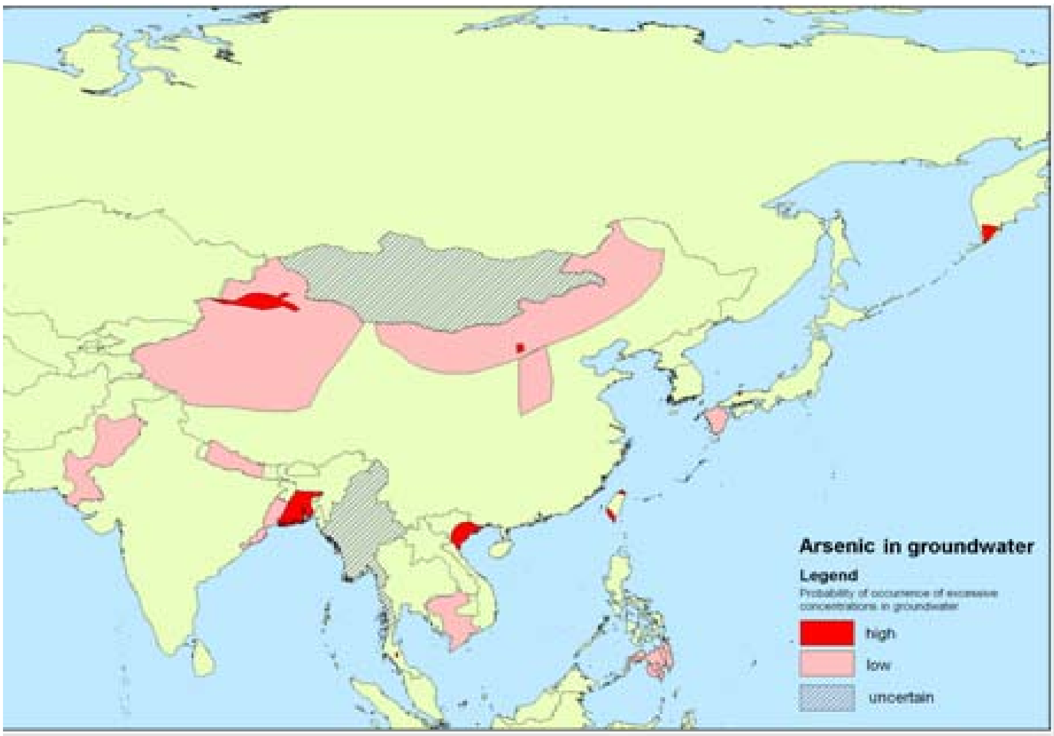

Fig 1-3 Arsenic in Groundwater in Asia (From IGRAC)

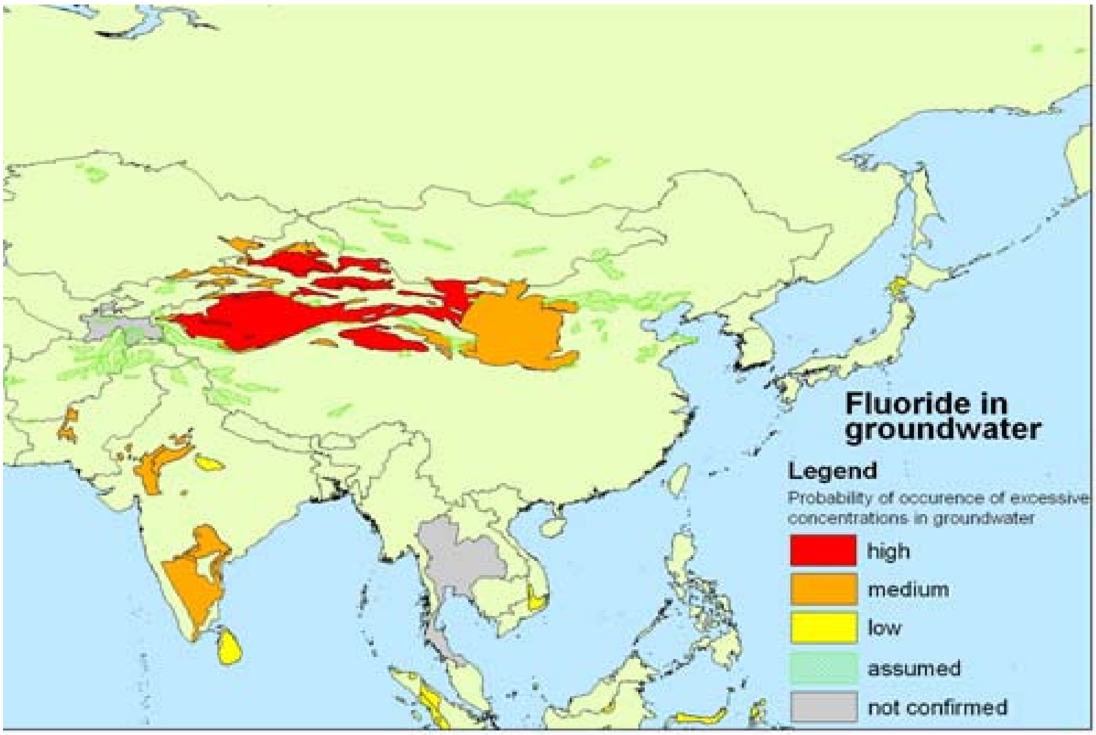

Fig.1-4 Fluoride in Groundwater in Asia (From IGRAC)

1.3.2. Overexploitation of groundwater. Groundwater overexploitation occurred in many areas of Asia, such as Gujarat of India, North China plain and some areas of Pakistan. They related to the declination of ground-water levels, reduction of well outputs, and seawater intrusion in coastal aquifers, land surface subsidence and movement of mineralized or polluted waters into the aquifer. Generally, the declination of groundwater levels results in the increased cost of ground water owing to the expenditure involved in deepening the wells and pumping up water from the correspondingly increased depths. In some cases, overexploitation could lower the water table to such depths that the existing wells have to be abandoned. Countries facing problems related to excessive withdrawal of ground water in certain locations include China, India, Japan, Maldives, Republic of Korea, Sri Lanka ， Thailand ,and so on.

For example, in Thailand, increasingly heavy pumpage of ground water in Bangkok during 1955-1982 caused a decline of 45 to 50 meters of the groundwater levels. The lowering of water levels by these depths had resulted in the abandonment of old wells, increased pumping costs and encroachment of seawater. In order to prevent the situation from getting worse, it is necessary to reduce the pumping rates that would result in the cessation of declination of water levels, particularly in the central areas of Bangkok. It was reported that by May 1985, the piezometric level in central Bangkok had risen by about 2.5 meters.

1.3.3. Groundwater Pollution and Contamination. Groundwater contaminated is often derived from of industry, agricultural and subsistence pollution, which in turn comes from increased economic activities. Drainage waters from irrigated lands for example, usually contain high concentrations of objectionable minerals. These contaminated waters which flows off the land through ditches, may seep into the soil and pollute the ground water that is pumped from wells. Countries facing this kind of problem include the Republic of Korea, Thailand and Viet Nam, etc. In the Republic of Korea, the expansion of industry during the last decade and the modernization of agriculture, has exposed its vulnerable (shallow and permeable) alluvium aquifers to various sources of contamination. In Thailand, until quite recently, shallow ground water was generally free from pollution. However, at present it is observed that groundwater has become contaminated in some places where aquifers are directly recharged by polluted rivers or directly reached by irrigating water. Similarly, in Viet Nam, it is observed that in agricultural areas underlain by karstic limestone, fertilizers have reached the karstic water circulation, thus contaminating the ground water.

1.3.4. Problems related to coastal areas. Seawater intrudes to inland, encroachment of salt water is also a serious groundwater problem, particularly in coastal areas. Since a large portion of the region's population is located along the coasts, there are many problems of this kind in this region. Countries and regions with problems of this nature include China, Japan, Thailand and Viet Nam. Basically, encroachment occurs when the water levels in a freshwater aquifer are lowered than the point where salt water can invade beds bearing fresh water. Although the encroachment tends to be a slow process, in an area where pumping is continuous, encroachment still tends to be an irreversible process. As groundwater is extracted from the wells, the salt water slowly moves through the water- bearing beds in the direction of the wells and, unless corrective measures are taken, the salt water will ultimately begin to contaminate the water in the wells. Such contamination manifests itself in a gradual increase in the salt content of the water being pumped. For example, in Thailand, the rapid lowering of the water table due to over draught has caused shallow aquifers in Bangkok contaminated with salt water. In Viet Nam, seawater intrusion into coastal aquifers is a major problem. In the lower part of its major river basins, as well as in the coastal plains, the average salinity of ground water is approximately 3 g/l to 4 g/l, while the maximum salinity sometimes reaches as high as 10 g/l, thus rendering the ground water unsuitable for drinking.

1.3.5 Land subsidence. In some Asian countries of the region, the withdrawal of large amounts of groundwater has caused serious problems of the subsidence of the land surface. Some of countries facing such problems include China, Japan and Thailand. Land subsidence is more damaging in coastal cities, such as Bangkok and Tianjin. In Japan, from 1961 to now, the occurrence of land subsidence and/or seawater intrusion was the result of overexploitation of groundwater brought about by the remarkable growth of industries and the expansion of agricultural production. Land subsidence has occurred in the low-lying land of the plains and basins where the principal cities, Tokyo, Nagoya, Osaka, Yamagata, Kofu etc., are located. In Thailand, overexploitation of groundwater exists in many locations, particularly around Bangkok area. In Bangkok, the field evidence of land subsidence has been observed in the form of protrusion of well casings above the ground surface. Estimates based on the protrusion of well casings that were installed about 30 years ago indicate that the average subsidence rate in the city is approximately 1.8 to 1.9 centimeters per year. A detailed survey of ground levels carried out in Bangkok during the period 1979-1981 indicated that the existing benchmarks are 30 to 80 centimeters below their original elevations recorded 30 to 40 years ago. At present, about half of the city is less than 0.5 meters above the mean sea level. As in Bangkok, Shanghai also experienced a severe subsidence problem between 1921-1965, particularly from 1949 to 1957, during which an increase in groundwater pumpage resulted in a corresponding increase in the rate of subsidence as well as the area affected. The measures taken in China to solve the subsidence problem included: Broadening the area from which groundwater is extracted; reducing the amount of groundwater extraction; recharging the aquifers artificially wherever possible; selecting appropriate aquifers for groundwater extraction. These measures were said to be effective and to have achieved positive results. It should be noted that where subsidence has occurred, it is not possible to reverse the process by any means. Hence, it is very important to establish and implement effective groundwater management program to prevent land subsidence derived from over pumping.

2.4 Transboundary aquifers in Asia

Transboundary aquifers, as part of groundwater resource systems, are important for Asian countries. The aquifers are involved within the relationship between countries, regions, as well as along the international rivers. There are several transboundary aquifers, involving two or more countries in Asia. There are concomitances of rivers passing through several countries, such as Mekong River, Ganges Rivers and Heilongjiang-Amur River. Research on transboundary aquifers is significant for the management of shared groundwater resources of neighboring countries or regions.

Transboundary aquifers in Asia have been briefly discussed. They are based on groundwater systems analysis. For the countries such as China, Russia and India inhabit large areas, The number of international transboundary aquifers in Asia is less than those of other continents. Twelve transboundary aquifers, which are very significant, are demarcated as table1- 2 and Fig 1-5. That is the production of the UNESCO-IHP programme. Those aquifers in Asia are important for building a society where all civilizations coexist harmoniously and accommodate each other. According to the groundwater resource data collected, the groundwater systems in central, east, and south Asia are analyzed. The aquifers on the national boundary of China are evaluated in detail. The research on the middle basin of Heilongjiang-Amur River has been taken as the first case in East Asia. The information about the groundwater flow should be exchanged among the Asian countries, which share the transboundary aquifer system. They are the basic requirement for the joint management of water resources.

Table 2 Transboundary Aquifers in Asia

No	Name of Transboundary Aquifer System	Countries sharing this aquifer system	Type of aquifer system	Extension [km^2]
1	Ertix River Plain	Russia, Kazakhstan	1	120000
2	West Altai	Russia, Kazakhstan	1,2	40000
3	Ili River plain	China, Kazakhstan	1	53000
4	Yenisei upstream	Russia, Mongolia	1,2	60000
5	Heilongjiang River plain	China, Russia	1	100000
6	Central Asia	Kazakhstan,Kyrgyzstan,Uzbekistan, Tajikistan,Turkmenistan,Afghanistan	1,2	660000
7	India River plain	India, Pakistan	1	560000
8	Southern of Himalayas	Nepal, India	1	65000
9	Ganges River plain	Bangladesh, India	1	300000
10	South Burma	Burma, Thailand	2	53000
11	Mekong River plain	Thailand, Laos, Cambodia, Vietnam	1	220000
12	New Guinea Island	Indonesia, Papua New Guinea	2	870000

Type of aquifer system: 1 - porous, 2 - fissured/fractured, 3 - karst

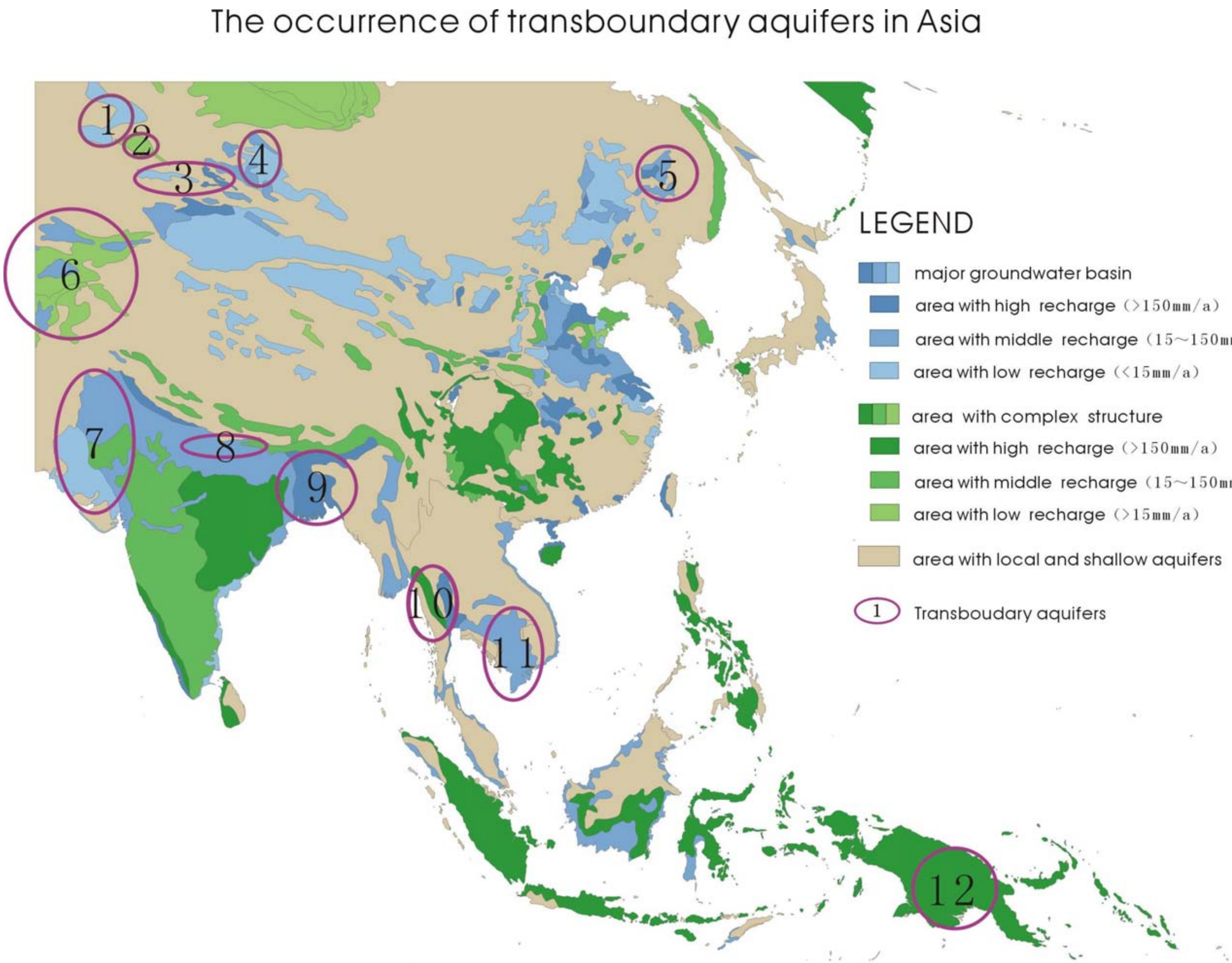

Figure 1-5 Transboundary aquifers in Asia

2.5 Challenges for Hydrogeologists

Groundwater demands and dependent environmental problems are driving forces for Asian hydrogeologists. There are so many issues for solution. The main tasks are groundwater assuring for the livelihoods and food security of millions of people, groundwater sustainable usage for the socio – economic sustainable development, groundwater effective management. The groundwater monitoring, dynamic assessment and groundwater dependent ecosystems conservation are the majors. Greater knowledge and improving basic data through research are prerequisites for better management of groundwater system. We should realize just using last century's schemes no longer solves challenges related to today's groundwater situation. Understanding the characteristics and behaviour of groundwater resources is the basis. It would also be crucial to investigate characteristics and behaviour of resources user communities and the institutional framework under which the resource is appropriated. There is an urgent need for expansion in the knowledge of user and institutional perspectives in the groundwater knowledge base.

In general, there are two basic approaches for dealing with the problems related to overexploitation of aquifers: the preventive approach and the remedial approach. The main objective of the preventive approach is to forestall overexploitation by enacting and enforcing appropriate groundwater legislation. The remedial approach is useful for cases where the problem of overexploitation has already taken place and usually requires recharge of the aquifers by artificial means. It should be noted that artificial recharge of aquifers is not always possible, and even if it is, it tends to be a costly process. Another possible measure to solve overexploitation of ground water is to limit or reduce the supply of ground water and increase that of surface water. In this regard it is necessary to have an integrated management of both surface and groundwater resources.

Therefore, it can be seen that groundwater benefits considerably impacted Asia. Groundwater use has indeed involved drinking, food production and created livelihood opportunity for millions of people. The prime aim in governing groundwater is to ensure the negative impacts of intensive use dose not exceed the benefits. The key challenge for hydrogeologists is to devise ways and means of reducing the negative impact of groundwater usage without significantly reducing benefit flows. In this context, hydrogeologists in Asia have an important role to act in providing updated data and analyses that will help decision makers in formulating implementable and socially acceptable policy responses.

3 Groundwater Resources and Transboundary aquifers of China

3.1 Geography and Water Resources

Topography of China, from the Qinghai-Tibet Plateau in the west to the coastal areas in the east, the average altitude decreases from 4,800 m (locally over 5,000 m) to less than 50 m above sea level. Mountains, hills and plateau cover about two thirds of the total territory of China, while basins and plains only account for one third . The mountain ranges mostly west to east and north-east to south-west. The west-east ranges can be grouped into three belts from north to south, which are the Yinshan - Tianshan, the Qinling - Kunlun and the Nanling belts. The mountains are composed of boundaries of topographical sub-areas. The north-east/south-west ranges may be roughly divided into two belts- that is, the belt which joins the Changbai Mountains, the Liaodong hilly regions and the Wuyi Mountains, and the belt of the Great Taihang-Wushan-Xuefeng Mountains, with broad plains located inside. The latter of the two belts is also the eastern edge of the Nei Mongol, Loess and Yun-Gui plateaus. Furthermore, the north-south Helan-Daxue Mountains constitute a great division between the eastern and western parts of China. Because of the topography, permafrost occurs on plateaus of western China, and vertical zoning of climates is manifest there. For example, the annual precipitation in some of the high mountainous areas in the north-west increases abruptly with the rise of altitude.

The mean annual precipitation of China is about 600 mm. The vast areas to the west and north of the Greater Hinggan-Yinshan-Helan-BayanHar-Gangdise Mountains (except the Altay, Tianshan and Qilian Mountain areas) are the arid climatic zones, where the annual mean precipitation is less than 200 mm. The areas eastwards and southwards from this range to the range of the south-eastern Tibet Plateau-eastern Qinghai-the southernmost part of Gansu-southern slope of the Qinling Range-north of the Huai River-Shandong peninsula (except the areas of the Changbai and Greater and Lesser Hinggan Mountains in north-east China) belong to the semi-arid and semi-humid climatic zone, with the annual mean precipitation ranging from 200 to 800 mm. The vast areas extending southwards belong to the humid climatic zone, with the annual mean precipitation generally greater than 800 mm, and the maximum even up to 2,000 mm.

On the basis of the regional geologic and tectonic features and with the Yinshan-Tlanshan and Qinling-Kunlun latitudinal structural zones as the boundaries, the whole country can be divided into three major regions, the northern, central and southern regions. These three major regions have respectively gone through different geologic histories; hence they have different geologic features.

As a result of great subsidence and strong Variscan movement in the region which is to the north of the Yinshan-Tianshan Mountains, a thick sequence of Palaeozoic marine formations were tightly folded and intensely metamorphosed, and covered by part of alternating marine and continental Mesozoic strata. The Variscan granites and the late Palaeozoic volcanic rocks are relatively common, especially in the Greater and Lesser Hinggans and Altai Mountains, where granites cover one fifth or a quarter of the region's total area. In the eastern part of north-east China they occupy two thirds or so.

In most parts of the region between the Yinshan-Tianshan Mountains and the Qinling-Kunlun Mountains, the crustal movement was relatively moderate in the Palaeozoic period. This is mainly marked by: (1) Uplifts and subsidence en masse; (2) Relatively weak magmatic activity; (3) limited regional metamorphism; (4) Gently folded strata; (5) Fractures large in size but moderate in number. About two thirds of this region is occupied by a series of large and medium size Mesozoic and Cainozoic structural basins, in which Mesozoic, Tertiary and Quaternary sediments in substantial thickness are distributed, mainly of continental Origin. In other parts of the region are mainly tightly folded and metamorphosed Archean rocks and less tightly folded, essentially unmetamorphosed or slightly metamorphosed rocks of Sinian period and partly of Palaeozoic of Mesozoic era.

To the south of the Qinling-Kunlun Mountains is a region which has experienced the longest duration of transgressions since the Sinian period, and during which marine formations have been developed the most. It is also a region where the Orogenic movement has been strong and the compressive folding, faulting and magmatic activity have been relatively intense since the Mesozoic. The structural basins of the Mesozoic and Cainozoic eras are small in extent and also few in number. Quaternary sediments are not developed to a large extent.

It is evident that the latitudinal Qinling-Kunlun structural zone plays a dominant role in the regional occurrence and distribution of ground water.

As for rivers and lakes, outwards drainage systems ，running over a total area about two thirds of the whole territory of China，occur mainly in the eastern and southern parts of China, with most rivers flowing eastwards into the Pacific Ocean .Whereas the internal river systems drain the northern and western parts, forming lakes in their lower reaches or depressions, or disappearing in the deserts. Rivers and lakes are densely distributed in the areas, which is in the south of the Qinling Range and the Huai River. They carry quantities of water and serve as important ground-water recharge Sources or discharge Outlets in the areas. To the north of the Qinling Range-Huai River divide, rivers and lakes are sparsely scattered. As the small amount of precipitation is concentrated in summer, the seasonal variations of water volume and water level in these rivers and lakes are considerable.

3.2 Characters of Aquifers and Groundwater Resources

The east to west trending Qinling-Kunlun structural zone divides the whole territory of China into the northern and southern parts both geologically and physiographically.

Since the Mesozoic and Cainozoic, especially since the Yanshanian orogeny, a series of structural basins of various sizes have developed. Large and medium sized, such basins are distributed in the vast areas north of the Qinling-Kunlun Mountains. In the eastern part of China are the Song-Liao Plain and the Huang-Huai-Hai Plain, which is connected southwards with the Yangtze Delta. In the north-west are the major interior basins, at the edges of which extend the sloping piedmont plains, while the centers of which are occupied by deserts. Loess plateau lies between the eastern plains and the interior basins.

All the major interior basins are extensively covered by thick porous sediments, which are very favorable to the infiltration, storage and flow of ground water. In the eastern plains, the alluvium-diluvia deposits yield an abundant and relatively stable quantity of pore water, which up to now bas been relatively highly exploited and utilized. To the south of the Qinling-Kunlun Mountains, only thin layers of loose deposits can be found over very small areas in the intermontane basins. In short, pore water in unconsolidated sediments occurs over large areas to the north rather than to the south of the Qinling-Kunlun Mountains.

There are appreciable differences in the distribution of karat fissure-cavity water between the areas north and south of the Qinling-Kunlun Mountains. In the northern areas, the karat fissure-cavity water occurs mainly in dolomitized Cambrian and Ordovician rocks which are moderately karstified. Generally, karst features are not conspicuous on the surface, and big springs or spring groups gush out only in the places where buried karst is relatively developed. In the southern areas, karst fissure-cavity water occurs abundantly in the upper Palaeozoic and lower Mesozoic carbonate rocks. These rocks are younger in age, pure in carbonate composition and rather intensely karstified, resulting in a series of underground rivers and huge solution caves, and also typical karat landscapes.

The quality of shallow ground water (unconfined or slightly confined ground water at shallow depths) to the north of the Qinling-Kunlun divide is entirely different from that to the south. Ground water at shallower depths tends to have a higher mineralization towards the north. The concentration of total dissolved solids is often greater than 1,000 ppm. In the northwestern region it may reach as high as several tens of thousands ppm under high evaporation conditions. On the contrary, the total dissolved solids in ground water on the southern side of the dividing line are mostly less than 1,000 parts per million owing to extensive leaching.

In the eastern part adjoining the coastal belt, which is influenced by the moisture-laden monsoons and amply supplied by precipitation, ground water is commonly fresh and contains about 1,000 ppm of total dissolved solids or less, except in the coastal areas where ground water is relatively highly mineralized. While in western China groundwater quality varies widely with regard to the chemical composition of the ground water, area and vertical zonings can be clearly recognized in the major interior basins and plains in the north, whereas the zoning is very indistinct in the southern intermontane basins.

The latest investigation showed that natural recharge resource of underground freshwater was about 884 billion m^3/a, accounting for 1/3 of the total water resource, with that of mountainous area being 656 billion m^3/a, that of plain area being 228 billion m^3/a. Allowable withdrawal of underground freshwater is 353 billion m^3/a, with that of mountain area being 197 billion m^3/a, that of plain area being 156 billion m^3/a. In addition, groundwater natural recharge, whose mineralization degree is 1-3 g/L and 3-5 g/L, is 28 billion m^3/a and 12 billion m^3/a respectively.

Natural recharge resource of underground freshwater in the south and north of China are different obviously, accounting for 70% and 30% of the total number respectively.

3.3. Issues in Groundwater Development

Groundwater has steady quantity and good quality. Furthermore, it won't be polluted easily. So it is an important water resource for our life and production. In China, large-scale groundwater exploitation started and increased rapidly after China was set up in 1949. In 1950s , there is only sporadic groundwater exploitation; in 70s , the amount of exploitation increased to 57 billion m3/a; in 80s , it increased to 75 billion m^3/a. For now, groundwater exploitation （including a little weak mineralized groundwater） has exceeded 100 billion m^3/a ,accounting for 1/5 of the total number. Groundwater withdrawal in the northern part of China counts for 76% of the whole country.

There are 400 cities exploiting and using groundwater all through the country, and groundwater counts for 30% of the total number of urban water use. In the southern cities, groundwater is the major water source. Groundwater use of cities in North China and Northwest China accounts for 72% and 66% of the total amount of water use respectively.

The potential of groundwater exploitation in the whole country is considerably huge. Underground freshwater resource of shallow aquifer is 260 billion m^3/a, and groundwater resource with the mineralization degree being 1-5g/L is 14 billion m^3/a.

（1）status of groundwater quality

Overall status of groundwater environment in China is not bad. The area of underground freshwater, weak mineralized groundwater and middle mineralized groundwater is 8.1 million km2, 0.54 million km2 and 0.84 million km2 respectively. Affected by the geological conditions, there are still 70 million people who have no clean groundwater to drink in China. They are suffering from arsenics, floozies, Struma, big condyle and some other endemics. According to statistics by area, Groundwater in 63% of the whole terrain can be drunk directly; Groundwater in 17% of the whole terrain can be drunk after properly treated; Groundwater in 12% of the whole terrain can be used for industry and agriculture; Groundwater in less than 8% of the whole terrain cannot be drink.

Groundwater quality of China has some regional features as follows: Groundwater quality in southern part of China is better than that of northern part ; Groundwater quality in eastern plain area is better than that of western interior basin; Groundwater quality of mountain area is better than that of plain area; Groundwater quality in piedmont plains and intermontane plains is better than that of coastal area and the middle of basin; Groundwater quality in deep aquifer is generally better than that of shallow aquifer.

（2）status of groundwater pollution

In the 253 major groundwater exploitation zones of 185 cities, there are 63 zones whose pollution trend is aggravating, accounting for 25%; there are 45 zones whose pollution trend is alleviating, accounting for 18%; there are 145 zones whose pollution is relatively steady, accounting for 57%. The pollution components are mainly nitrate, nitrite, and nitrogen in ammonia, chloride and heavy metal.

Groundwater planar pollution of the shallow aquifer in Huai river drainage area is aggravating. Organic pollutions resulting in cancer, aberrance and variation have been examined in the groundwater of Beijing, Tianjin and Yangtze River delta to some extent.

（3）land subsidence and ground fissure

There are more than 50 countries where land subsidence and ground fissure have taken place by 2003, with the subsidence area being 94 thousand km^2. The most serous regions are Yangtze River delta, North China Plain, Fenwei basin, and so on.

Yangtze River delta is the most serious subsidence region in China, with the area of accumulative subsidence amount exceeding 200 mm in the surrounding 10,000 km^2, accounting for 1/3 of the total area. In addition, ground fissure hazards take place there.

The biggest subsidence amount in North China Plain has exceeded 3.1 meters, and there is a negative elevation area of $20km^2$ in the inshore zone, with the storm tide disaster very serious there. Furthermore, 20 ground fissure hazards appeared, of which the longest one is 4 kilometers.

（4）groundwater depression cones

There are about 180 groundwater depression cones in the whole country, with the total area being 190 thousand km^2. In the 121 depression cones provided with complete statistic, there are 54 depression cones with ampliative areas, 43 depression cones with reduced areas, 24 depression cones with steady areas.

（5）ground collapse

In the 23 provinces of the whole country, more than 1,400 karst collapses have taken place, with the total number of collapse holes exceeding 40,000.The provinces where collapses mainly take place are Liaoning, Hebei, Shanxi, Shandong, Hunan, Hubei, Guizhou, Guangxi, Guangdong, Jiangsu, Zhejiang, Anhui, Jiangxi, Fuijan, Yunnan and so on, with ground collapses of karst region in Guangxi province being the most serious.

（6）Seawater intrusion in coastal area

The regions in China suffering from seawater intrusion from north to south are: Liaoning, Hebei, Shandong, Guangxi, Hainan, and so on. Seawater intrusion in the area around Bohai sea developed rapidly, and the total area affected reached 2457 km^2 in 2003, increasing 937 km2 compared to 1980s', with a rate of 62 km^2 / a.

3.4 International Transboundary Aquifers of China

ISARM was launching in the sixth phase of IHP organized by UNESCO. It contains demarcating and analyzing the transboundary aquifer systems, encouraging every country sharing groundwater resource to cooperate with each other, as well as insuring the sustainable utilization of the aquifer system. A great deal of modern hydrogeological theories and techniques are applied, and a complete set of integrated research techniques and working directory is formulated. ISARM has organized a series of researches of representative examples in America, Africa and Europe. Cooperating with the departments and organizations concerned, the author has done a series of researches on this aspect. Above all, in the programme on mapping the WHYMAP, the author demarcated the transboundry aquifers in east Asia. According to the data about groundwater resource collected from countries in Asia, the author analyzed the groundwater systems in central, east, and south Asia, and demarcated the significant transboundary aquifers in east, south and Southeast Asia. Furthermore, the transboundary aquifers across the boundary of China were analyzed, which mainly contain the Middle Heilongjiang–Amur River basin across the boundary of China and Russia, the Yili River valley plain and the Ertix valley plain across the boundary of China and Kazakhstan, and the transboundary aquifers across the boundary of China and Mongolia, China and Korea, China and Vietnam, China and Burma. (Showed in Fig.2-1 and Table 2-1)

Table 2-1 International Transboundary Aquifers of China

No.	Name of Transboundary Aquifer System	Countries sharing th aquifer system	Extension in China [km^2]	Type of aquifer system
1	Ertix River Plain	China，Kazakhstan	16754	1
2	Tacheng Basin	China，Kazakhstan	11721	1
3	Ili River Valley	China，Kazakhstan	26000	1
4	Middle Heilongjiang-Amur River Basin	China，Russia	45000	1
5	Yalu River Valley	China，Korea	11210	2
6	Nu River Valley	China，Burma	35477	3
7	Upriver of Zuo River	China，Vietnam	32227	3
8	Beilun River Basin	China，Vietnam	30170	3

Type of aquifer system: 1 - porous, 2 - fissured/fractured, 3 - karst

Fig.2-1 International Transboundary Aquifers of China

The basic characters of the transboundary aquifers across the boundary of China，the sequence numbers of which are 1,3,4,7 in the table 2, are as follows.

1-Ertix valley plain aquifer: This aquifer is a transboundary aquifer shared by China and Kazakhstan. The Ertix River originates from southern slope of Altai Mountains, with a total length of 2669 kilometers and a drainage area of over 1070000 square kilometers. In Xinjiang, China, the length is 546 kilometers, the drainage area is 57000 square kilometers. After flowing out of the national boundary, the Ertix River flows into the ZhaiSang lake of Kazakhstan, and then flows into the E'Bi lake of Russia. At last, it flows into Arctic Ocean. The valley plain aquifer is made up of Quarternary sand gravel, where there is no steady cohesive soil sediment. The area of China part is 16000 square kilometers, and the runoff module of natural recharge is about 150000 $m^3/(km^2 \cdot a)$.

3-Yili River valley plain aquifer: This aquifer is a transboundry aquifer shared by China and Kazakhstan. The total area is 53,000 square kilometers, and the area in China is 26000 square kilometers. The water resource of Yili River mainly comes from the thaw of Tianshan Mountain of China. The influx of the surface river water flowing into Kazakhstan is about $12\times10^9 m^3/a$, and water flows into Lake Balkhash finally. The valley plain aquifer includes Quaternary pore water and fissure water of Mesozoic sandstone. Generally, the runoff direction of groundwater is consistent with the surface water. The groundwater flows into valley from the two sides of the piedmont, which is V shaped, and it flows towards west into Kazakhstan from China, getting across the boundary. It is estimated that the runoff flux getting across the boundary is about $6\times10^8 m^3/a$. Groundwater and surface water of Yili River plain, which is a valuable natural resource shared by the two counties, sustain the social and economic development of Xinjiang of China and the regions with large population in Kazakhstan.

4-Middle Heilongjiang–Amur River basin: This aquifer is a transboundary aquifer shared by China and Russia. The total area is estimated to be 10×10^4 km^2, and the area of Russia part is 55000 km^2. The southern part called Sanjiang plain which is located in China， with an area of $4.5\times10^4 km^2$. The flat and low-lying plainare formed due to the sand deposition of Heilongjiang – Amur River, Songhua River and Wusuli River. The annual average precipitation of this area is 500~650mm. This aquifer is divided into Quarternary pore aquifer、Tertiary pore aquifer and Pre-Quarternary bedrock fissure aquifer. The groundwater flows from high elevation area of piedmont to low elevation area, which is the confluence of Heilongjiang-Amur River and Wusuli River. The groundwater of the middle Heilongjiang-Amur river basin is still in equilibrium, with a much higher content of Fe and Mn.

7-Karst aquifer of upper Zuojiang valley in the southwest of Guangxi province: This aquifer is a transboundary aquifer shared by China and Vietnam. The area of the region in China is 32000 square kilometers, and the runoff module of natural recharge is about 400000 $m^3/km^2 \cdot a$. The karst area is made up of solid thick-bedded limestone、dolomitized limestone、calcareous dolomite. Geomorphologically，from northwest to southeast, there are Fengcong-valley、Fenglin-valley and Gufeng plain in the both riversides of Zuojiang valley. The groundwater in the aquifer is mainly in the form of karst fissure water and subterranean stream. The subterranean stream, big karst valley and surface water subsystem extend towards the northeast and northwest. With Heishuihe River being the boundary, the western subterranean stream flows towards southeast, and the eastern subterranean stream flows towards southwest. The catchment area of subterranean stream is generally 25-120km^2, and the outflow in the dry season is 50-500 L/s. The depth of groundwater is mostly less than 30m, even less than 10m somewhere, and annual variation of water level ranges within 10-20m. The probability of reaching holes in the underground karst is 33%-50%.

3.5 Pilot study of Provinces Transboundary Aquifers in China

China is with a large territory, and the approaches that deal with the international problem of transboundary aquifers can be used as a reference for dealing with the problem of transboundary aquifers in China. There are 26 hydrogeological units in China, 15 of which are across several provinces. For example, Erdos Basin is across Shaanxi、Gansu、Ningxia、Shanxi and Inner Mongolia. North China Plain is across Beijing、Tianjin、Hebei、Shandong and Henan; Yangtze River delta is across Shanghai、Jiangsu、Zhejiang; Songliao Plain is across Heilongjiang、Jilin、Liaoning, and so on. When we investigate and evaluate the geology of groundwater system, the administrative boundary becomes an inevitable problem that needs to be considered. A lot of problems such as the distribution of groundwater resource in the same aquifer exploited and utilized by the neighboring provinces, and the geology environmental problem of the neighboring province resulted from exploitation of groundwater. What is important for the social needs of hydrogeology is to resolve transboundary resource problems which result in dissension easily, maintaining social stabilization near the administrative boundary, and promoting common development. In the following part, representative examples of transboundary aquifers in China will be recounted, subject to further investigations of hydrologists.

(1)Alluvial fan aquifer of Juma River: Across the boundary of Beijing and Hebei. The well field that will be built for solving the lash-up water supply of Beijing located in the middle part of the Juma River alluvial fan, and the aquifer is gravel mostly. Through analyzing the hydrogeological condition of Juma River as well as the forecasted result of the regional groundwater model, exploitation of the well field will consume the groundwater reserves. By comparing the exploitation blue prints, it is advised that the exploitation of lash-up well field should be $1.5 \times 10^4 m^3/d$. In that case, the groundwater level of Hebei will not descend too much, and the thickness of the saturation zone will maintain about 70% of the whole thickness.

(2) Karsts aquifer of Chezhoushan: Across the boundary of Tianjin and Hebei: The Ning River north well field located in southwest of the syncline of Chezhou mountain is built for providing water supply of Binhai new developed area of Tianjin. The Hancheng well field in Fengrun area of Tangshan、the Dachangliu well field and the Chezhoushan Middle School, Limazhai well field, which are in the same karsts hydrogeological cells, will be affected by exploiting and utilizing of the Ning River north well field. A large-scale pumping test counted the drawdown of groundwater of every well field in Hebei 20 years later, if exploited 60000m3/d. The result indicates that under certain conditions, the groundwater level of the Quarternary pole aquifer and the karsts system will descend because of the exploitation of the Ning River north well field, and the existing well fields in Hebei will be affected ever. The increasing drawdown improved cost of the running, but can still be operated within a normal scope. The environment geological effects for exploiting the Ning River north well field are analyzed by the hydrogeological investigation.

(3)Karst aquifer of eastern Erdos Basin: Across the boundary of Shaanxi、Shanxi and Inner Mongolia. It includes the karsts aquifers of Tianqiao basin, Lioulin basin and Yumenkou basin. The recharge area of the system mainly locates in Shanxi, one part of the cavern water discharges into the Yellow River, and the other part discharges into Shaanxi. The discharge area of the cavern water system is located in both banks of Shanxi and Shaanxi, being the enrichment area of the cavern groundwater. So the eastern Erdos Basin has the condition for establishing the lash-up well field. The exploration and evaluation of the groundwater, completed according to the cavern water system, provides the base of exploitation and utilization. It is confirmed that there are more than ten cavern groundwater well fields locating in the close together region of Shanxi and Shaanxi respectively. Because each cavern water system has close internal hydraulic connection, and the construction of energy base utilizes the cavern water, we have to according to the entire aquifer system programming, considering the exploitation of the well field in the neighboring provinces together.

(4) Aquifer of Yangtze River delta : Across the boundary of Jiangsu、Shanghai and Zhejiang, which is an economically developed area with large population . Suzhou-Wuxi-Changzhou of Jiangsu province 、 Shanghai and Hangzhou-Jiaxing-Huzhou of Zhengjiang province locate the same basic Quarternary sedimentary Champaign. Because of over-exploitation of the groundwater, land subsidence and the ground fissure are formulated, which brought a large economic losing and restricted the sustainable development. Due to over-exploitation of groundwater in Suzhou-Wuxi-Changzhou of Jiangsu province, land subsidence had crossed boundary of provinces, affecting major cities like Shanghai. Unfortunately, the survey and prevention measures of land

subsidence in Shanghai, which started early and single, had not been performed in a satisfactory manner. As a result, the hydrologists investigated and evaluated the whole Yangtze River delta aquifer including base constitution、Quarternary configuration、groundwater resource and land subsidence. The uniform monitor net of land subsidence is designed and some mechanism is established covering three provinces, in order to protect the groundwater resource of Yangtze River delta and prevent subsequent land subsidence.

4 Case study - Transboundary Aquifer between China and Russia

4.1 Geography and Hydrology of Middle Heilongjiang-Amur river Basin

Middle Heilongjiang-Amur river basin is encircled by mountains. The west is Xiaoxingan Mountains, the northwest is Buren heights in Russia, the east is Sihote-Aline mountain range and the south is Wanda mountain of China. The total area is 100000 km^2. The part in China called Sanjiang plain, with an area of 45000 km^2. The area of Russia part is 55000km^2. (Showed in Fig.3-1) The basin is an important economic region of Northeast China and the Far East of Russia, including Kiamusze city, which is an important city in the Far East of Russian Federation.

The stratified physiognomy of the Middle Heilongjiang-Amur river basin can be divided into 3 ranks. The first and the second ranks are made up of the lower plain, with an altitude of 50-60m. And the elevation is about 100m. Heilongjiang-Amur River, Wusuli River and Songhua River run cross the area and form a valley plain. The fan-shaped sandy gravel plain, which is composed of slimy gravel layers, located in the piedmont of the eastern slope of Less Hingan. Towards east , it is conterminous with Songhua River and Heilong River， with the thickness of sediment being 15～25m, elevation being 50～70m.The sandy gravel valley plain that is composed of mealy clay、gravel and pebble, is situated in the Songhua River，Heilongjiang－Amur River ，Wusuli River and the main tributary valley of them, including terrace of the first order and floodplain, with the landform elevation being 40～50m, specific elevation being 5～10m. The sedimentary low plain that is composed of loessial powder clay soil、mealy clay sand and gravel, is located in the middle of Songhua river valley, with a landform elevation being 60～80m. Clay low plain composed of loessial powder mealy clay、silt mealy clay sand, is located in the large low plain in the east of Tongjiang-Fujin-Jixian, with the landform elevation of 50～60m.

Middle Heilongjiang-Amur river basin locates in the east part of Asia continent, west bank of Pacific Ocean. It is of typical continental monsoon climate, with the annual average temperature fluctuating from minus 4 to 4 degrees centigrade. In winter, much of the wind comes from northwest and it is cold and dry under the control of Mongolia high-pressure climate. In summer, on the contrary, much of the wind comes from southeast, resulting in the hot and rainy weather under control of the Pacific Ocean subtropical high-pressure. The annual mean temperature of the area is 2.8℃,with the highest temperature of 37.7 ℃ and the lowest temperature of –38.8 ℃. The annual mean precipitation of middle Heilongjiang-Amur River basin fluctuates from 500-650mm. In summer, there is enough and intensive rainfall because of effects caused by monsoon of southeast Asia .The precipitation from June to August every year account for 63.8％ of the whole year's, While the precipitation of autumn and spring only account for 12.5% and 21.0% of the whole year's respectively. The precipitation fluctuates in an obvious manner during different seasons and years. Furthermore, wet and dry years alternate obviously. The precipitation in wet years is 2.4 times as much as that of dry years.

The water systems of the Middle Heilongjiang-Amur river basin are well developed, and the Heilong River, Songhua River and Wusuli River are the main water systems. See Fig 3-2.

Heilongjiang River gets its name from the color of its water that flows through the densely forested regions covered with black humus soil. It is the boundary river between China and Russia, which runs across the northern part of China. Its headstream includes the northern source and the southern source.. The northern source Shileka River originates from the eastern foothills of the Mount Kent in Mongolia, and the southern source Arguna River originates from the western slope of China's Great Hinggan Mountains. After the convergence of the southern source and the northern source at the Mohe County, China, the river is referred as the Heilong River that flows east, but turns to the north at Khabarovsk. Finally, it feeds into the Sea of Okhotsk. The Heilongjiang River flows across China, Russia and Mongolia. Its total length is 4,400 kilometers, as the 11th largest river in the world. Its drainage area is up to 1,855,000 square kilometers, ranking the 10th largest in the world. The drainage area within China is about 893,400 square kilometers, accounts for 48% of the total drainage area.

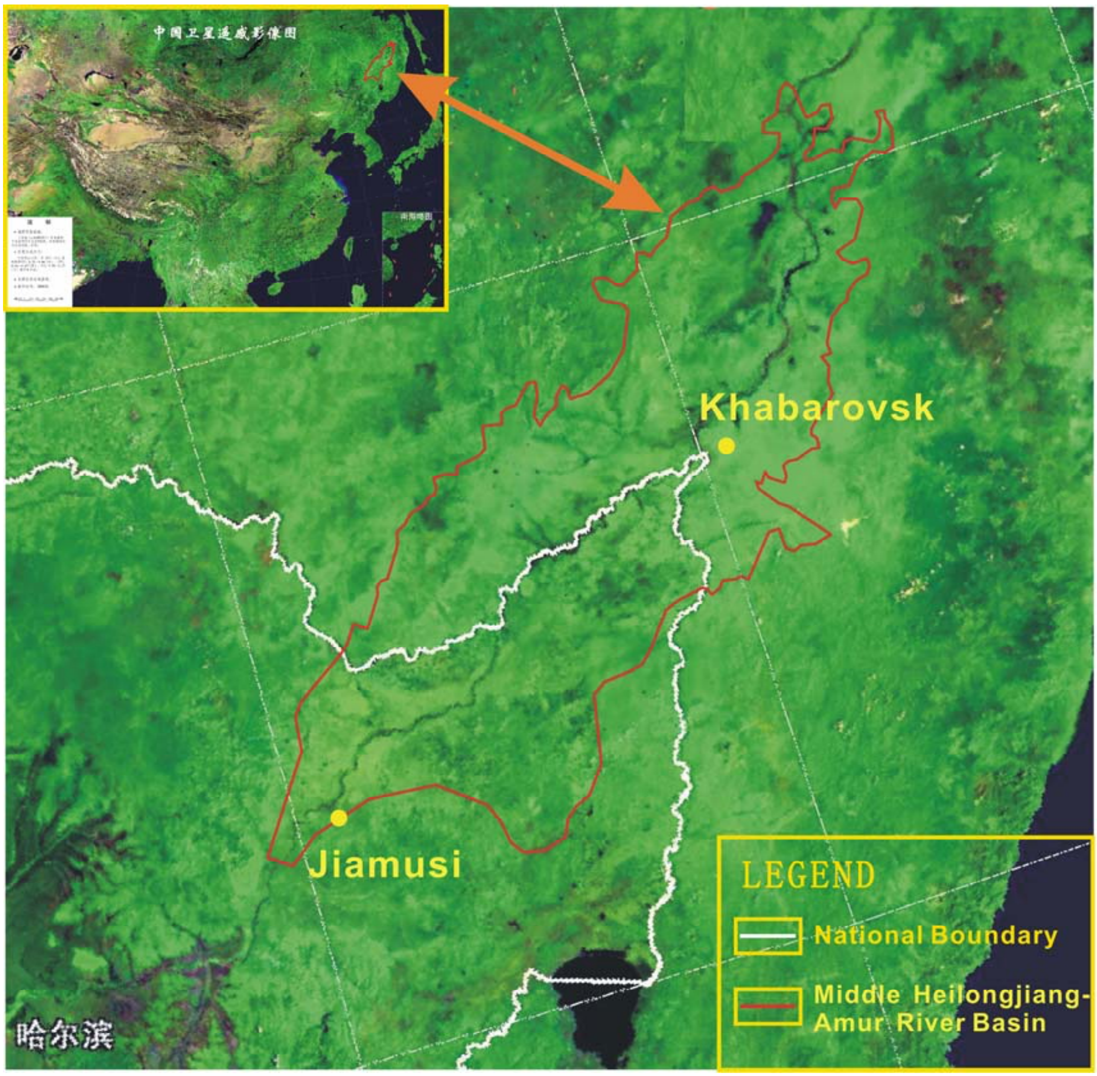

Fig 3-1 Middle Heilongjiang-Amur River Basin

Songhua River is the largest tributary of the Heilong River, with a total length of 2309 kilometers and a drainage area of over 546,000 square kilometers. Its headstream includes the northern source and the southern source. The southern source--Second Songhua River originates from the Heaven Lake of China's Jilin province, and the northern source Nenjiang River originates from the south of the middle Yilehuli mountain of China's Great Hinggan Mountains. After the convergence of the southern source and the northern source at the Sanchahe river in Mongolia municipality, China, the river is referred as the Songhua River that flows through Jiamusi, Luobei, Suibin, Fujin and Tongjiang. Finally, it feeds into the Heilong River.

The total length of the Wusuli River is 890 kilometers, with a drainage area of nearly 7,000 square kilometers. The drainage area within China is about 56000 square kilometers, accounting for 30% of the total drainage area. Its headstream includes east source and west south/source. The east source is located in the west foot of the Sihote-Aline mountain range of Russia, flowing from south to north. And the west source originates from Khanka. Wusuli River is flowing through the low plain located in the middle of Wanda mountain of China and Sihote-Aline mountain range of Russia. The length of the main channel is 500 kilometers, and the annual runoff is 619×10^8 m^3.

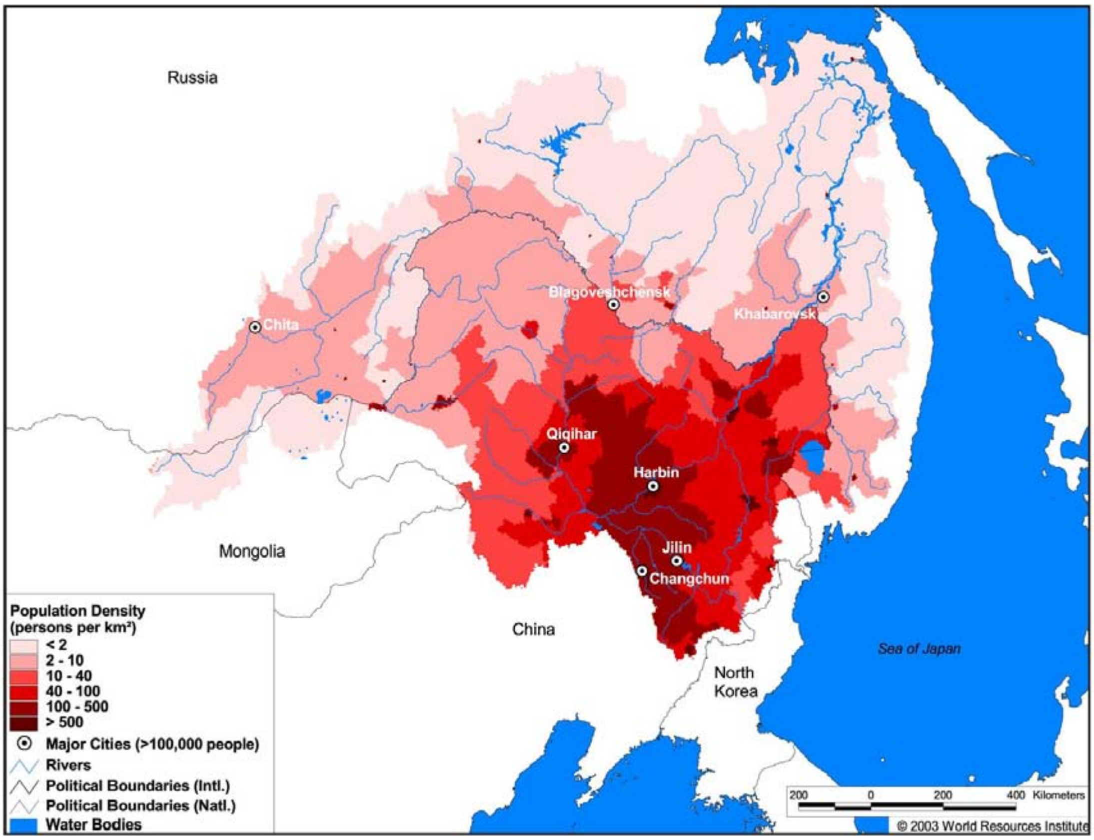

Fig.3-2 Heilongjiang-Amur River system
(From World Resources Institute)

Photo 1 Between of China and Russia

Photo 2　Heilongjiang-Amur River

4.2　Hydrogeological Conditions

Middle Heilongjiang-Amur river basin is a large-scale water-stored structure encircled by mountains. A variety of stratums with weak permeability、magmatic rock of low mountain and hill area are in the north、east、south and west of the groundwater system, forming the water-repellent boundaries of aquifer; The mud rock and the entire bedrock distributed in the base of Tertiary aquifer are the water-repellent boundary of lower plane. The groundwater system of Heilongjiang River is a relatively independent and uniform system, and the groundwater is still in equilibrium.

Groundwater level of piedmont in the west of the basin is 80~90m, and that in the south of the basin is 70~85m. However, groundwater level of the zone of draining datum plane in the middle of the basin is only 35m, and the total difference of water level is 35~55m. It is obvious that, the groundwater flows from high elevation area of piedmont to low elevation area, where Heilongjiang River and Wusulijiang River converge, with a large difference of potential energy.

The groundwater system of middle Heilongjiang-Amur river basin is a large-scale aquifer system, where pore water of Quaternary unconsolidated sediment, pore-fissure water of Tertiary clastic rock, Pre-Quaternary fissure water in bedrock etc. are buried. All the aquifers, which have direct or indirect hydraulic relation, constitute the storing space and runoff channels of the area.

Quarternary pore aquifer is the most extensive one of the aquifers in the middle Heilongjiang-Amur river basin. Besides the extension, its reserves, exploitation and research degree of hydrogeology are the highest, too. The aquifer is divided into single unconfined aquifer and double confined-unconfined aquifers. The aquifers are alluvial, alluvial-diluvial and alluvial-lacustrine unconsolidated sediments. The space among grains constitutes the storing space and runoff channels. The large and thick Quarternary made up of sand, gravel is the water-stored basin, which contains abundant groundwater. The thickness of the aquifer is increasing from the edge to the middle of the basin. The thickness of the piedmont area is 2-40m; that of the middle is 60-150m; and that of the thickest area is 300m. The lithology of the aquifer is fine sand, medium sand and sand gravel, and the hydraulic conductivity is 12-35m/d. The yield of single well is 1000-5000m^3/d. The depth of groundwater in floodplain is 0.5-3m,that of other area is 3-16m, which is generally less than 5m.

The thickness of the sediment in the Russia part of the basin is up to 2000m. The sediment is composed of sedimentary rock, igneous rock and metamorphic rock, and the range of hydrogeological research is limited to 300m. The middle of Quarternary aquifer is made of sand gravel, medium sand and cohesive soil. The Quarternary aquifer is an artesian aquifer.

There is a cohesive soil layer with a thickness of 2-17m, covering the sand and sand gravel layers in the eastern area of the China part, which forms a close confined aquifer. The lateral runoff is the main recharging source of groundwater. Because of the water-repellent roof is quite thin, and the lithology is sandy clay and sandy loam, the groundwater can be recharged by precipitation and surface water. The sand gravel is exposed in the western basin，where the aquifer is unconfined. The groundwater is recharged by precipitation, bedrock fissure water and river water in flood season.

Tertiary pore fissure aquifer of clastic rock mostly distributes in the depression and rift of the basin, and the rest with less area distributes in the piedmont. The lithology is marl、sandstone and gravel, and the pore and fissure of sandstone and gravel are developed, carrying clastic rock pore fissure water. In the vast low plain, the roof depth of the Tertiary clastic rock pore fissure aquifer is increasing from piedmont to the center of depression. Roof depth in piedmont is 40~50m, and at the center of depression is increasing to more than 300m. Disclosed by drill hole, generally, the aquifer is 2~3 layers, the most are 7 layers, with accumulative thickness reaching 100m. Lithology are sandstone、gravel, with moderate cementation, forming the rock system of pore-fracture confined aquifer. The groundwater is confined. Extensive asymmetric reticulate rotten fracture aquifer and wire like structure fissure water bearing distribute in bedrock area.

4.3 Groundwater Resources

China and Russia have not evaluated the groundwater resource of Heilongjiang-Amur river basin together, but the two countries calculated the groundwater resource of their own area respectively according to the native standard and method.

The annual average groundwater recharge of China part is $51.4\times10^8m^3$, and the total annual groundwater withdrawal is $37.1\times10^8m^3$.

The groundwater reserve of the Amur river basin in Russia part totaled 150 m^3/s, namely $47.3\times10^8m^3/a$, and the total groundwater withdrawal module is $3.7L/s.km^2$.

According to that the groundwater withdrawal of China part being $37.1\times10^8m^3/a$ and the groundwater storage of Russia part being $47.3\times10^8m^3/a$, it can be seen that it is accordant to the proportion of area, which illuminates that the two parts of the basin have similar Hydrogeological condition and status of groundwater resource.

According to the result of investigation and evaluation, the groundwater annual recharge of China part under the balance condition are as follows: the vertical recharge is $33.8\times10^8m^3/a$; the river recharge is $5.8\times10^8m^3/a$; swamp and marsh recharge is $7.3\times10^8m^3/a$; lateral runoff recharge of the neighboring region is $4.5\times10^8m^3/a$; precipitation infiltration recharge of vertical recharge is $27.8\times10^8m^3/a$; regression infiltration recharge of irrigation is $6.0\times10^8m^3/a$. The groundwater annual discharge of China part under the balance condition are as follows: river discharge is $2.2\times10^8m^3/a$; swamp and marsh discharge is $1.4\times10^8m^3/a$; evaporation discharge of groundwater is $4.6\times10^8m^3/a$; lateral runoff discharge of the neighboring region is $6.1\times10^8m^3/a$. The total discharge of groundwater is equal to the total recharge. The groundwater of the basin is in a balance state, and the natural circulation of groundwater is in a favorable situation.

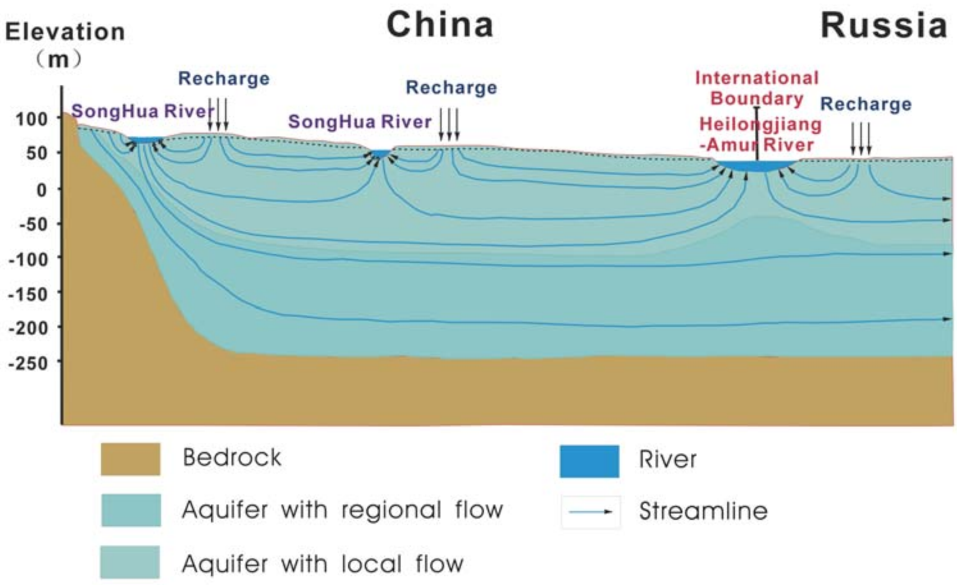

Fig.3-3 section of Middle Heilongjiang-Amur River Basin

The local groundwater in the aquifer near the national boundaries discharges into Heilongjiang River and Wusuli River. The regional groundwater is flowing from China part to Russia part. (Showed in Fig. 3-3) It is estimated that the runoff flux getting across the boundary and flowing from China to Russia is about $1.52 \times 10^8 m^3/a$. The two countries should establish a perfect management system of water resources for this aquifer, to insure the sustainable utilization of the water resource.

4.4 Groundwater Quality

The chemical formation of Groundwater in middle Heilongjiang-Amur River basin is affected by geological structure, topography, hydrodynamics, climate and other factors. Simultaneous influence of these factors results in the quality character of groundwater.

According to the investigation result of the groundwater quality in China part, the groundwater chemical type of the pore water of Quaternary unconsolidated sediment is mainly HCO_3-Ca.Mg, besides HCO_3-Ca, HCO_3-Na.Ca. The content of humic acid in groundwater is high, and the majority is low mineralized weak acidic soft water. The mineralization degree is generally less than 0.5g/L, and in most area is between 0.2g/L and 0.75g/L. pH is 6.5-7.5, total hardness is 1.45-4.29mmol/L. and the most pore water of Quaternary unconsolidated sediment is good for drinking and irrigation. The groundwater chemical type of the pore-fissure water of Tertiary clastic rock is HCO_3-Na or

HCO_3-Ca, and the mineralization degree is 0.2-0.48g/L, pH is 6.30-7.65.

Among the juvenile components, Fe has a high concentration, with a content of 0.3~24 mg/L, and the highest is 40mg/L. The content of Mn is 0.2-0.4mg/L, and the highest is 12mg/L. The water with high content of Fe and Mn distributes extensively, becoming the notable character of the groundwater in that region. Influenced by environment and hydrogeological conditions, its distribution has obvious character of district and belt. The content is increasing from basin boundaries to its center. In the south of Songhua River, the content of Fe is 1.6-24mg/L. Furthermore, its content in the deep groundwater is higher, and in drill holes and machine wells the content fluctuates within 3~15mg/L.

The content of SiO_2 in the Quaternary pore water replenished by precipitation is high, which is generally 20~30mg/L. The content of SiO_2 increases from southwest to northeast. The dissolved SiO_2 of high content influences the composing of low degree mineralized fresh water seriously. At the same time, the groundwater of this area has dissolved oxygen, CO_2 and nitrate. Evaluating in the term of the standard of China, the grade and grade groundwater mainly distribute in the west of the area, namely Songhua River catchment. The grade and grade groundwater, namely the groundwater with favorable quality, mostly distribute in the east and south, which is near the national boundaries. The content of fluorine in groundwater of this area is generally low, and the content is 0.18mg/L. Besides, this area is generally short of iodine.

The groundwater of Quarternary pore aquifer in the Russia part is fresh water whose mineralization degree is 0.2-0.3g/L and in the ground it even exceeds 100m, with the mineralization degree increasing a little. Chemical type of the groundwater changes from HCO_3-Na in the margin of the basin to HCO_3-Mg.Ca, then to HCO_3-Ca.Fe in the middle of the basin. Fe of groundwater comes from the surrounding mountainous areas, congregating in the middle of the basin. The content of Fe is about 20-30mg/L, and in local area even reaches 80mg/L. Besides Fe, the Mn, Si, Ba and Li in the groundwater also have high content. The groundwater quality of Tunguss deposit in the neighboring of Khabarovsk City is correlative to life of the people and need of the industry, therefore, Russia is in the process of applying the modern technique to depress the content of Fe, Mn in the groundwater directly.

The ions with superscalar mostly root in the dissolving of minerals containing Fe or Mn. There are some advantageous geology conditions to dissolve minerals, such as the rocks and groundwater of this area containing plenty of organic substance, deoxidizing environment on the geological structure and abundant carbon dioxide in groundwater. When these conditions occur together, Fe with high order will then converts into Fe^{2+}, and Mn with high order would be dissolved in water. Moreover, this area is flat and with lower elevation. Slow runoff and the comparatively weak alternation of the groundwater, which is advantageous to the lixiviation of groundwater and enrichment of elementary, make the groundwater rich in Fe and Mn.

4.5 Groundwater Usage

Groundwater of middle Heilongjiang-Amur River basin is the primary water supply for life and irrigation of the two countries. Middle Heilongjiang-Amur River basin has some merits such as the extensively distributed aquifer and the groundwater that is not easily polluted. As a result, the Kiamusze city of China and Khabarovsk City of Russia regard the groundwater of riverside source field in the Songhua River and Heilongjiang-Amur River as their curcial water supply . According to the statistic, in the 21st, the withdrawal of groundwater in the China part of the basin is $21.3 \times 10^8 m^3/a$, accounting for 2/3 of the total groundwater withdrawal. The Exploitation depth in Russia part of the basin is limited to less than 100m, and the actual withdrawal is much less than the storage of groundwater. The groundwater recharge of the whole basin and the groundwater discharge including withdrawal are in a balance state as a whole, and the groundwater runoff keeps a crude state.

An ancient riverway lies in the frontier of piedmont alluvial fan in the west of China part, and the aquifer accepts plentiful recharge, so the exploitation potential of the shallow aquifer is huge. Because of the rivers and marshes assemble In the middle of the basin, groundwater should be exploited both deeply and shallowly.

A series of geological environment problems occur during the exploitation of the groundwater, such as draining off the wells and the regional descending of groundwater level. In the China part, the shallow aquifer is exploited, which results in regional descending of groundwater level, with the annual average rate of descending of 0.5-1m, even 2.2-2.8m in some places. The water level of the coalfields has descended sharply. Generally, the annual drawdown fluctuates from 2 to 3 m., and in some year even more than 4m. With the draining off of the wells and the descending of the groundwater level, the wells near the residential area were dried up. All the 6 water wellfields of Jiamusi city exploit the pore aquifer in loose rock masses, and the irrigation wells together with enterprise-owned wells exploit this aquifer in most time. In 2000, there were 1656 wells in Jiamusi city, and the total yield reached $1.56 \times 10^8 m^3$. At present, there are two depression cones called eastern depression cone and western depression cone in the intensive exploitation area, and groundwater level is descending continuously.

There are large marsh areas distributed in the middle Heilongjiang-Amur River basin, which are mainly located in the low plain areas of Wusuli River and Heilongjiang-Amur River. 50 years ago, part of the marsh in the part of China was about 34000km^2, but now it has decreased to 4500km^2. Marsh is an important part of environment related to the groundwater. The Chinese government is adopting measures to reclaim wetland from tilth to protect and resume the marsh in this area.

4.6 Cooperation between China and Russian Federation

The Chinese government has been working on the protection of water resources in the Songhua and Heilong River, and has also established relevant programmes for pollution control. The joint monitoring of the boundary river of China and Russia has laid down a solid foundation for the cooperation of environmental protection between China and Russia. According to the unite communique of the ninetieth prime minister meeting between China and Russia, the two countries will continue to cooperate on joint monitoring for water quality of transboundary river, and would consider to establish an agreement between governments for transboundry water resource protection.

In February,2002 ,China and Russia subscribed an aide-memoire, in order to deal rationally with the water quality problem of the boundary river .Furthermore, they had also appointed responsible department for monitoring. According to the aide-memoire, the departments concerned in China and Russia had carried out 8 monitors for Heilongjiang-Amur river and Ussuri river. What also need to be pointed out is that the good water quality of Heilongjiang-Amur river and the regulation of its branch Songhua river have received recognition of experts from Russia.

Photo 3 People coexist harmoniously on Heilongjiang-Amur River

In 2005, an accident in a petro-chemical plant in Jilin led to a major pollution on the Songhua River in China. the Chinese State Environmental Protection Administration (SEPA) invited an expert team of the United Nations Environment Programme (UNEP) for a field mission to the affected region. The Chinese and Russian governments initiated cooperation over the incident. China has provided relevant information to the Embassy of the Russian Federation in China, and the two countries have also agreed to set up a joint monitoring team.

From December, sampling and testing were taken at the cross-section with the participation of Russian experts. The samples were divided into three portions. One was tested in China with the observation of Russian experts; one was taken to Russia for testing; and one was kept in storage for future use. At the same time, joint monitoring were also carried out at the rest of the monitoring points within China and Russia. The joint sampling at the pollution plume position was carried out timely. China and Russia strengthen joint monitoring. China donated equipment and materials to assist Russia to respond to potential damage and risks, including 6 pieces of monitoring equipment, 150 tones of activated carbon and 6 air compressors. At the same time, upon the request of Russia, Heilongjiang Province began the construction of a diversion dam on the Fuyuan waterway. The dam prevents polluted water from flowing through the intakes of drinking water in Khabarovsk City and also protects Russian residents along the lower reaches of the Ussuri River from being harmed by pollution. The pollution plume will not flow through the lower reaches of Xiaohezi of Fuyuan County, therefore Chinese residents living in this area will also not be affected. The dam will protect water quality on the Fuyuan waterway.

From December 2005 to now, the geological survey department of China has timely sampled and tested the groundwater in the aquifer along the Songhua River from Jilin to Heilongiang. The dynamic monitor indicates that the groundwater has not contained benzene, and the middle Heilongjiang-Amur river basin has not been polluted by the accident of Songhua River pollution.

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