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Transboundary Aquifers in Asia – A Preliminary Inventory and Assessment



IHP VII Technical Document in Hydrology
UNESCO Office in Beijing & Jakarta, 2010

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Note from the Editors

This publication is compilation of contributed research papers on transboundary aquifers inventory in Asia under UNESCO-IHP VII Theme on International Shared Aquifers Resources Management. The editors changed the format of the papers for the sake of uniformity, from which we hope readers to feel comfortable, and arranged the order of papers in order to reflect better where their contents are categorized into. However, only a minimum modification was made to the papers.

The editors give special acknowledgment to all the contributors of the case studies for their time and effort in compiling the case study papers. Parts of the some chapters are adopted from UNESCO-IHP publication on Atlas of Transboundary Aquifers-Global Maps, regional cooperation and local inventories.

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FOREWORD

Transboundary aquifers are increasingly becoming the lifeblood of agricultural and industrial production, sustaining the livelihoods of communities in many areas of the world. The importance of transboundary aquifers as a water source has come to the fore in the context of climate change, when increasing temperatures and reductions in rainfall are limiting surface water availability and creating uncertainty in relation to the future sustainability of these resources.

In recognition of their critical tole transboundary aquifers are often referred to as "hidden treasures" underground. Unfortunately, the sustainable management of transboundary aquifers is often left off policymakers' agendas. Compared with surface rivers, which attract a lot of attention due to their visibility, there are far fewer national policies and regulations dealing with the management of aquifers. Transboundary aquifers are given even less attention due to the perceived difficulties in sharing these resources between two or more countries.

Few cooperative paradigms have been established between countries or at the regional level to protect transboundary aquifers. Data exchange on the geographic, geological and hydrogeological parameters of aquifers remains low among countries sharing these valuable resources. This lack of cooperation has resulted in transboundary aquifers being increasingly vulnerable to pollution and excessive exploitation. The lifeblood of aquifer-dependent communities is being drained along with the resources of these "hidden treasures". To tackle the challenge, the International Shared Aquifer Resources Management (ISARM) programme was launched jointly in 2000 by UNESCO and the International Association of Hydrogeologists. The programme aims at improving knowledge and cooperation for sustainable management of transboundary aquifers. In recent years hundreds of scientists, with the support of UNESCO-IHP, have dedicated themselves to this cause generously providing their expertise, research findings and insights to protect this invaluable treasure.

I am glad to note the progress of ISARM. The compiling of a Global Atlas containing information related to 270 aquifers shared by two or more countries has been a major achievement. By presenting detailed parameters and comparisons of the aquifers, the Atlas has effectively contributed to the collaborative management of transboundary aquifers. The spirit of cooperation this manifests will have a beneficial impact on efforts for transboundary aquifer protection around the globe. The Contributions from Asian hydrogeologists have played a key role in the growth of ISARM. It is their professionalism and commitment in establishing high-level coordination that has resulted in the publication of this volume on "Transboundary Aquifers in Asia-a preliminary inventory and assessment". As a regional atlas, this volume presents extensive geological, geographic and hydrogeological data and other information crucial to the future sustainability of transboundary aquifers in Asia. When combined with other regional atlases for Africa, America and Europe, this volume will contribute to a global inventory of transboundary aquifers.

Knowledge inspires action. I hope that the publication of this volume will alleviate the problems related to insufficient information and contribute to enhanced cooperation among Asian countries for sustainable management and protection of transboundary aquifers in future.

Abhimanyu Singh
Director UNESCO Office in Beijing
UNESCO Representative China, DPRK, Japan, Mongolia and Republic of Korea

FOREWORD

Groundwater, as a precious resource hidden underground, is an important component of the global water system. Transboundary aquifers containing substantial amount of groundwater often carry crucial ecological and social implications. Yet, it is unfortunate that transboundary aquifers have hardly been in the forefront of political and scientific discussions, and have not received due attention by policymakers. Approximately 40% 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 an important component of global water resource system. The world's largest aquifers, including the Rum-Saq, the Nubian, and the North Sahara aquifer contain substantial amount of water. Apart from their environmental function as vital natural resources, the aquifers also have crucial social implications.

Most of the natural resources occur in transboundary conditions and for sound management of these resources, cooperation between countries the UN Agencies are working with several national and regional organizations. One such initiative is UNESCO led International Shared (transboundary) Aquifer Resources Management (ISARM), forming part of the International Hydrological Programme (IHP). The ISARM initiative, which has been operational since 2003, also benefits from close cooperation with the International Association of Hydrogeologists (IAH), with the Organization of American States (OAS), with other regional and international institutions, as well as with UN organizations such as the Food and Agriculture Organization (FAO) and the UN Economic Commission for Europe (UNECE), to name but a few.

One of the objectives of the ISARM Programme from the outset was to conduct global and regional inventories of transboundary aquifers. It is with pleasure that I am able to report that this objective has been substantially achieved through the global atlas of transboundary Aquifers published by IHP during 2009. As a follow up of this initiative a regional inventory of transboundary aquifers with very well structured in three parts viz groundwater conditions in Asia; regional major transboundary aquifers inventory and case studies from country / basin level.

The publication also provides a factual backdrop to the recent Resolution of the UN General Assembly on the Law of Transboundary Aquifers Resolution 63/124 by a lead expert from UN International Law Commission and I have pleasure in commending this volume to the Member States.

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PREFACE

At the 14th session of the Intergovernmental Council of UNESCO's International Hydrological Program in 2000, the Council adopted Resolution XIV-12 launching the International Shared Aquifer Resources Management (ISARM) project, in partnership with the International Association of Hydrogeologists. The ISARM project aims to promote studies on transboundary aquifers to improve scientific knowledge and to develop a toolkit for the management of transboundary aquifers. Over the past decade the Programme has made huge leaps forward by compiling a global atlas of 270 aquifer systems that are shared by two or more countries (UNESCO IHP, 2009). Compiling the inventory, as the cornerstone of the atlas, was not an easy task. The gathering, comparison and integration of data required the coordinated effort of experts from many different countries. The dedicated scientists involved in the Programme, with the support of the UNESCO-IHP and its network of national committees, played a critical role in facilitating cooperation among Member States of the UN that share transboundary aquifers. Experts in the Asian region, in particular, have demonstrated a high level of coordination and cooperation. Their efforts have resulted in the present inventory and the Asian case studies presented in this volume.

Regional atlases have already been compiled for the continents of Europe, America and Africa. The addition of the Asian inventories has brought forward the completion of global inventories and assessments. The purpose of the atlas series is to provide a consistent set of basic information on the geography, geology and hydrogeology of transboundary aquifers. Until the year 2000, there was little information available to enable Member States to compare transboundary aquifers and develop policies addressing matters of joint concern on the management and sound use of transboundary waters. Rivers that cross international boundaries are visible and the discussions between neighbouring countries can be easily facilitated through a direct recognition of their value. Aquifers, on the other hand, are a 'hidden resource' and are often ignored by policy-makers. Transboundary aquifers have remained out of the scope of many joint management and cooperation efforts as a result. Insufficient scientific data has hampered joint management to date and the global inventory has helped to address these hidden resources explicitly.

The present volume of the inventory of transboundary aquifers for Asia is organised into three parts. The first deals with general issues related to aquifer resources management, the approaches adopted in the global mapping projects and the application of the same principles in the Asian region. The second part describes the major transboundary aquifers in the Asian region including their hydrogeological backgrounds. The third part of the atlas sets out several case studies from the Asian region on aquifers found in association with the major transboundary river systems including the Heilongjiang-Amur River Basin, the Mekong River Basin, and the Indus River Basin. These river basins contain huge aquifer systems which are highly connected to surface water resources and have large rural and urban populations dependent upon them for their water needs.

The UN's International Law Commission (ILC), with the technical support of UNESCO IHP and in consultation with a network of ISARM experts, has prepared a draft instrument that deals with the use and protection of transboundary aquifers. This work has been undertaken concurrently with the scientific work associated with the preparation of the atlas. In December 2008, the UN General Assembly adopted a Resolution encouraging Member States to make use of the Draft Articles prepared by the UN ILC as a basis for the development of cooperation on their shared transboundary aquifers. The UN General Assembly also proposes to discuss the status of the Draft Articles at its session in 2011, with a view to making a decision on their final form (Convention, guidelines, or other). A summary of the Articles is given in this volume.

The inventory of Asian transboundary aquifers is put forward as a contribution to international discussions relating to the scientific, socio-economic, environmental and legal aspects of major transboundary aquifers. It is hoped that the data provided in this volume will underpin further cooperation and enhanced scientific assessment of these precious resources.

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1. Groundwater and its Importance

Most of the Earth's freshwater is not found in lakes and rivers, but instead is stored underground in aquifers. Groundwater constitutes about 95% of the freshwater on our planet (discounting freshwater locked in polar ice caps), making it fundamental to human life and economic development. Indeed, aquifers provide a valuable base-flow, supplying water to rivers during periods when there is no rainfall to feed the river systems. They are, therefore, an essential resource that requires protection, so that groundwater can continue to sustain humanity and the various ecosystems that depend on it. The contribution from groundwater is vital; perhaps as many as two billion people depend directly upon aquifers for drinking water, and almost 40% of the world's food is produced by groundwater irrigated agriculture. In the future, aquifer development will continue to be fundamental to economic development and to the reliable supply of water for domestic, industrial and irrigation uses.

However, recognition of the pivotal role of groundwater in human development is relatively recent and still patchy. This omission is understandable; water stored in the ground beneath our feet is invisible, and so its depletion or degradation due to contamination can proceed unnoticed. In our rivers, lakes and reservoirs, however, drying-up or pollution rapidly becomes obvious and is reported by the media.

There are many reasons why society has found it so useful to develop groundwater, but among the most important are:

- aquifers are very convenient sources of water because they are natural underground reservoirs and can have an enormous storage capacity, much greater than even the largest man-made reservoirs. For example, in the four decades up to the early 1980s, an estimated 500km^3 of groundwater, equivalent to more than three times the total volume of either Lake Kariba or Lake Nasser, was withdrawn from the Ogalalla aquifer that underlies portions of eight states in central USA. Such storage capacity enables timely use of water, which can be pumped out during dry periods when corresponding surface resources, such as rivers or reservoirs, may be unable to provide enough water.
- many aquifers are also able to offer natural protection from contamination, so untreated groundwater is usually cleaner and safer than its untreated surface water equivalent.
- groundwater is relatively easy and cheap to use. It can be brought into use progressively with little capital outlay, and boreholes can often be drilled close to where the water supply is needed.
- it is a resource that is organisationally easy to develop; individuals can construct, operate and control their own supply, often on their own land.

Globally, groundwater use is enormous, but it is generally recognised that the extent of its use tends to be underestimated, not least because the very ease and ubiquity of groundwater development means that much vital small-scale use is excluded from official statistics. Groundwater is often taken for granted by governments and society. In the year 2000, twenty-three cities of the world

-three cities of the worlda population of more than 10 million, and are thus classed as "megacities". Over half of these cities rely upon, or make significant use of, local groundwater. China alone has more than 500 cities, which draw two-thirds of their water supply from aquifers. The use of groundwater for domestic supply is even more widespread in smaller towns and rural communities; this is well illustrated in eastern China, where the Huang-Huai-Hai aquifer system supplies nearly 160 million people. It is estimated that almost one-third of Asia's drinking water supply comes from groundwatsupply comes from groundwater.

During the last 30 to 40 years there has been an enormous rise in food production in many countries through the increased use of irrigation. Much of this irrigation water has been drawn from groundwater as people realise the advantages to increased productivity of timely irrigation and security of application. The rapid rate of growth in irrigation is perhaps best illustrated in India, where the amount of land irrigated by surface water has doubled between 1950 and 1985, but the area irrigated from aquifers has increased by 113 times, so that by the 1990s aquifers supplied more than half of the irrigated land.

Much of the world's industry is concentrated in developed and rapidly emerging economies.Third World economies account for only about 14 per cent of the world's industry and 60 percent of these economies are concentrated in nine countries, mainly in south-east Asia. This pattern is reflected both in the percentage of water withdrawn for industrial use and in the per capita volume of water used in industrial production .

Long standing hydrological research and investigation of the global water cycle has demonstrated that 99% of all accessible fresh water on the planet is found in aquifers. Almost 2 billion people on the planet rely entirely on a nearby aquifer for all of their daily water needs, and it is stated that groundwater is one of the most extracted resources on Earth.

The World's aquifer resources are an important component in sustainable development. Aquifers, and the groundwater in them, form one component of the broad context of the hydrological cycle system. Operating in a complex interrelationship, aquifers are thus an inseparable part of the environment. In nature, groundwater is a key element in many geological and hydro-geochemical processes, and it is a geotechnical factor in the conditioning of soil and rock behaviour. When discharging from an aquifer, groundwater also has an ecological function, as it sustains springs, river base-flows, lakes and wetlands and their aquatic habitats.

As with any naturally occurring resource, its excess use, over and above its natural replenishment rate, will result in impacts of a harmful nature, a phenomenon easily observed in the case of natural forests or easily appreciated in the case of marine fisheries. Just as excess fishing from rivers will harm aquatic habitats, so also excess withdrawal from aquifers will harm ecosystems that depend on aquifer-supplied water. Just as the science underlying sound management of forests and fisheries is well understood, so also is the science of aquifer resource management. The difficulty in the application of science to the sound management of aquifers lies in the fact that they are below ground and are a phenomenon that suffers from being 'out of sight', and thus 'out of mind', of the policy makers. By using much of the available modern day technologies, hydrogeologists have made tremendous strides in helping to visualise the hidden resources in aquifers through maps and three-dimensional models.

Nevertheless, there remains a knowledge gap linking science and sound policy. In the past three to five decades, withdrawal of water from aquifers has increased exponentially, reflecting humanity's increasing need for food and industrial production. A basic raw material of production is the freely available groundwater in aquifers, which is generally treated as a common good, and is subject to poor regulation. Global groundwater withdrawals are estimated to average from 600 to 800km^3/year. In many parts of the world, agriculture and particularly irrigation systems depend on groundwater resources. Groundwater is also the main drinking water source for more than a third of the world's population.

Aquifers receive replenishment from rainfall and are therefore mostly renewable. Depending on the size and the climatic location of aquifers, the renewal period ranges from days and weeks (in karstic rocks) to years or thousands of years in large sedimentary basins. However, in regions where present day replenishment is very limited (such as in arid and hyper-arid regions) the groundwater resource can be considered to be 'non-renewable'. Replenishment from ancient rainfall, which has been lying in storage since the Pleistocene geological periods, has been called 'fossil water' (Foster and Loucks, 2006) for convenience.[1]

The increasing recognition by the international community that fresh water resources are threatened because of the insufficient adoption of science-based policy tools has given an impetus to the detailed analysis of water resources in aquifers and to the adoption of a range of tools for their better management. Among the range of tools that have been developed is the improved 'visualisation' of aquifers and the resources contained in them.

This publication is a first collation of Asian regional and national inventories of the 'hidden' resources that summarises all available data collected by UNESCO-IHP.

1.1. Groundwater in Asia

Asia borders on the Arctic Ocean in the north, the Indian Ocean in the south, the Pacific Ocean in the east, and the Mediterranean Sea in the west. It covers an area of 44 million square kilometres and has a population of 3.5 billion. It is the largest continent in the world, both in area and population. There are 48 countries and regions in Asia. Geographically, it can 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. Asia's coast line is 69,900km long. There are many islands and peninsulas; Kalimantan is the third largest island in the world. The characteristics of Asia's topography are big gurgitations of the earth's surface, high in the centre with low surrounding areas, alternating with apophysis and depressed areas. Mountains, highlands and hills compose three quarters of the total area. Plains constitute another quarter and cover an area of 10 million square kilometres. At the epicentre are the Pamirs, a series of mountains which extend to the fringe of the continent. The Qinghai-Tibet altiplane, with an average altitude of 4,500m, is called "the roof of the world", and Everest, with an altitude of 8844.43m, is the highest mountain in the world. The plains are situated in the outboard of mountains and tablelands, and include the North China plain, Northeast China plain, Middle and Lower reaches of Yangtze River plain, Hindustan River plain,

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[1] "Fossil water" is an incorrect term, as it implies a change of state i.e. fossils are formed by the petrifaction of organic materials.

Ganges River plain, Mesopotamia plain and West Siberian plain. The Dead Sea is the lowest depression in the world with an altitude of 400m below sea level.

There are many rivers in Asia. Most of their sources are from the central mountains and flow radially in every direction. The major rivers that flow into the Pacific Ocean are the Heilongjiang-Amur River, the Yellow River, the Yangtze River, the Pearl River and the Mekong River. The major rivers that flow into the Indian Ocean are the Indian River, the Ganges River, the Salween River, the Ayeyarwady River, the Tigris River and the Euphrates River. The major rivers that flow into the Arctic Ocean are the Ob River, the Yenisei River, and the Lena River. The inland rivers are situated in the central and western arid areas of Asia. The major inland rivers are the Sill River, the Amu River, the Ili River, the Talimu River and the Jordan River. There are not as many lakes in Asia compared to other continents, and they can be classified into 5 regional 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 saltwater lake in the world; Lake Baikal is the deepest lake in the world and the biggest freshwater lake in Asia; the Dead Sea (which is actually a lake) has the lowest depression; Lake Balkhash is an inland lake with both freshwater and saltwater.

The three climate zones across the Asian continent are frigid, temperate and torrid zones. The climatic types are various and complex. Southeast Asia, South Asia and the south-eastern 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 most parts of north Asia are in the semi-humid, semi-arid zone. There are various levels of precipitation in different areas around Asia. The main direction of rainfall is from the humid southeast towards the northwest. There is abundant rainfall near the equatorial zone. Annual rainfall is more than 2,000mm. There are rainless periods throughout the year in the southwest and central Asian regions; large areas have less than 150mm of precipitation.

Groundwater resources vary across Asia. Some regions are underlined by aquifers extending over large areas, while the floodplain alluvial deposits usually accompany 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 little rainfall and strong evaporation in the inland arid areas of Central Asia. However, the thawing of glaciers and snow in the high mountains is favourable to groundwater recharge. The Loess Plateau in Central Asia has a specific topography. Continuous aquifers are only distributed in Loess tableland. The carbonate rocks are widely distributed in Southeast Asia. In southern China and on the Indochina peninsula, there is stratified limestone from the late Paleozoic and Mesozoic in which karst is considerably developed. The reef karst can be found on coastal islands. A lot of Quaternary volcanic rock is extensively distributed on the circum-Pacific islands, which forms asymmetrical ring aquifers. The piedmonts of volcanoes mostly contain spring water with a high water quality.

Groundwater resources assessments have been done in most countries in Asia. Evaluation and mapping of groundwater recharge and runoff of individual basins and regions are in progress. The medium-scale hydrogeological surveys have performed regional quantitative assessments of natural groundwater resources in most countries in Asia. Groundwater runoff is an important component of the hydrological cycle. Local hydrogeological conditions of different regions affect the distribution of groundwater runoff/precipitation ratios. Those ratios are less than 10% in the arid areas of Central Asia, and more than 40% in the karstic areas of 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, and continuous water quality and natural groundwater discharge and abstraction networks are operational in urban areas. Groundwater assessment, monitoring and data management activities are undertaken regularly in China, India, Japan, Korea, Malaysia and Thailand, but are done less frequently in other developing Asian countries.

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

The development of groundwater has increased in the past 30 years. The ratio of groundwater abstraction with mean recharge is done at the country level. There are many areas where the over-abstraction of groundwater occurs at the provincial level. In some arid regions of Asian countries, where sufficient renewable groundwater resources are not available, non-renewable groundwater is being exploited to support development, such as in the coastal area of the north China plains.

Groundwater is crucial for human drinking and food security, especially in developing countries. The impact of groundwater use is positive and includes benefits such as increased productivity, food security, job creation, livelihood diversification, and general economic and social improvement. In the long run, and especially in overexploitation situations, the impact of groundwater extraction might be negative, with effects such as the permanent lowering of the water table, deterioration of water quality and saline intrusion in coastal areas. The social and economic dimensions of groundwater use, as well as its benefits, are important for development in Asia. Some of these benefits are linked to the inherent characteristics of groundwater as a resource. 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 voids helps purify water used as drinking water. The almost ubiquitous availability of groundwater makes it 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 food security and has helped to 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 of 210 million tons in 2002-2003. Similarly, Bangladesh, which was dependent on foreign aid for a long time, had sufficient food supply in 1999-2000 due to groundwater irrigation. Groundwater irrigation can be an effective way to alleviate poverty, especially in water abundant areas such as the eastern part of India, Bangladesh and Nepal.

Since the 1970s, groundwater extraction has increased greatly in China, India, the 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 hectares in 1970-1971 to 33.1 million hectares in 1998-1999, an increase of over 178%. The number of groundwater extraction mechanisms rose from less than 1 million in 1960 to almost 26-28 million in 2002. In Pakistan's Punjab region, the number of mechanized wells and tube wells increased from barely a few thousand in 1960 to 500,000 in 2000. Bangladesh saw an increase in the number of tube wells, from 93,000 in 1982-83 to almost 800,000 in 1999-2000.The groundwater extraction in China was 111km^3 at the end of the last century compared to 57km^3 in the 1970s and 75km^3 in the 1980s, doubling in the last 30 years. It is estimated that there ware 3,500,000 tube wells used for agriculture, withdrawing 68km^3 of water in 1999, constituting 61% of the total groundwater withdrawal. But it has decreased since the 1980s when groundwater used for agriculture was 88% of the total. On the North China plains, groundwater irrigation has supported the development of agriculture over the past 30 years.

Table 1-1 Water availability per person/ per year in 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	Vietnam	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

1.2. Problems with Groundwater in Asia

Problems with groundwater are due to natural causes and human actions. Natural causes affect the quality of groundwater in the arid and semi-arid areas, especially in the central part of Asia. Global climate change has diversified the hydrological conditions in both inland and coastal areas of Asia. Problems caused by human actions are groundwater overexploitation, resulting in supply shortages, and related land subsidence, seawater intrusion, and groundwater contamination. These problems have increased rapidly over the last 20 years.

1.2.1. Groundwater Quality

Most renewable groundwater is of high quality for domestic use and does not require treatment, but the majority of groundwater is unacceptable for drinking in its natural form. In arid and semi-arid areas, there is a high salt content in shallow groundwater.

There are high contents of arsenic and fluorine in groundwater in many regions of Asia. In Bangladesh and the neighbouring Indian states of west Bengal, the high level of arsenic in the groundwater used for drinking has become a public health time-bomb. 61 out of Bangladesh's 64 districts found arsenic in their groundwater. An estimated 35 million people are at risk of being exposed to arsenic poisoning through drinking water. In China, groundwater with high arsenic levels was found in several areas including Inner Mongolia. Fluoride is a common constituent of groundwater. Natural sources are connected to various types of rocks and to volcanic activity. Activities in agriculture (e.g. use of phosphate fertilizers) and industry (e.g. clays used in ceramic industries or burning coal) also contribute to high fluoride concentrations in groundwater. High levels of fluoride in groundwater have emerged as an important environmental problem in India, Pakistan, Vietnam and Indonesia. The high fluoride content of groundwater has caused endemic problems in some areas of northern China. The supply of drinking water must be treated with advised methods.

1.2.2. Overexploitation of Groundwater

Groundwater overexploitation has occurred in many parts of Asia, such as Gujarat in India, the north China plains and in some areas of Pakistan. They relate to the decline of groundwater levels, reductions in well outputs, seawater intrusion in coastal aquifers, land surface subsidence, and movement of mineralized or polluted waters into aquifers. Generally, the decline in groundwater levels results in increased costs 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, the Maldives, the Republic of Korea, Sri Lanka and Thailand. In Thailand, for example, increasingly heavy pumping of ground water in Bangkok between 1955 and 1982 caused a decline of 45 to 50 meters in groundwater levels. The lowering of water levels by these depths resulted in the abandonment of old wells, increased pumping costs and the encroachment of seawater. In order to prevent the situation from getting worse, it is necessary to reduce pumping rates to an intensity that stops the decline in 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.

1.2.3. Groundwater Pollution and Contamination

Groundwater contamination is often a result of industrial, agricultural and subsistence pollution, which in turn is due to increased economic activity. Drainage water from irrigated lands, for example, usually contains high concentrations of objectionable minerals. The contaminated water that flows off the land through ditches can seep into the soil and pollute the groundwater that is pumped from wells. Countries facing this kind of problem include the Republic of Korea, Thailand and Vietnam. In the Republic of Korea, the expansion of industry during the last decade and the modernization of agriculture have exposed its vulnerable (shallow and permeable) alluvium aquifers to various sources of contamination. In Thailand, until quite recently, shallow ground water had been generally free from pollution. However, at present, groundwater has become contaminated in some places where aquifers are directly recharged by polluted rivers or directly reached by irrigation water runoff. Similarly, in Vietnam, in agricultural areas underlain by karstic limestone, fertilizers have reached the karstic water circulation and have contaminated the groundwater.

1.2.4. Problems Related to Coastal Areas

Particularly in coastal areas, seawater intrusion and the encroachment of salt water is a serious issue for groundwater use. Since a large portion of the region's population is located along coasts, there are many problems of this kind in Asia. Countries and regions with problems of this nature include China, Japan, Thailand and Vietnam. Basically, encroachment occurs when the water levels in a freshwater aquifer are lowered to 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 irreversible. 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, it 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-extraction has caused shallow aquifers in Bangkok to become contaminated with salt water. In Vietnam, 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 groundwater is approximately 3 g/l to 4 g/l, while themaximum salinity sometimes reaches as high as 10 g/l, thus rendering the ground water unsuitable for drinking.

1.2.5. Land Subsidence

In some Asian countries, the withdrawal of large amounts of groundwater has caused serious land subsidence problems. 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 present, the occurrence of land subsidence and/or seawater intrusion was the result of overexploitation of groundwater brought about by the remarkable growth in 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 of Tokyo, Nagoya, Osaka, Yamagata and Kofu are located. In Thailand, overexploitation of groundwater exists in many locations, particularly around Bangkok. In Bangkok, field evidence of land subsidence has been found in the form of the protrusion of well casings above ground level. 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 centimetres 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 centimetres 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 from 1921-1965, and particularly between 1949 to 1957, during which an increase in groundwater pumping 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; and 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 an effective groundwater management program to prevent land subsidence caused by over-pumping.

1.3. Challenges for Hydrogeologists

Increasing demand for groundwater and resulting environmental problems are key challenges for Asian hydrogeologists. There are many issues that need to be resolved. The main tasks are the assurance of groundwater for the livelihoods and food security of millions of people, the sustainable use of groundwater for sustainable socio–economic development, and the effective management of groundwater into the future. Groundwater monitoring, dynamic assessment and the conservation of groundwater dependent ecosystems are the major ways to address these issues. Greater knowledge and the improvement of basic data through research are prerequisites for the improved management of groundwater systems. We should realize that using last century's schemes alone is no longer sufficient to solve the challenges related to today's groundwater situation. Understanding the characteristics and behaviour of groundwater resources is the basis for future action. It is also crucial to investigate the characteristics and behaviour of resource user communities and the institutional framework under which the resource is appropriated. There is an urgent need to add increased understanding of user and institutional perspectives to the groundwater knowledge base.

In general, there are two basic approaches for dealing with the problems related to the 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 groundwater is to limit or reduce the supply of groundwater and increase that of surface water. In this regard, it is necessary to have integrated management of both surface and groundwater resources.

It can be seen that the benefits of groundwater have considerable impacts on Asia. The use of groundwater has involved drinking, food production and the creation of livelihood opportunities for millions of people. The aim in governing groundwater is to ensure the negative impacts of intensive use will not exceed the benefits. The key challenge for hydrogeologists is to devise ways and means of reducing the negative impacts of groundwater use without significantly reducing benefits. In this context, hydrogeologists in Asia have an important role in providing updated data and analyses that will help decision-makers to formulate implementable and socially acceptable policy responses.

2. Hydrogeological Mapping and Assessment: The WHYMAP Project

During the past decades, the interest in groundwater has increased considerably due to water shortage problems at a local, regional and even global level. The use of groundwater is considered an appropriate way out of regional water crises caused by population growth, economic growth and the associated water shortage problems. But information on these 'hidden' resources is still weak in many places. The Worldwide Hydrogeological Mapping and Assessment Project (WHYMAP) is being led by UNESCO and the German Federal Institute for Geosciences and Natural Resources (BGR). It was launched in 1999 by UNESCO as part of the IHP Programme to contribute to the worldwide efforts to better understand, manage and protect aquifer resources.

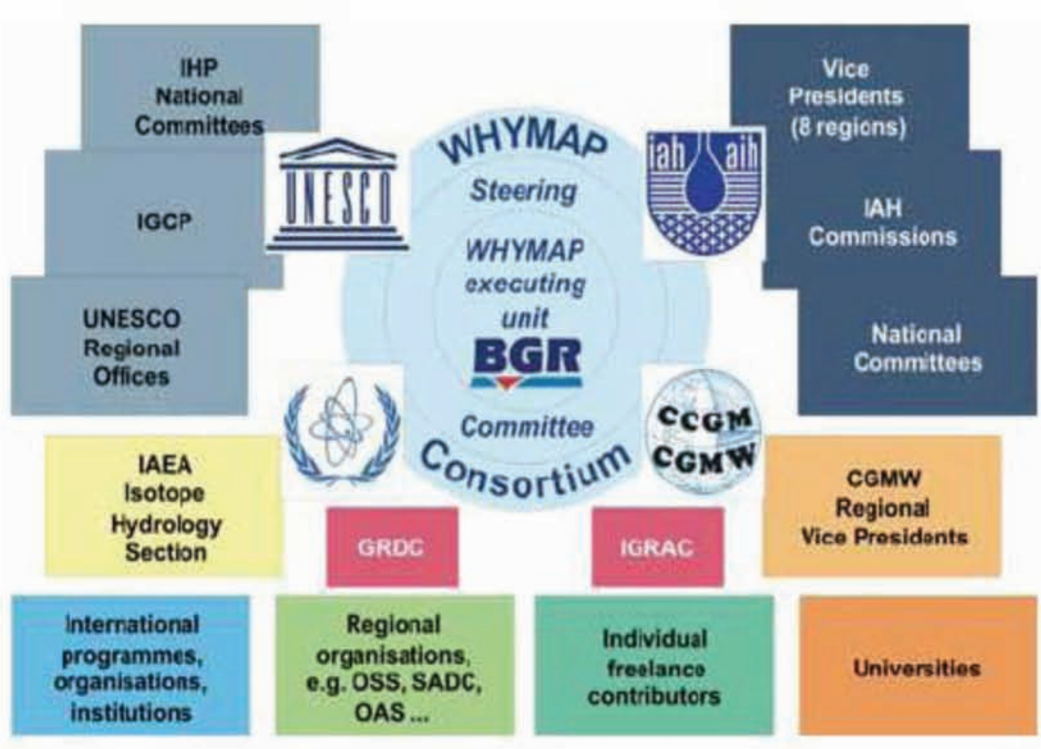
The programme aims at collecting, collating and visualising hydrogeological information at a global scale in a geographic information system (GIS). Maps are convenient tools to convey groundwater related information in an appropriate way to groundwater experts as well as to non-experts and politicians, e.g. they are used for international publications like the World WaterAssessment Programme (WWAP) issued by the United Nations. WHYMAP thus brings together the huge hydrogeological mapping efforts at regional, national and continental levels.

Close cooperation with the International Groundwater Resources Assessment Centre (IGRAC) in Utrecht is assured through UNESCO to clarify the role of groundwater in discussions on the Millennium Development Goals declared by the international community.

2.1. The WHYMAP Structure

WHYMAP is the joint programme of a consortium consisting of UNESCO, the Commission for the Geological Map of the World (CGMW), the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The consortium is responsible for the general thematic outline and management of the programme. As the executing unit, BGR provides important resources in terms of manpower, mapping capabilities and data. In 2002, a committee of eminent international experts was established under the supervision of the consortium. This WHYMAP-Steering-Committee is supported by the continental Vice Presidents of the IAH and CGMW, the UNESCO regional offices and the National Committees of UNESCO's International Hydrological Programme IHP.

The WHYMAP Programme has already produced a number of maps presenting the Groundwater Resources of the World. As a first step of the realisation, continental drafts at the working scale of 1 : 10 000 000 were compiled based on existing hydrogeological maps of continents, regions and countries. Because the available maps were not homogeneous, specialised interpretation and translation were necessary to make this information compatible with the designated legend of the global map.



Coping with the different and often unknown projections of these maps was also a special challenge.The continental drafts are revised and completed by the members of the WHYMAP-Steering-Committee along with other hydrogeological mapping experts who contribute regional knowledge from all parts of the world. Finally, a new consistent global groundwater map is compiled by adjusting and merging the continental drafts. Step by step, different thematic layers are prepared for the global groundwater map. In some cases, a single organisation or a group of institutions is responsible for the compilation of one specific thematic layer, e.g. the information on groundwater recharge is developed under the auspices of IAEA, while the layer on transboundary aquifer systems is mainly realised by IGRAC and the International Shared Aquifer Resources Management (ISARM) project led by UNESCO. Different IAH commissions are working on global maps of karst aquifers, groundwater vulnerability, coastal aquifers and the hydrogeology of hard rocks.

The main focus of the WHYMAP Programme is the establishment of a modern digital Geo-Information System (GIS) in which all global data relevant to groundwater is stored together with its geographic reference. Hydrogeological information published in national and regional maps is converted into a digital version, and is available in a GIS compatible format. Scanned maps are integrated as graphics, and metadata is collected for each map. These activities have led to a world-wide information system on hydrogeological maps.

From the WHYMAP-GIS database, a variety of high quality thematic map products at different scales and complexities can be derived. In addition, the information is visualised via an internet-based map server application, which is available at <http://www.whymap.org>.

2.2. First Results and Products

A first overview at a scale of 1 : 100 000 000 was compiled as a contribution to the 3rd World Water Forum in Kyoto in March 2003 and published in the first World Water Development Report (WWDR) of the United Nations.

In August 2004, a first special edition of the global groundwater resources map at a scale of 1 :50 000 000 was released at the International Geological Congress in Florence.

A second special edition at the same scale that focused on the transboundary aquifer systems of the world was compiled for the Fourth World Water Forum in Mexico City in March 2006. The corresponding explanatory text on the back of each map gives background information on the project and a description of the map itself. On the one hand, this is intended to inform the scientific community about the WHYMAP Programme and asks for contributions. On the other hand, WHYMAP aims at raising awareness of groundwater as an important natural resource amongst politicians and the general public. Several thousand copies of the map have been sold and distributed at important conferences and symposia.

2.3. Recent Products

Global groundwater maps: a global groundwater wall map 'Groundwater Resources Map of the World 1 25 000 000 (edition 2008)' .

Continental groundwater maps: Africa/ Asia/ Southeast Asia, Australia and New Zealand/ Europe/ North America/ South America.

Additional global maps for publications and presentations, in particular: River Basins and Transboundary Aquifer Systems, River Basins and Mean Annual River Discharge, Mean Annual Precipitation, Groundwater Recharge (1961–1990) per Capita.

Geographic Information System (GIS) with supra-national, continent-wide, groundwater related data.

WHYMAP Web Mapping Application: The Web Mapping Application, with embedded World-wide Hydrogeological Map Information System (WHYMIS), aims at visualizing hydrogeological information collected within the WHYMAP project at a global scale. For more regional or country level interest, additional information on available hydrogeological maps is provided. The Transboundary Aquifer Systems global map and other maps can be downloaded from <http://www.whymap.org>.

3. Asian Hydrogeological Mapping

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Global economic integration must take account of the world's resources and environment. Rapid economic development in Asia means that it also faces the challenge of resource guarantee and environmental protection. Due to rapid social and economic development and high rates of population growth, the resource and environmental issues facing Asia in the twenty-first century are staggering. The shortage of energy and resources, environmental deterioration and frequent geological disasters constitute a threat to the living environment and to the sustainable economic development of Asia and even the world. In particular, the guarantee of water resources and the geological environment exert an immediate influence on the sustainable development of Asia.

Entitled "Mapping of Groundwater Resources and Environmental Geology in Asia", the project was initiated by the IAH China Chapter and financially assisted by the China Geological Survey. It will be undertaken by the Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, in co-operation with hydrogeologists from other Asian countries. The project will obtain guidance and technical support from the IAH Mapping Commission, the UNESCO Office in Beijing and other international organizations.

The objective of the project is to do a comprehensive study of the status of groundwater resources and environmental geology in Asia; to compile a series of maps of groundwater resources and environmental geology; to establish a database of groundwater resources and environmental geology for Asia; and to provide the basis for the development and utilization of natural resources, water resources planning and environmental protection within Asia.

The work starts with the collection of groundwater resources and environmental geology data from Asian countries, especially data since 2000, including scientific reports, published maps, databases and other related information. Thereafter, all the collected information will be classified and an outline made for the mapping of groundwater resources and the geological environment. The output will be a series of maps and a database for groundwater resources and the geological environment. The project also studies the process of international cooperation in the management of international river basins such as Greater Mekong and Kerulen River Basins.

The expected achievements of the project include: a Map of Groundwater Resources in Asia (1:8,000,000); a Map of Groundwater Environment in Asia (1:8,000,000); a Map of Groundwater Development and Utilization in Asia (1:8,000,000); a Map of Geothermal Resources in Asia (1:8,000,000); a Hydrogeological Map of Asia (1:8,000,000); and a database of groundwater resources and environmental geology in Asia. With respect to the mapping work, the wholeregion will be divided into six sub-regions: northern Asia, eastern Asia, southern Asia, south-eastern Asia, central Asia and western Asia.

The project aims to study groundwater resources and the geological environment in Asia on an intercontinental regional scale, and will compile a series of maps for groundwater resources and environmental geology. It will also establish a real-time information integration system of groundwater resources and environmental conditions in Asia so as to provide the basis for the development and utilization of natural resources, water resources planning as well as geological environment protection.

Regionalism will be applied to the geological environment in Asia based on the geomorphotectonic framework, natural geography, geological environment and human activities. The project also covers the study of groundwater resource distribution of various aquifers (pore water, fissure water and karst water) in Asia, the calculation of groundwater recharge (runoff) modulus, and the natural recharge and exploitation of each groundwater region (system). The project will also establish a spatial database of groundwater resources and the geological environment in Asia in order to realize transboundary data sharing and promote the building of transbasin, transboundary, even transcontinental information systems on groundwater resources and environmental geology.

In accordance with the continental geomorphology and the natural geographical conditions in Asia, the main characteristics of the continental groundwater geological environment will be documented through the full analysis of groundwater and its surroundings, latitude, and the relationship between the climatic horizontal zoning and the topographic vertical zoning. It will reflect groundwater occurrence, groundwater quality, groundwater resources status, geothermal resources and groundwater environment issues related to human activities.

The appropriate mapping method will be used for this project by basing it on former compilations, in particular the “Map of Groundwater Resources in China”, the “Map of Groundwater Environment in China”, the “Map of Groundwater Resources over the World” and similar maps from Asia, Europe and America. It the meantime, the database and the information administrative system for the Asia Groundwater Resources and Environmental Geology will be set up.

The compilation is organized in the form of international cooperation to first compile the maps and then to create the map series of the continental groundwater resources and environment. International cooperation will improve academic exchanges and scientific development in groundwater and the natural environment upon which the population of Asia relies.

The compilation will be by way of uniform rules to make the continental maps of groundwater resources and environmental geology along with the zonal mapping. The maps will then be joined together for the final compilation. Joint international mapping together with this project can be the model by which map series are made. The former mapping method can be used together with new and creative techniques for the compilation.

Different countries with different research standards may be considered to be equal for the project but to be responsible for their contribution to the project. The zonal compilation together with the mapping coordination to create one useful resource makes full use of international cooperation, and allows the contributors to the map series to be subject to the same standards and equal demands.

The continental mapping project may help to increase academic exchanges and to improve the development of the discipline. There is only one technical requirement for mapping: the specific scale will be 1:8000,000 for the continental map, 1:5,000,000 for the six regional maps, and 1:2,000,000 for the individual country which provides the data.

The basic way of making the geological base map should be to standardize one mapping rule in accordance with the mapping content. To analyze and compare the study status of the groundwater resources and environments of each country in Asia, the mapping outline and performance rules should be made suitable to the mapping content to show the features of groundwater resources and the surrounding environment.

In order to make clear the conditions in areas without sufficient data, remote sensing interpretation and mapping should be made with the application of RS technique and data from MODIS and NOVA. The project has adopted the GIS technique to establish a real-time information management system and realize data sharing with other partners.

Groundwater resources and environmental geology should be studied together by applying the general theories and techniques applicable to the study of groundwater systems". I am unsure what the "to make out the division scale of one. The transboundary aquifer comparison technique should be applied to study the development and utilization of groundwater resources in the transboundary area. The leading country of each region should be responsible for the data collection concerning groundwater resources and environmental geology within the region and the deadline for data collection was the end of 2009.

The analysis and processing of data will be based on groundwater resources and environmental geology and the overall requirements of different regions will provide the basis for the mapping of groundwater resources and environmental geology in Asia. The typical and representative data will be selected for comparison and analysis to study the degree of each region.

3.1. Map of Groundwater Resources in Asia

Groundwater resources zoning will be based on the ocean system, the river system and thegeographic unit, as well as the groundwater resources evaluation of the country. Each regional map should include the groundwater pattern, the natural recharge modulus and natural groundwater resources, exploitable water resources and deep aquifer reserves with exploitable conditions. Groundwater natural recharge usually uses the modulus (104m^3/a.km^2) or recharge amount (mm/y). Its grade can be based on the recharge conditions of morphology, climate, hydrology, and aquifer medium. Therefore, the available quantity of groundwater is reflected by the water unit which may show the exploitable amount and the deep aquifer reserves. What should be noticed is the repeat calculation at the folded areas between the units when you calculate the different groundwater system's amount. Notice should be taken of the important 'protected groundwater resource areas' where groundwater is at risk of overexploitation potentially causing negative effects.

The compilation should be based on the evaluation result of the groundwater resources assessments for each country. The compilation for countries without evaluation can be by way of remote sensing interpretation to the natural recharge amount (mm/y).

3.2. Map of the Groundwater Environment in Asia

The main content includes the spatial distribution of groundwater quality, the water quality type and geochemical zone, the special area with original chemical components which may impact human health, and the hazards induced by unreasonable exploitation. Groundwater quality refers to the Quality Standard for Drinking Water of the WHO. Water quality is divided into grades according to the total dissolved solids, hydrochemical type, water quality and water pollution. Hydrogeochemical zoning is based on the hydrochemical type and total dissolved solids to present the regional horizontal zones. It can also express the vertical zoning and the chemical components which may impact health and can become a hazard induced by unreasonable exploitation.

3.3. Map of Hydrogeology in Asia (Revision):

The existing map of hydrogeology in Asia should be revised. The map mainly reflects groundwater type and the capacity of groundwater occurrence and its yield. The regions are divided in accordance with climate and geomorphology. The deep-buried groundwater will be ranged in the wide plain and large basin with the capacity of water supply. The map also includes the outcrop of springs, subterranean river and thermal springs etc.

The existing map of hydrogeology in Asia was published years ago and was compiled by China. At present, the continental maps are gradually being renewed with new information about regional strata, groundwater type and reserves. Groundwater potential and yield capacity can be evaluated by way of aquifer medium as the fissure structure groundwater, the underlying karst groundwater and the fracture-fissure basin to obtain variation of the recharge to groundwater.

3.4. Map of Geothermal Resources in Asia

The main contents of the map will include the pattern of geothermal resources, the boundaries of geothermal fields, geothermal control structure lines, and the outcrop of geothermal springs and their special chemical components.

Pilot mapping of the following selected areas have been carried out so far:

- Hydrogeological Map of Lancang River-Mekong River Basin
- Groundwater Environmental Map of Lancang River-Mekong River Basin
- Groundwater Resources Map of Lancang River-Mekong River Basin
- Groundwater Resources Map in the catchment basin of the Herlen River and its adjacent areas
- Groundwater Environmental Map in the catchment basin of the Herlen River and its adjacent areas
- Hydrogeological Map in the catchment basin of the Herlen River and its adjacent areas.

Hydrogeological Map of Lancang-Mekong River Basin

Scale 1:5 000 000

(Pilot map)

Legends

Types of ground water occurrence	Yield capacity				
	Ultimate	Strong	Medium	Weak	Minimum
The fissure aquifer					
The karst aquifer					
The fractured aquifer					

Groundwater boundary and its code

Distribution of multi-structure fissure aquifer (deep-confined aquifer) (The figure shows the buried depth)m

Underlain karst distribution (The figure shows the buried depth)m

Fractured-fissure basin (The figure shows the buried depth)m

Frosted-melt area

Spring(ascending spring L., descending spring R.)

Subterranean river

Thermal spring

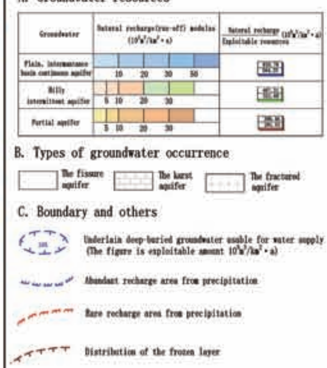
Crater

Code	Groundwater system	Area ($10^4 km^2$)
Ⅰ	Lancang-Mekong River Basin	79.5 (81.1)
Ⅱ	Yuanjiang-Red River Basin	11.30
Ⅲ	Nujiang-Thanlwin River Basin	32.5
Ⅳ	Ayeyarwady River Basin	43.1
Ⅴ	Yarlung Zangbo-Brahmaputra River Basin	93.8
Ⅵ	Changjiang(Yangtze River) Basin	120.6 (179.9)
Ⅶ	Pearl River Basin	27.6 (45.4)
Ⅷ	Beibuwan Rivulet—Lei-Qiong Regions	45.37

Groundwater Resources Map of Lancang-Mekong River Basin

Scale 1:5 000 000 (Pilot map)

Legends



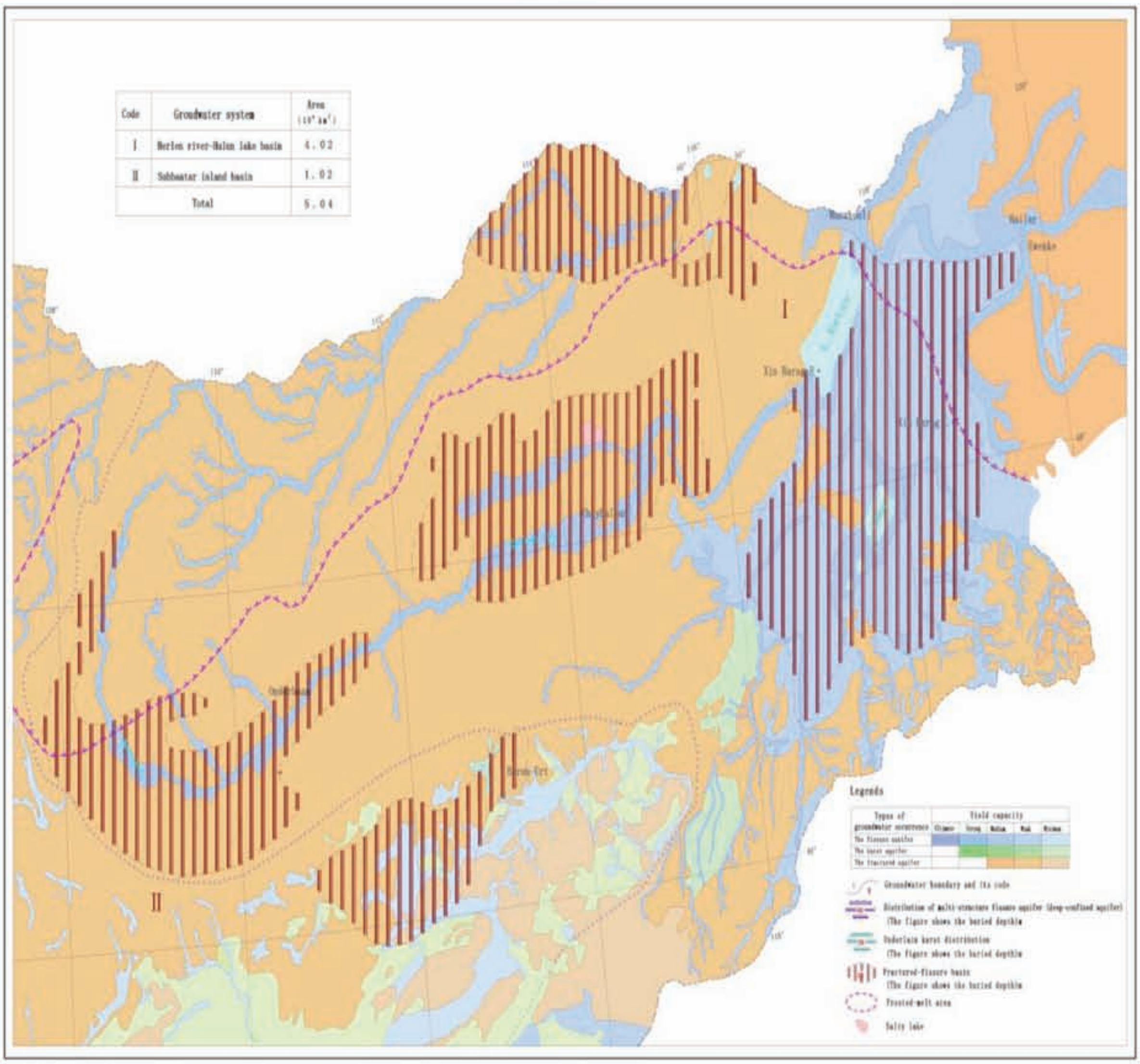
Mekong R. groundwater resources(10^8m^3/ a)

Groundwater resources	Fissure water	Karst water	Fractured water	Total
Natural recharge resource	427.43	284.96	712.39	1424.79
Exploitable resource	256.46	170.97	427.44	854.87

Code	Groundwater system	Area (10^4km^2)
I	Lancang-Mekong River Basin	79.5 (81.1)
II	Yuanjiang-Red River Basin	11.30
III	Nujiang-Thanlwin River Basin	32.5
IV	Ayeyarwady River Basin	43.1
V	Yarlung Zangbo-Brahmaputra River Basin	93.8
VI	Changjiang(Yangtze River) Basin	120.6(179.9)
VII	Pearl River Basin	45.37
VIII	Beibuwan Rivulet—Lei-Qiong Regions	45.37

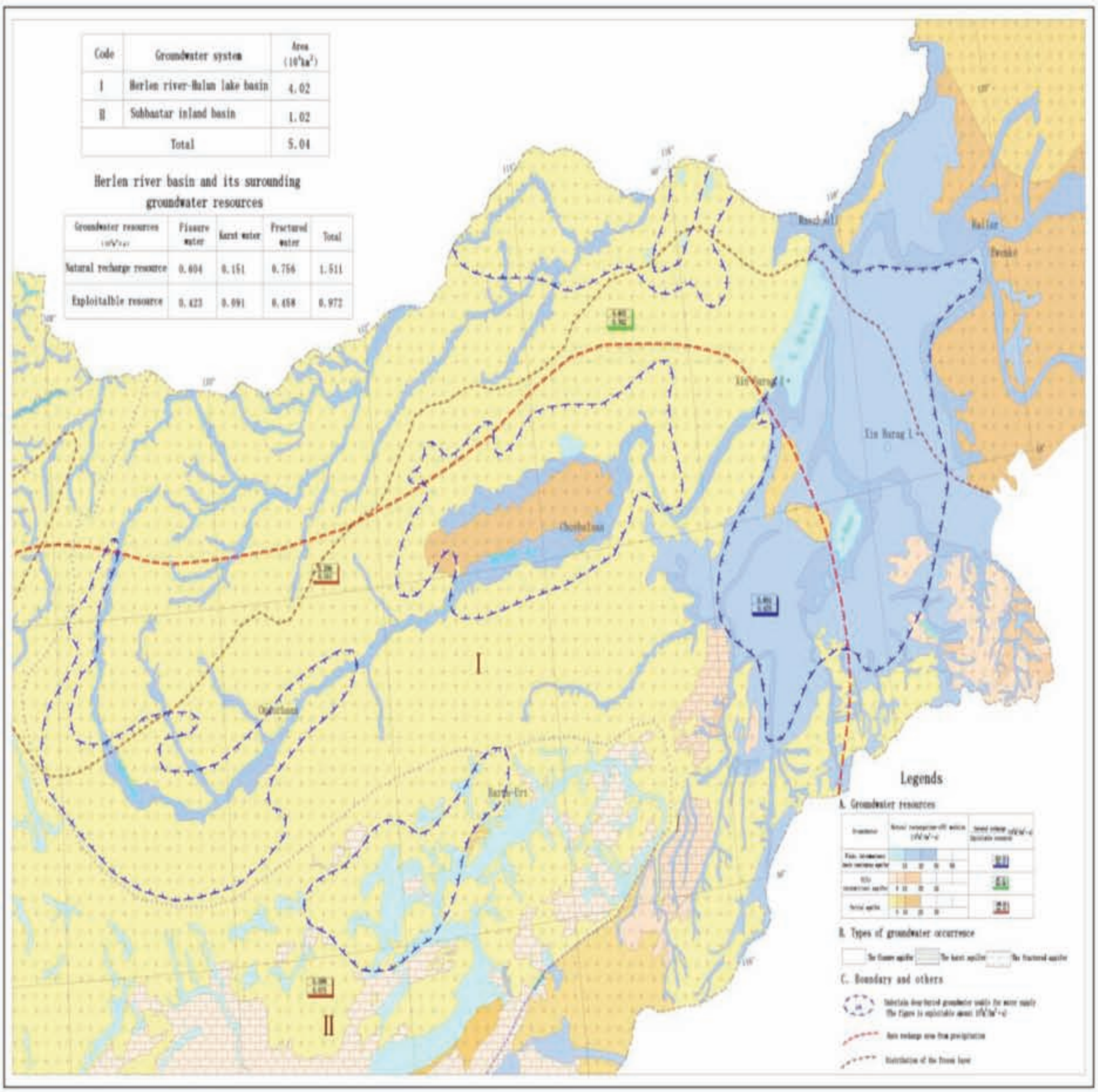
Hydrogeologic map in the catchment basin of the Herlen river and the peripheral region (Pilot map)

Scale 1:2 000 000



Map of groundwater resource in the catchment basin of the Herlen river and the peripheral region (Pilot map)

Scale 1:2 000 000



4. International Shared Aquifer Resources Management

THE INTERNATIONAL SHARED AQUIFER RESOURCE MANAGEMENT (ISARM) PROGRAMME was launched by the International Hydrological Programme of UNESCO in June 2000. Until then, no global estimation for transboundary aquifers was available. The Intergovernmental Council of UNESCO's International Hydrological Programme (IHP) responded to this knowledge gap at its fourteenth session (23–25 June 2000) and adopted a resolution to launch a worldwide inventory and assessment of transboundary aquifers.

ISARM is a UNESCO led multi-agency effort aiming at improving cooperation between countries sharing aquifers and aquifer systems. It has developed a multidisciplinary approach including five focal areas. It intends to contribute to the understanding of a) scientific, b) socio-economic, c) legal, d) institutional and e) environmental issues related to the management of transboundary aquifers.

It is coordinated and sponsored by UNESCO International Hydrological Programme (UNESCO-IHP). IHP cooperates with a wide number of organizations, including the International Association of Hydrogeologists (IAH), UN Food and Agriculture Organisation (FAO), UN Economic Commission for Europe (UNECE), Organisation of American States (OAS), International Network of Water-Environment Centres for the Balkans (INWEB), International Groundwater Resources Assessment Centre (IGRAC), World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), Federal Institute for Geosciences and Natural Resources (BGR), Bureau de recherches géologiques et minières (BRGM), the Sahara and Sahel Observatory (OSS), UN Economic and Social Commission for West Asia (UNESCWA) and GEF (Global Environment Facility).

This program has launched a global inventory and a number of global and regional initiatives. These are designed to delineate and analyze transboundary aquifers and aquifer systems and to encourage riparian states to work cooperatively toward mutually beneficial and sustainable shared groundwater resources management.

4.1. Specific Objective of ISARM

- To establish a network of experts from different disciplines for identification and definition of shared aquifers resources.
- To promote scientific, legal, socio-economic, institutional and environmental assessment of shared aquifer resources.
- To identify several Case Studies of shared aquifers and support multidisciplinary experts teams to conduct detailed investigations.
- To learn, from Case Studies, the issues relevant to good management of shared aquifers resources.

- To raise the awareness of policy and decision makers of the significant and importance of transboundary aquifer resources, forming a critical component of the world freshwater resources.

- To promote co-operation among experts from the different countries that share transboundary aquifers, through making available scientific tools, water resource management options and methodologies that apply to such aquifers.

4.2. Scope of Activities

- Carrying out and publication of the inventories of shared aquifers.

- Preparation and wide distribution of material promoting the concept of co-operation for optimal and sustainable management.

- Dissemination of existing information on shared aquifers.

- Setting up of databases.

- Preparation of training course material and organisation of the courses.

4.3. Partners

ISARM is sponsored by UNESCO International Hydrological Programme (UNESCOIHP) and is operating in coordination with UNESCO-IHP National Committees, Member States and differen-tintergovernmental, governmental and international associations. It operates through a joint effort of a number of organizations, including among others:

- International Groundwater Resources Assessment Centre (IGRAC)

- International Association of Hydrogeologists (IAH)

- UN Food and Agriculture Organisation (FAO)

- UN Economic Commission for Europe (UNECE)

- Organisation of American States (OAS)

- International Network of Water-Environment Centres for the Balkans (INWEB)

- The Sahara and Sahel Observatory (OSS)

- UN Economic and Social Commission for West Asia (UNESCWA)

- Bureau de Recherches Géologiques et Minières (BRGM)

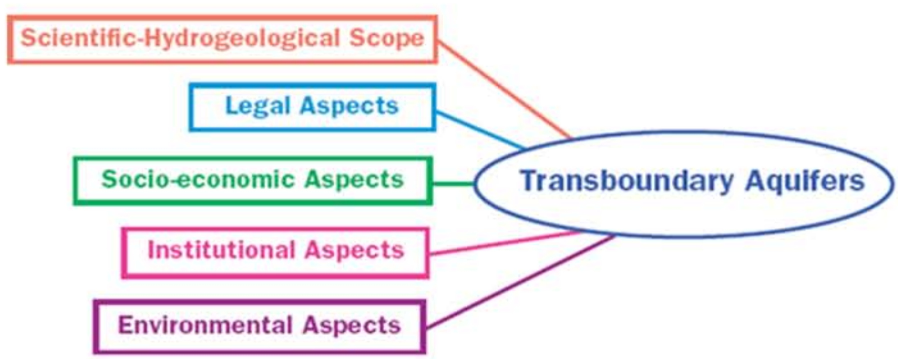
- The German Federal Institute for Geosciences and Natural Resources (BGR)
- Global Environment Facility International Waters (GEF IW)
- United Nations International Law Commission (UNILC).

4.4. ISARM Five Focal Areas: Issues for Multidisciplinary Management

The sustainable and equitable use of the groundwater resources contained in transboundary aquifers requires a full understanding of the aquifers characteristics (geology and hydrogeology) as well as the clear definition of aspects related to legal, socio-economic, institutional and environmental aspects.

At a global scale, sustainable development of transboundary aquifers seems to be hampered by weak social and institutional capacity, and poor legal and policy frameworks. This is even further amplified because of contrasting levels of knowledge, capacities and institutional frameworks on either side of many international boundaries. Whereas there are good examples of how such issues have been dealt with in managing international rivers, there is no equivalent body of knowledge for the management of shared aquifers, the majority of which have only recently been inventoried.

The ISARM Programme has identified five key focus areas that require attention for sound development of transboundary aquifers. The ISARM Framework Document published by UNESCO in 2001 gave a preliminary overview of each focus area (this document can be downloaded at <http://isarm.net>).



4.4.1. Scientific-Hydrogeological Scope

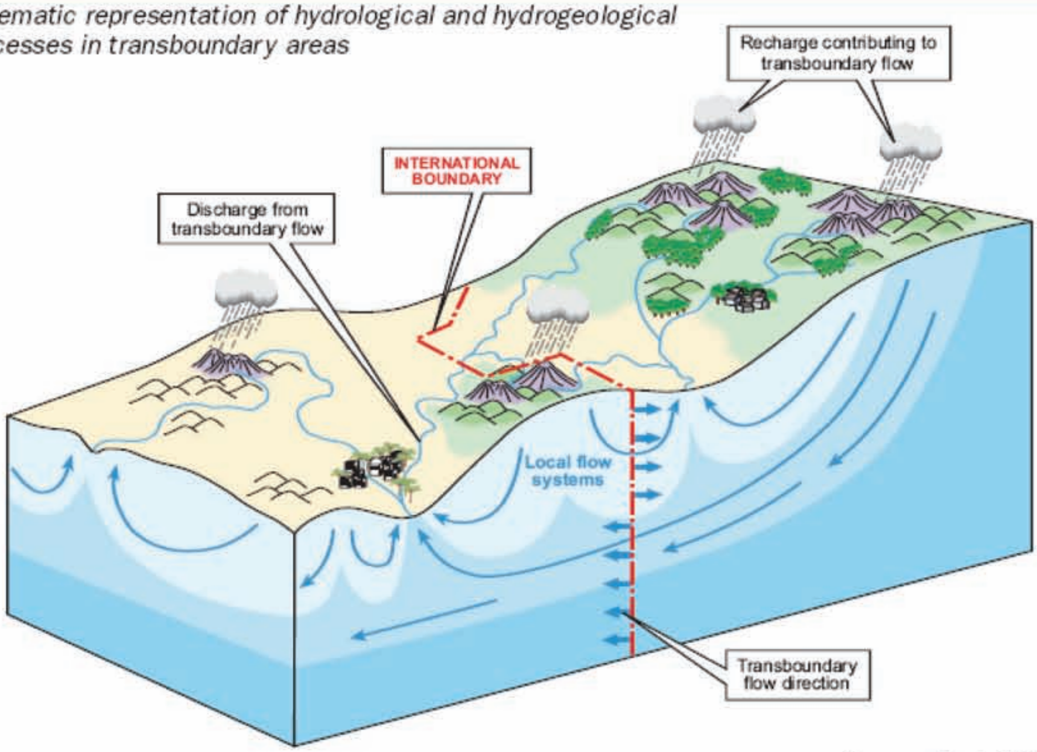
There are striking contrasts in the approach to the management of transboundary river basins and of transboundary aquifers, despite the fact that the actual utilisation of the resource, i.e. water, is for identical purposes, namely drinking, industrial use and irrigation.

The water resources in aquifers are contained into a 3-dimensional system; resources may be extracted from, and used extensively over outcrop and subcrop, the replenishment may take place from any, or all of the 3-dimensions.

The key features of transboundary aquifers include a natural subsurface path of groundwater flow, intersected by an international boundary, such that water transfers from one side of the boundary to the other (see figure below). The aquifer might receive the majority of its recharge on one side, and the majority of its discharge would occur in the other side. Moreover, the subsurface flow system can include regional, as well as a local movement of water.

Then, management strategies cannot be easily considered on an upstream versus downstream approach as for international rivers.

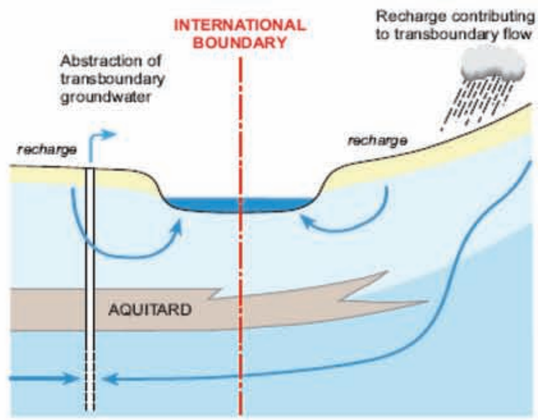
Schematic representation of hydrological and hydrogeological processes in transboundary areas



Source: Puri, 2001.

Even where international boundaries may follow such features as rivers, the aquifers underlyingthem may not reflect the true transfer of groundwater flows from one side to another (see figure below).

Interaction between surface and groundwater flows near an interstate boundary



Source: Puri, 2001.

Very few international political boundaries follow natural aquifer physical features, and water resources can cross them unhindered. In hydrogeological terms, these crossing resources can only be estimated through good observations and in situ measurements of selected hydraulic parameters.

The recognition of transboundary aquifers should lead to mutual international acceptance of an effective cooperation for the equitable management of shared groundwater resources. A new approach towards sharing benefits should be considered. Nevertheless, it is essential to study the characteristics of the entire aquifer or aquifer system that can include all aquifers that are hydraulically interconnected, directly by lateral or indirectly through vertical contact or through fractures and low permeability formations (aquitards).

Good and reliable information is crucial to facilitate co-operation among aquifer stakeholders. All stakeholders should have easy access to good, reliable data on abstractions, water quality, aquifer water levels.

With such an approach it should be possible to establish mutually accepted rules, adopted by all parties, based on a holistic definition of the aquifer system and principles of equivalence of impacts of abstraction.

4.4.2. Legal Aspects

Many countries do not have legal instruments to regulate and monitor the use of national groundwater resources and very few bilateral agreements exist to regulate management of transboundary groundwater. Until recently, at the global and international level, there was no legal instrument to deal comprehensively with transboundary aquifers and addressing their specific characteristics. To overcome this gap, the UN International Law Commission (UNILC), which is in charge of the codification and progressive development of international law, has included in 2002 in its program of work the topic of Shared Natural Resources and decided to start its work with the topic of ‘transboundary groundwater’. Then since the year 2003 UNESCO- IHP and UNILC have cooperated for the preparation of an international legal instrument for the management and use of transboundary aquifers that resulted in a complete set of articles on The

Law of Transboundary Aquifers (UNILC report, July 2008) that was presented in October 2008 at the UN General Assembly. The UN General Assembly (UNGA) has then adopted the 11 December 2008 a Resolution (A/RES/63/124, see Appendix III) annexing these articles. This allows to expect an increased consideration of transboundary aquifers by Member States and improved attention at regional and international level. The articles represent a milestone in the international recognition of the crucial function of transboundary aquifers for humans and the environment. They can be used as an example for bilateral and regional agreements.

The articles provide clear guidance and a reference to member states and national regional and international organizations on the use and management of shared aquifer resources. The articles define a transboundary aquifer or aquifer system as 'an aquifer or aquifer system, parts of which are situated in different States' (article 2). The articles recommend the setting up of a conceptual model of the transboundary aquifer or aquifer system (article 13§2 of the UNGA Resolution) in view of identifying key parameters to monitor, such as the evaluation of the quality and quantity of the waters and the assessment of the vulnerability.

4.4.3. Socio-Economic Use-based Management Approaches

As presented above, transboundary aquifer governance has been recognized at the global level in The UN General Assembly Resolution, 63/124, 11 December 2008 on the draft Articles on the Law of Transboundary Aquifers. The draft articles provide guidance for the utilization, protection and management of shared aquifer systems based on equitable utilization, no-harm and State cooperation to meet common social and economic needs. The transboundary effects of aquifer utilization should be taken into account, with alternatives and consideration of the costs of related measures. A few countries have recently established cooperative mechanisms on shared aquifers and initiated bi- and multilateral dialogues with development of soft law cooperative arrangements for management of shared aquifers. With the transboundary aquifers being increasingly recognized as a critical strategic natural and socio-economic resource for regional and national development, regional economic development and environmental organizations (e.g. AMCOW/AWF, SADC, OAS, etc.) are assuming an important role in this process. The efficient management of transboundary groundwater water use in an aquifer is an economic, social and political issue encompassing the sectors and international borders. The effective transboundary management involves trade-offs between the sectoral uses striking a balance between additional economic growth and water resource depletion, degradation and related environmental concerns. It targets the adoption of a common policy framework combined with decentralized institutions, management and environmental protection and active participation by the stakeholders. With the high rates of change in urbanization and agricultural intensification, the current supply oriented technical and administrative approach for managing transboundary groundwater resources is increasingly inadequate to address competing international demands, without mobilizing the socio-economic levers for different uses and services (FAO, 2003) at the national level. As a result, and with the priority of national economic development and the cooperation between aquifer States, socio-economic drivers and economic policy instruments are increasingly considered in transboundary aquifer management. Effective transboundary management involves trade-offs between sectoral uses with a balance between additional economic growth and water resource depletion, degradation and related environmental concerns. With a general gap in the institutional arrangements for enforcement of transboundary aquifer management measures at local level, one institutional opportunity, at low transaction cost iscommon resource based management under the legal public trust doctrine.

The current resource and supply-oriented technical and administrative management approaches are insufficient to address actual and future sectoral and international water use conflict and allocation to rapidly growing demands from transboundary aquifers for urban supplies and agricultural intensification.

4.4.4. Institutional Aspects

A comprehensive institutional response to acknowledged transboundary aquifer management problems has not yet emerged. There are no institutions that can equate to such bodies as the Rhine Commission or the Chad Basin Commission. Multilateral finance agencies have barely started to include groundwater in basin wide projects. Shared groundwater tends to be flagged as part of a river basin commission mandate – however, groundwater cannot be subject to the same type of input-output controls that govern flows in shared watercourses.

Domestic management arrangements for implementation of international agreements may be severely handicapped for managing shared aquifers. Closely related to the valuation and competition issues, the distribution of groundwater resources and its use creates major challenges for management and the institutional arrangements for implementation. Transboundary aquifers can extend across multiple geographic, administrative and political regions. In this situation, local agencies generally have little hope of influencing regional groundwater conditions through isolated actions under their direct control. The institutional mechanisms that will deal with transboundary aquifers issues therefore need to differentiate between the domestic management regime and that required for international management.

Institutional, cultural and ethical dimensions are likely to be as important as technical and macroeconomic dimensions in the evolution of approaches to address existing and emerging transboundary groundwater problems. Sharing basic data and information on transboundary shared aquifer systems and the projected demands are clearly important, but so too is the joint promotion of effective management.

An important institutional issue for management of transboundary shared aquifer systems is therefore the scope of regional co-operative frameworks, broadly scoped social and economic communities, versus basin and aquifer commissions. Regional economic bodies could be mandated and have capacity to:

- act from the authority of political economy;
- set policy and guidelines for water management in the region;
- integrate water and economic issues into the regional economy;
- mitigate and compensate for externalities and negative impacts of regional policy on individual member states as well as the environment;

- monitor effectiveness and compliance with water management and environmental standards at regional and national level and

- identify benefits sharing possibilities.

Individual governments and the economies in a region do not form single entities but are collective in nature, and decisions represent balanced negotiated outcomes acceptable to sectors and executive, legislative and judicial powers. These facts call for introduction of alternative approaches to economic analysis in international water management, to maximise the positions of individual states and then use the agglomerated result for well informed negotiations.

4.4.5. Environmental Issues

The environmental issues that affect transboundary aquifers are wide ranging and can be viewed both from a local and a global perspective. Within the framework of the World Water Assessment Programme (WWAP) of the United Nations system, UNESCO-IHP has undertaken the task to develop groundwater resources indicators for environmental sustainability.

A first presentation of the elaboration of the indicators was contained in the World Water Development Report (WWDR) that was presented at the Third World Water Forum in Kyoto in March 2003. Most aquifer systems have ecosystems, landscape elements, or pre-existing water users that are dependent on current discharge or recharge patterns.

Further development may require trading off these dependencies in favour of new plans or policy. If dependencies are not well understood or considered, management changes may have major unanticipated impacts. There is often no inherent conflict between preservation of these ecosystems and withdrawals from transboundary aquifers for socio-economic development when the functioning of the aquifers is well studied and all possible impacts considered.

Since an aquifer system is essentially below ground, biodiversity issues generally relate to the regions where aquifers discharge as for example through rivers, lakes or swamps and coastal zones. Frequently this generates the specific characteristics of the dependent special ecosystems, related to the physical and hydrochemical features of the aquifer (Gilbert et al., 1997).

In many regions, but especially arid regions, discharging groundwater fed water bodies can be absolutely critical to the maintenance of biodiversity. Even in temperate climates, the discharge region of a transboundary aquifer can provide specific conditions of quality, temperature and nutrients that rare species will be reliant upon.

Discharge of transboundary groundwater into lakes and inland seas supports important migratory bird conditions and discharge in coastal zones supports specific marine ecosystems. Aquifer over abstraction and excessive fertiliser application in the irrigation areas can have negative impacts on the quality of groundwater flowing to surface water bodies, wetlands, oasis, and the coastal areas. The impact of climate change on transboundary aquifers of the world is yet to be fully evaluated.

The consequences of either of these impacts on abstraction, maintenance of wetlands, discharge to water bodies could be very serious, especially where well developed infrastructure has been established. Global sea level changes may impact marine saline intrusion – the hydraulic reference point change could mean that many aquifers may extend inland intrusions, thus affecting groundwater quality.

Aquifer response to stimuli such as climate change will be even more gradual than those resulting from human intervention. The detection of these impacts will require a very careful analysis of data. For transboundary aquifers, the need for consistent data and a comprehensive conceptual understanding is essential.

5. Major Transboundary Aquifers of Asia

The Asian continent covers 44 million square kilometers and has a population of 3.5 billion people. It is the largest continent in the world, both in area and size of population. There are 48 countries and regions in Asia, a number of which have a population of more than 100 million e.g. China, India, Indonesia, Japan, Bangladesh and Pakistan. The combination of large populations and rapid growth means increasing demands for water resources.

There are several transboundary aquifers in Asia involving two or more countries. UNESCO's International Hydrology Program (IHP) in cooperation with China Geological Survey has identified 12 major and significant transboundary aquifers, primarily porous or fissured/fractured aquifer systems. The successful management of these shared aquifers will contribute to peaceful relations between Asian states.

Transboundary aquifers, as part of groundwater resource systems, are important for Asian countries, and are a consideration in the international relations of the region, as well as in the management of the international rivers. There are several transboundary aquifers involving two or more countries in Asia, and a number of rivers passing through several countries, such as the Mekong River, the Ganges River and the Heilongjiang-Amur River. Research on transboundary aquifers is significant for the management of shared groundwater resources of neighbouring countries or regions.

Transboundary aquifers in Asia have been discussed briefly and studies are based on groundwater systems analysis. For countries with large areas (such as China, Russia and India), the number of international transboundary aquifers in Asia is less than that on other continents. Twelve transboundary aquifers, which are very significant, are demarcated in the following table and figure. Management of these aquifers is important for building a society where all civilizations can 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 the Heilongjiang-Amur River has been taken as the first case in East Asia. Information about groundwater flows should be exchanged among Asian countries that share transboundary aquifer systems. These are basic requirements for the joint management of water resources.

The occurrence of transboundary aquifers in Asia

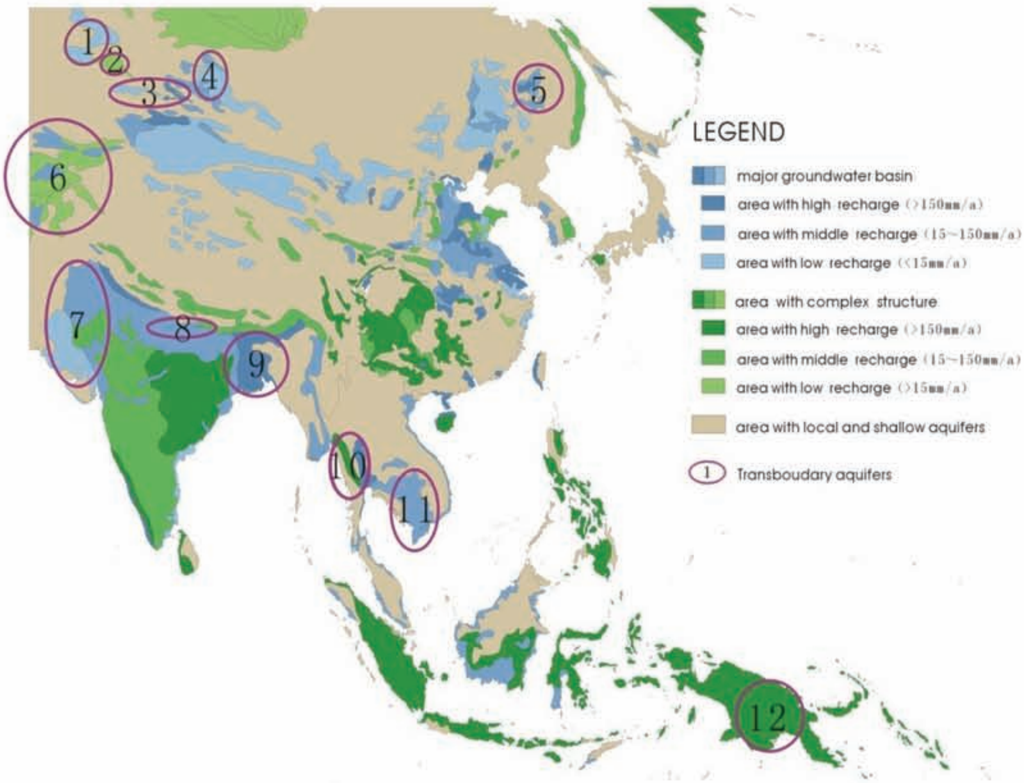


Table Transboundary Aquifers in Asia

No	Name of Transboundary Aquifer System	Countries sharing this aquifer system	Type of aquifer system	Extension [km2]
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

6. Case Studies on Transboumdary Aquifers from Asia

6.1. Groundwater Resources and Transboundary Aquifers of China

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6.1.1. Geography and Water Resources

The topography of China, from the Qinghai-Tibet Plateau in the west to the coastal areas in the east, has an average decrease in altitude from 4,800m (locally over 5,000m) to less than 50m 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 mountains range from west to east and north-east to south-west. The west to east ranges can be grouped into three belts from north to south: the Yinshan-Tianshan belt, the Qinling-Kunlun belt, and the Nanling belt. The mountains are composed of boundaries of topographical sub-areas.

The north-east/south-west ranges may be roughly divided into two belts: 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 in China is about 600mm. 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 200mm. The areas eastwards and southwards from this range to the range of the south-eastern Tibet Plateau - eastern Qinghai - the southernmost part of Gansu - the 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 800mm. The vast areas extending southwards belong to the humid climatic zone, with the annual mean precipitation generally greater than 800mm, and even reaching a maximum of 2,000mm.

On the basis of the regional geologic and tectonic features, and with the Yinshan-Tianshan 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 each gone through different geologic histories and therefore have different geologic features.

As a result of great subsidence and strong Variscan movement in the region 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 approximately two-thirds.

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 there are mainly tightly folded and metamorphosed Archean rocks and less tightly folded, essentially unmetamorphosed or slightly metamorphosed rocks of the Sinian period and partly of the Palaeozoic or Mesozoic era.

To the south of the Qinling-Kunlun Mountains is a region that has experienced the longest duration of transgressions since the Sinian period, and during which marine formations have been the most developed. It is also a region where there has been strong orogeny, and the compressive folding, faulting and magmatic activity has 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 groundwater. As for rivers and lakes, outward drainage systems occur mainly in the eastern and southern parts of China, running over a total area about two-thirds the size of China’s entire territory, with most rivers flowing eastwards into the Pacific Ocean. 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 these areas, which are south of the Qinling Range and the Huai River. They carry quantities of water and serve as important groundwater recharge sources or discharge outlets in these areas. To the north of the Qinling Range - Huai River divide, rivers and lakes are sparsely scattered. As a small amount of precipitation is concentrated in summer, the seasonal variations of water volume and water level in these rivers and lakes are considerable.

6.1.2. Characteristics of Aquifers and Groundwater Resources

The Qinling-Kunlun structural zone, which spans from east to west, divides China into northern and southern parts both geologically and physiographically. Since the Mesozoic and Cainozoic, and especially since the Yanshanian orogeny, a series of structural basins of various sizes have developed. Large and medium sized basins are distributed in the vast areas north of the Qinling-Kunlun Mountains. The Song-Liao Plain and the Huang-Huai-Hai Plain, which are connected southwards by the Yangtze Delta, are situated in the eastern part of China. The major interior basins lie in the north-west; sloping piedmont plains extend at their edges, and deserts occupy their centres. The 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 favourable to the infiltration, storage and flow of groundwater. In the eastern plains, the alluvium-diluvia deposits yield an abundant and relatively stable quantity of pore water, which up to now has 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 groundwater (unconfined or slightly confined groundwater at shallow depths) to the north of the Qinling-Kunlun divide is entirely different from that to the south. Towards the north, groundwater at shallower depths tends to have a higher mineralization. The concentration of total dissolved solids is often greater than 1,000 parts per million (ppm). In the north-western region, it may reach as high as several tens of thousands ppm under high evaporation conditions. In contrast, the total dissolved solids in groundwater on the southern side of the dividing line are mostly less than 1,000 ppm 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, groundwater is commonly fresh and contains about 1,000 ppm of total dissolved solids or less, except in the coastal areas where groundwater is relatively highly mineralized. While groundwater quality in western China varies widely with regard to the chemical composition of the groundwater, in the north, area and vertical zonings can be clearly recognized in the major interior basins and plains. The zoning in the southern intermontane basins, however, is not very distinct. The latest investigation showed that naturally recharged resources of underground freshwater were about 884 billion m^3/a, accounting for one-third of total water resources; mountainous areas accounting for 656 billion m^3/a and plains areas accounting for 228 billion m^3/a. The permitted level of underground freshwater withdrawal is 353 billion m^3/a; 197 billion m^3/a for mountainous areas and 156 billion m^3/a for plains areas. In addition, groundwater natural recharge whose degree of mineralization is 1-3 g/L and 3-5 g/L is 28 billion m^3/a and 12 billion m^3/a respectively.

Naturally recharged underground freshwater resources in the south and north of China are obviously different, accounting for 70% of the total number in the south and 30% in the north.

6.1.3. Issues in Groundwater Development

Groundwater has a steady quantity, good quality and it isn't easily polluted. It is, therefore, an important water resource. In China, large-scale groundwater exploitation started and increased rapidly after the modern Chinese state was established in 1949. In the 1950s, there was only sporadic groundwater exploitation; in the 1970s, the amount of exploitation increased to 57 billion m^3/a; in the 1980s it increased to 75 billion m^3/a. Up to now, groundwater exploitation (including a little weak mineralized groundwater) has exceeded 100 billion m^3/a, accounting for one-fifth of the total number. Groundwater withdrawal in the northern part of China accounts for 76% of the country's total withdrawal.

There are 400 cities exploiting and using groundwater throughout the country, and groundwater accounts for 30% of the total urban water use. In the southern cities, groundwater is the major water source. In cities in northern and north-western China, the proportion of groundwater out of total water consumption is 72% and 66% respectively.

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

6.1.3.1. Status of Groundwater Quality

The overall status of the groundwater environment in China is not that bad. The area of underground freshwater is 8.1 million km^2, weak mineralized groundwater is 0.54 million km^2, and middle mineralized groundwater is 0.84 million km^2. Despite these geological conditions, there are still 70 million people in China who have no access to clean groundwater. They are suffering from arsenic poisoning, struma, condyles and other afflictions. According to statistics for various areas, 63% of groundwater of the whole terrain can be drank directly, 17% can be drank after being properly treated, 12% can be used for industry and agriculture, and 8% is not potable.

The quality of groundwater in China varies by region and can be summarized as being better as follows: groundwater quality in the southern part of China than in the northern part; better; groundwater quality in the eastern plain area than in the western interior basin; better in groundwater quality of mountain areas than in plains areas; better area; groundwater quality in piedmont plains and intermontane plains than in coastal areas and in the middle of basins; and groundwater quality in deep aquifers is generally better in deep aquifers than in shallow aquifers.

6.1.3.2. Status of Groundwater Pollution

In the 253 major groundwater exploitation zones in 185 cities, there are 63 zones (accounting for 25%) whose pollution trend is aggravating, accounting for 25% of zones; there are 45 zones (accounting for 18%) whose pollution trend is alleviating, and accounting for 18% of zones; there are 145 zones (accounting for 57%) whose pollution is relatively steady, accounting for 57%

of zones. The pollution components are mainly nitrate, nitrite, nitrogen in ammonia, chloride and heavy metal.

Groundwater planar pollution of the shallow aquifer in the Huai river drainage area is getting worse. Organic pollutants resulting in cancers, aberrances and other variations have been observed to some extent in the groundwater of Beijing, Tianjin and Yangtze River delta.

6.1.3.3. Land Subsidence and Ground Fissures

By 2003, there were there were more than 50 countries where land subsidence and ground fissures had taken place, with a subsidence area of 94,000km^2. The most seriously affected regions in China are the Yangtze River delta, the North China Plain, and the Fenwei basin.

The Yangtze River delta is the most serious subsidence region in China, with the area of accumulative subsidence exceeding 200mm in the surrounding 10,000km^2, accounting for one-third of the total area. In addition, ground fissure hazards also occur.

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

6.1.3.4. Groundwater Depression Cones

There are about 180 groundwater depression cones in the whole country, with a total area of 190,000km^2. Of the 121 depression cones for which there are complete statistics, there are 54 with ampliative areas, 43 with reduced areas, and 24 with steady areas.

6.1.3.5. Ground Collapse

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

6.1.3.6. Seawater Intrusion in Coastal Areas

The regions in China suffering from seawater intrusion from north to south are: Liaoning, Hebei, Shandong, Guangxi, and Hainan. Seawater intrusion in the area around the Bohai sea has developed rapidly, and the total area affected reached 2,457km^2 in 2003, increasing 937km^2 compared to the 1980s1980's, with a rate of 62km^2 / annum.

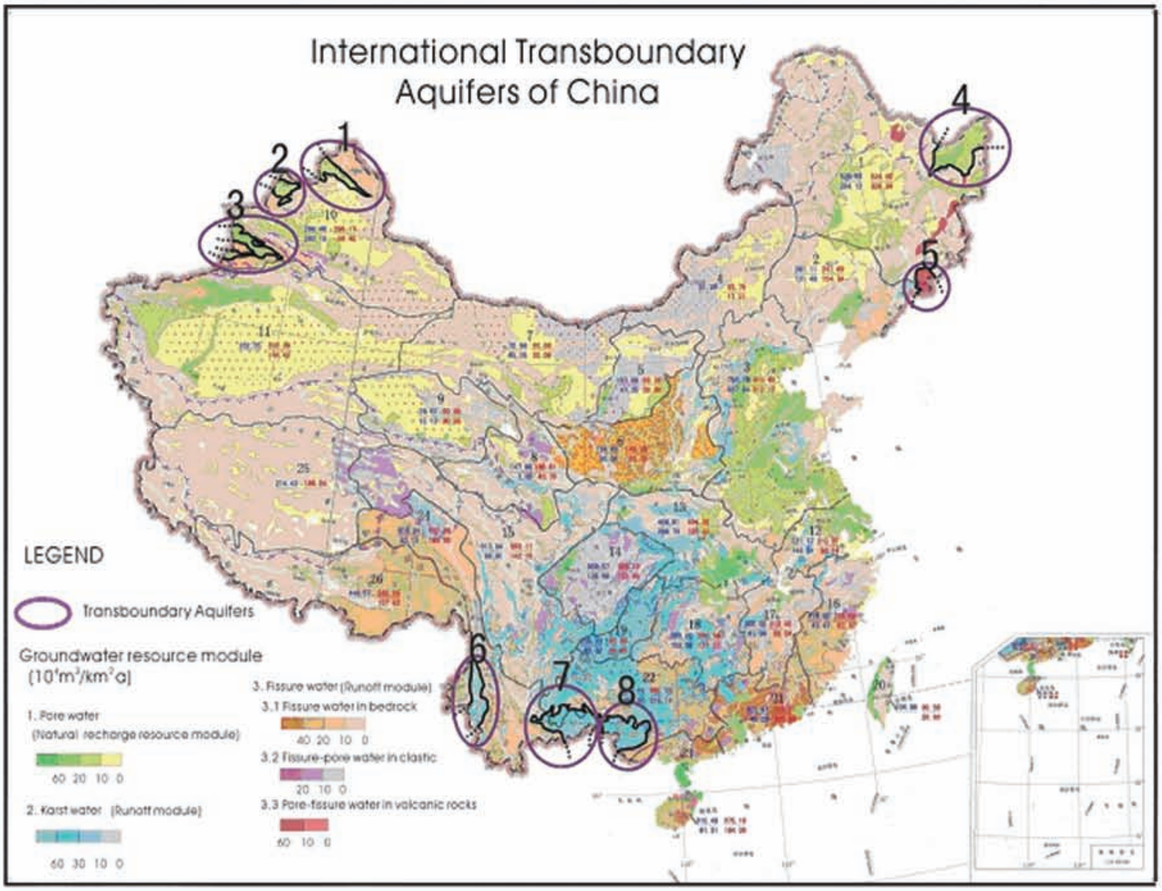
6.1.4. International Transboundary Aquifers of China

ISARM was launched in the sixth phase of the IHP organized by UNESCO. It contains demarcation and analysis of the transboundary aquifer systems, encouraging every country sharing groundwater resources 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 have been applied, and a complete set of integrated research techniques and a working directory has been formulated. ISARM has organized a series of research on representative examples in America, Africa and Europe. Cooperating with the departments and organizations concerned, the author has done a series of research on this subject. Above all, in the programme on mapping the WHYMAP, the author demarcated the transboundary aquifers in East Asia. According to the data for groundwater resources 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 include the Middle Heilongjiang–Amur River basin across the boundary with Russia, the Yili River valley plain and the Ertix valley plain across the boundary with Kazakhstan, as well as the transboundary aquifers across China's boundaries with Mongolia, Korea, Vietnam, and Burma.

Table International Transboundary Aquifers in China

No.	Name of Transboundary Aquifer System	Countries sharing this aquifer system	Extension in China [km2]	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



China shares eight transboundary aquifers with other countries as shown in figure above. Their characteristics are elaborated upon in this section.

1. Ertix valley plain aquifer: this aquifer is a transboundary aquifer shared by China and Kazakhstan. The Ertix River originates from the southern slope of the Altai Mountains, with a total length of 2,669km and a drainage area of over 1,070,000km^2. The length of this river within China is 546 km and the drainage area is 57,000km^2. After flowing over the national boundary of China, the Ertix River flows into the Zhaisang lake of Kazakhstan, which subsequently feeds into the E'Bi lake of Russia, and finally depletes into the Arctic Ocean. The valley plain aquifer is made up of Quaternary sand gravel, where steady cohesive soil sediment is almost absent. The area within China is 16,000km^2 and the runoff module of natural recharge is about 150,000m^3/(km^2 a).

2. Tacheng aquifer: Tacheng basin is a part of the valley plain of the Yimin River. This aquifer is also a transboundary aquifer shared by China and Kazakhstan. The Yimin River originates from the southern slope of Harbahatai Mountains. After flowing out of China, the Yimin River flows into Lake Ala in Kazakhstan. The direction of groundwater flow is the same as that of the river. Average annual precipitation is 256mm. The aquifer is composed of Quaternary sands and base rock fractures. The area within China of the Yimin River aquifer is 21,000km^2, and the

3. Yili River valley plain aquifer: this aquifer is a transboundary aquifer shared by China and Kazakhstan. The total area of the aquifer is 53,000km^2, and the area within China is 26,000km^2. The water resources of the Yili River mainly come from the thaw of Tianshan Mountain of China. The influx of the river water flowing into Kazakhstan is about 12 billion m^3/year, which subsequently flows into the Lake Balkhash. 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 flows west into Kazakhstan from China. It is estimated that the influx of groundwater across the boundary from China to Kazakhstan is about 0.6 billion m^3/year. The groundwater and surface water of the Yili River plain sustain the social and economic development of Xinjiang province in China and regions with large populations in Kazakhstan. The aquifer is thus a valuable natural resource shared by the two counties.

4. Middle Heilongjiang-Amur River Basin: this aquifer is a transboundary aquifer shared by China and Russia. The total area is estimated to be 100,000km^2, and the area of the Russian portion is 55,000km^2. The southern part of the aquifer is called the Three River plain and is located in China with an area of 45,000km^2. The flat and low-lying plains are formed due to the sand deposition of the Heilongjiang-Amur River, the Songhua River and the River Wusuli. The annual average precipitation of this area is 500–650 mm. This aquifer is divided into Quaternary pore aquifers, Tertiary pore aquifers and Pre-Quaternary bedrock fissure aquifers. The groundwater flows from the higher elevation part of the piedmont to the lower elevation part where the Heilongjiang-Amur River meets the Wusuli River. The monitoring data on groundwater of the middle Heilongjiang-Amur River Basin shows that it is still in equilibrium, but with a much higher content of Fe and Mn.

5. Yalu River Valley: this is the transboundary aquifer shared by China and the D.P.R. Korea. The basalt fracture rock aquifers are the sources of water supply for both countries. The total dissolved solid of the groundwater is less than 0.2 g/L. Their chemical type is HCO_3-Mg-Ca.

6. Nu River Valley: this aquifer is a transboundary aquifer shared by China and Burma. The area within China is 35,477km^2, and the runoff module of natural recharge is about 300,000m^3/km^2 a. The annual average precipitation of this area is 1,600–2,700mm. Groundwater in the aquifer is mainly in the form of karst fissure water and subterranean streams and its chemical type is mainly HCO_3–Ca and HCO_3–Ca–Mg. Karst fissure groundwater in the aquifer is the main water source for local residents.

7. / 8. Karst aquifer of Upriver of Hong River and Zuojiang Valley: this aquifer is a transboundary aquifer shared by China and Vietnam. The area within China is 62,000km^2. The annual average precipitation of this area is 1,500–1,800mm and the runoff module of natural recharge is about 400,000m^3/km^2 per year. The karst area is made up of solid thick-bedded limestone, dolomitized limestone, and calcareous dolomite. Geomorphologically, from northwest to southeast, there are valleys and plains in both riversides of the Zuojiang Valley. The groundwater in the aquifer is mainly in the form of karst fissure water and subterranean streams. The subterranean stream, in line with big karst valley and surface water subsystems, extends towards the northeast and northwest. With Heishuihe River being the boundary, the western subterranean stream flows 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 streams is about 25–120km^2, and the outflow in the dry season is 50–500L/s. The chemical type of groundwater in the aquifer is mainly HCO_3–Ca and HCO_3–Ca–Mg. The depth of groundwater is mostly less than 30m and is even less than 10m in some places. The annual variation of water level ranges between 10–20m. The rate of karst cave and fracture of the underground limestone on volume is 33–50%. Groundwater in the aquifer comprised of karst fissure and subterranean streams is the main water source for local residents.

6.1.5. Transboundary Aquifers between Provinces of China

In addition to the aquifers that China shares with other countries, there are aquifers within China that cross internal provincial boundaries. These aquifers include: the Alluvial Fan Aquifer of Juma River across the boundary of Beijing and Hebei; Karsts Aquifer of Chezhoushan across the boundary of Tianjin and Hebei; Karst aquifer of eastern Erdos Basin across the boundary of Shaanxi, Shanxi and Inner Mongolia; and Aquifer of the Yangtze River delta across the boundary of Jiangsu, Shanghai and Zhejiang. These aquifers are distributed in different parts of China with diverse economic and social conditions. The monitoring and management of such aquifers need at least the same amount of attention as those of transboundary aquifers.

1. Alluvial Fan Aquifer of Juma River: this aquifer crosses the boundary between Beijing and Hebei. The well field that will be built for solving the lash-up water supply of Beijing is located in the middle part of the Juma River alluvial fan and the aquifer is mostly gravel. Through the analysis of the hydrogeological conditions of the 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 1.5×104m^3/d. In that case, the groundwater level of Hebei will not decline too much, and the thickness of the saturation zone will maintain about 70% of the whole thickness.

2. Karsts Aquifer of Chezhoushan: this aquifer crosses the boundary between Tianjin and Hebei. The Ning River north well field located southwest of the syncline of Chezhou Mountain has been built to provide water supplies to the newly developed area of Tianjin, Binhai. The Hancheng well field in the Fengrun area of Tangshan, the Dachangliu well field and the Chezhoushan Middle School, and the Limazhai well field are in the same karst hydrogeological cells and will be affected by exploiting and utilizing the Ning River north well field. A large-scale pumping test counted the drawdown of groundwater of every well field in Hebei in 20 years time, if exploited at 60,000m^{3}a rate of 60000m^3/d. The result indicates that under certain conditions, the groundwater level of the Quarternary pole aquifer and the karst system will decline because of the exploitation of the Ning River north well field, and the existing well fields in Hebei will be affected. The increasing drawdown increases the cost of the running the well fields, but they can still be operated within a normal scope. The environmental geological effects of exploiting the Ning River north well field are analyzed by hydrogeological investigation.

3. Karst aquifer of eastern Erdos Basin: this aquifer crosses 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 is mainly located 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 on banks of both Shanxi and Shaanxi, being the enrichment area of the cavern groundwater, and so the eastern Erdos Basin has suitable conditions 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 locatedlocated in the neighbouring nearby regions of Shanxi and Shaanxi. Because each cavern water system has close internal hydraulic connections and the construction of the energy base utilizes the cavern water, we have to consider the exploitation of the well field in the neighbouring provinces together, according to the entire aquifer system programming.

4. Aquifer of Yangtze River delta: this aquifer crosses the boundary of Jiangsu, Shanghai and Zhejiang, which is an economically developed area with a large population. Suzhou-Wuxi-Changzhou in Jiangsu province, Shanghai and Hangzhou-Jiaxing-Huzhou in Zhengjiang province, and Shanghai locate are located on the same basic Quarternary sedimentary area. Because of over-exploitation of groundwater, land subsidence and ground fissures, there were large economic losses and a restriction of sustainable development of the region. Due to the over-exploitation of groundwater in Suzhou-Wuxi-Changzhou in Jiangsu province, land subsidence crossed the boundaries of provinces, affecting major cities like Shanghai. Unfortunately, the survey and prevention measures of land subsidence in Shanghaiwere not performed in a satisfactory manner although they started early. As a result, the hydrologists subsequently investigated and evaluated the whole Yangtze River delta aquifer including base constitution, Quarternary configuration, groundwater resources and land subsidence. The uniform monitoring net of land subsidence has been designed, and associated mechanisms have been established, to cover the three provinces in order to protect the groundwater resource of Yangtze River delta and to prevent subsequent land subsidence.

6.1.6. Case study - Transboundary Aquifer between China and Russia

6.1.6.1. Geography and Hydrology of Middle Heilongjiang-Amur river Basin

The Middle Heilongjiang-Amur river basin is encircled by mountains; to the west are the Xiaoxingan Mountains, to the northwest the Buren heights in Russia, to the east the Sihote-Aline Mountain range and to the south the Wanda Mountains of China. The total area is 100,000km^2.The section in China is called the Sanjiang plain, with an area of 45,000km^2. The area of the Russian section is 55,000km^2. 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 the 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 100m respectively. The 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, is located in the piedmont of the eastern slope of Less Hingan. Towards the east, it is conterminous with the Songhua River and Heilong River, with the thickness of sediment between 15-25m and an elevation between 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 their main tributary valleys, including terrace of the first order and floodplain, with the landform elevation being 40-50m, and specific elevation being 5-10m. The sedimentary low plain, which is composed of loessial powder clay soil, mealy clay sand and gravel and has a landform elevation of 60-80m, is located in the middle of Songhua river valley. Clay low plain composed of loessial powder mealy clay and silt mealy clay sand are located in the large low plains in the east of Tongjiang-Fujin-Jixian, with landform elevations of 50-60m.

The middle Heilongjiang-Amur river basin is located in the east part of the Asian continent and near the western Pacific Ocean. It is of typical continental monsoon climate, with the annual average temperature fluctuating from -4 to +4 degrees centigrade. In winter, much of the wind comes from the northwest and it is cold and dry under the control of Mongolia's high-pressure climate. In contrast, during the summer, much of the wind comes from the 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°C, with a high temperature of 37.7°C and a low temperature of –38.8°C. The annual mean precipitation of the middle Heilongjiang-Amur River basin fluctuates between 500-650mm. In summer, there is enough water due to intensive rainfall because of effects caused by the monsoon of southeast Asia. The precipitation from June to August every year accounts for 63.8% of the whole year, while the precipitation between autumn and spring only accounts for 12.5% and 21.0% of the whole year respectively. The precipitation fluctuates in an obvious manner during different seasons and years. Furthermore, wet and dry years alternate. The precipitation in wet years is 2.4 times as much as that in 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.

The Heilongjiang River gets its name from the colour of its water, which flows through the densely forested regions covered with black humus soil. It is the boundary river between China and Russia, running across the northern part of China. Its headstream includes the northern source and the southern source. The northern source of the Shileka River originates from the eastern foothills of Mount Kent in Mongolia, and the southern source of the 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 to 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 kilometres, making it the 11th largest river in the world. Its drainage area is up to 1,855,000 square kilometres, ranking it the 10th largest in the world. The drainage area within China is about 893,400 square kilometres, accounting for 48% of its total drainage area.

The Songhua River is the largest tributary of the Heilong River, with a total length of 2,309 kilometres and a drainage area of over 546,000 square kilometres. Its headstream includes the northern source and the southern source. The southern source-second of the Songhua River originates from Heaven's Lake in China's Jilin province, and the northern source of the Nenjiang River originates from 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, on entering China the river is referred to as the Songhua River and flows through Jiamusi, Luobei, Suibin, Fujin and Tongjiang. Finally, it feeds into the Heilong River.

Middle Heilongjiang-Amur River Basin

The total length of the Wusuli River is 890 kilometres, with a drainage area of nearly 7,000 square kilometres. The drainage area within China is about 56,000 square kilometres, accounting for 30% of the total drainage area. Its headstream includes an eastern source and western source. The eastern source is located in the western foothills of the Sihote-Aline mountain range in Russia, flowing from south to north. The western source originates in Khanka. The Wusuli River flows through the low plains located in the middle of Wanda Mountain in China and the Sihote-Aline mountain range in Russia. The length of the main channel is 500 kilometres, and the annual runoff is $619 \times 108 m^3$.

6.1.6.2. Hydrogeological Conditions

The middle Heilongjiang-Amur river basin is a large-scale water-storage structure encircled bymountains. A variety of strata with weak permeability, magmatic rock with low mountains and hilly areas are in the north, east, south and west of the groundwater system form the water-repellent boundaries of the aquifer. The mud rock and the entire bedrock distributed in the base of the Tertiary aquifer are the water-repellent boundary of the lower plane. The groundwater system system of the Heilongjiang River is a relatively independent and uniform system, and the groundwater is still in equilibrium.

The groundwater level of the piedmont in the west of the basin is 80-90m, and the level in the south of the basin is 70-85m. However, the groundwater level in the zone of the 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 areas of the piedmont to low elevation areas where the 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 storage space and runoff channels of the area.

Quarternary pore aquifers are the most extensive of the aquifers in the middle Heilongjiang-Amur river basin. Besides the extension, its reserves, exploitation and degree of hydrogeology research 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 storage space and runoff channels. The large and thick Quarternary made up of sand and gravel is the water-storage basin, and contains abundant groundwater. The thickness of the aquifer increases from the edge to the middle of the basin. The thickness of the piedmont area is 2-40m, the thickness of the middle is 60-150m, and 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 a single well is 1000-5000m^3/d. The depth of groundwater in the floodplain is 0.5-3m, that of other areas being 3-16m, but generally less than 5m.

The thickness of the sediment in the Russia part of the basin can be up to 2,000m. The sediment is composed of sedimentary rock, igneous rock and meamorphic rock, and the range of hydrogeological research is limited to 300m. The middle of the 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 Chinese part, which forms a close confined aquifer. The lateral runoff is the main recharge source of groundwater. Because 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.

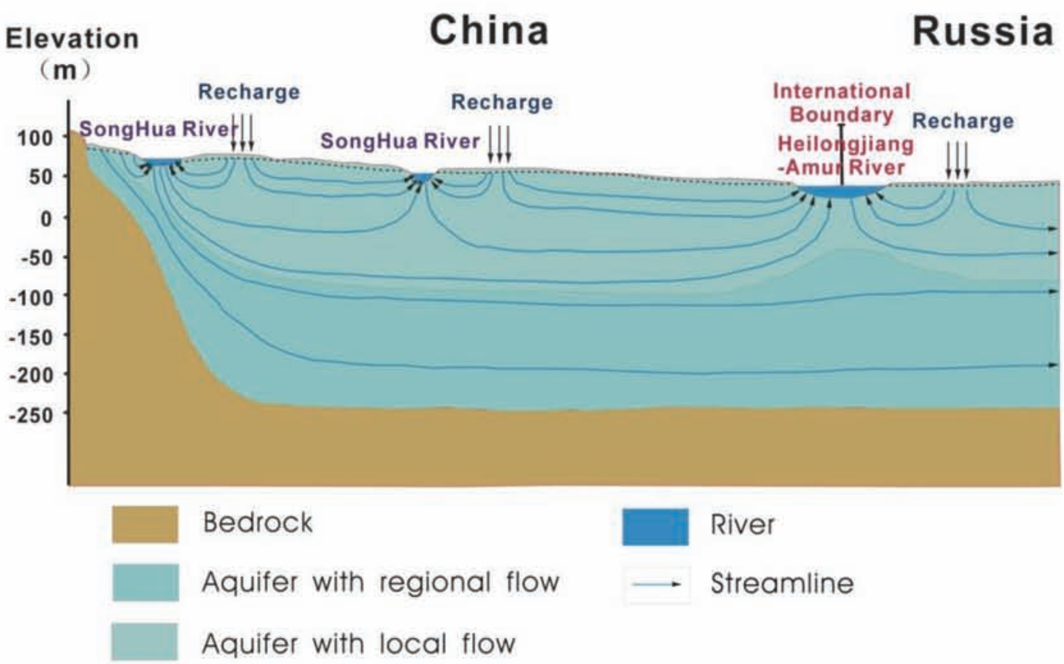
Tertiary pore fissure aquifers of clastic rock are mostly distributed in the depression and rift of the basin, and the rest, with less area are distributed in the piedmont. The lithology is marl, sandstone and gravel, and the pore and fissure of sandstone and gravel are developed, carrying clastic rock 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 centre of depression. Roof depth in piedmont is 40-50m, and at the centre of the depression increases to more than 300m. Disclosed by drill holes, the aquifer is generally 2-3 layers, the most being 7 layers, with accumulative thickness reaching 100m. The lithology is sandstone and gravel, with moderate cementation, forming the rock system of pore-fracture confined aquifers. The groundwater is confined. Extensive asymmetric reticulate rotten fracture aquifers and wire-like structured fissure water are distributed in the bedrock area.

6.1.6.3. Groundwater Resources

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

The annual average groundwater recharge in China's part is $51.4\times108m^3$, and the total annual groundwater withdrawal is $37.1\times108m^3$. The groundwater reserve of the Amur River basin in Russia's part is $150m^3/s$, namely $47.3\times108m^3/a$, and the total groundwater withdrawal module is $3.7L/s.km^2$. Considering that the groundwater withdrawal from China's part is $37.1\times108m^3/a$ and that the groundwater storage of Russia's part is $47.3\times108m^3/a$, it can be seen that it is in accordance with the proportion of the area, which shows that the two parts of the basin have similar hydrogeological conditions and status of groundwater resources.

According to the result of investigation and evaluation, the groundwater annual recharge of China's part under balance conditions are as follows: the vertical recharge is $33.8\times108m^3/a$; the river recharge is $5.8\times108m^3/a$; swamp and marsh recharge is $7.3\times108m^3/a$; lateral runoff recharge of the neighbouring region is $4.5\times108m^3/a$; precipitation infiltration recharge of vertical recharge is $27.8\times108m^3/a$; regression infiltration recharge of irrigation is $6.0\times108m^3/a$.The annual groundwater discharge in China's part under balance conditions is as follows: river discharge is $2.2\times108m^3/a$; swamp and marsh discharge is $1.4\times108m^3/a$; evaporation discharge of groundwater is $4.6\times108m^3/a$; lateral runoff discharge of the neighbouring region is $6.1\times108m^3/a$.The total discharge of groundwater is equal to the total recharge. The groundwater of the basin is in a balanced state, and the natural circulation of groundwater is in a favourable situation.



Section of Middle Heilongjiang-Amur River Basin

The local groundwater in the aquifer near the national boundaries discharges into the Heilongjiang River and Wusuli River. The regional groundwater flows from the part situated in China to that in Russia. It is estimated that the runoff flux getting across the boundary and flowing from China to Russia is about $1.52\times108m^3/a$. The two countries should establish a perfect management system of water resources for this aquifer to insure the sustainable utilization of the water resource.

6.1.6.4. Groundwater Quality

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

According to the investigation results of the groundwater quality in the Chinese section, 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 areas is between 0.2g/L and 0.75g/L. pH is 6.5-7.5, total hardness is 1.45-4.29mmol/L. and 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. Water with a high content of Fe and Mn distributes extensively, becoming the notable characteristic of groundwater in that region. Influenced by environment and hydrogeological conditions, its distribution has obvious characteristics of district and belt. The content increases from basin boundaries to its centre. 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 a range of 3-15mg/L.

The content of SiO_2 in the Quaternary pore water replenished by precipitation is high - generally 20-30mg/L. The content of SiO_2 increases from southwest to northeast. The dissolved SiO_2 of high content seriously influences the composition of low degree mineralized fresh water. At the same time, the groundwater of this area contains dissolved oxygen, CO_2 and nitrate. Evaluating in terms of the standards of China, Grade III and Grade IV groundwater mainly distributes in the west of the area, namely the Songhua River catchment. Grade I and Grade II groundwater, namely the groundwater with favourable quality, mostly distributes 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 the 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. The 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 the Tunguss deposit neighbouring Khabarovsk City is correlative to life of the people and needs of industry; Russia is therefore in the process of applying modern techniques to depress the content of Fe and Mn in the groundwater directly.

Ions with superscalar mostly root in the dissolving of minerals containing Fe or Mn. There are some advantageous geological 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.

6.1.6.5. Groundwater Usage

Groundwater of middle Heilongjiang-Amur River basin is the primary water supply for the life and irrigation of the two countries. Middle Heilongjiang-Amur River basin has some merits such as the extensively distributed aquifer and groundwater that is not easily polluted. As a result, the Kiamusze city of China and Khabarovsk City of Russia regard the groundwater of the riverside source field in the Songhua River and Heilongjiang-Amur River as their crucial water supply. According to statistics, in the 21st century, the withdrawal of groundwater in China's part of the basin is $21.3\times108m^3/a$, accounting for two-thirds of the total groundwater withdrawal. The exploitation depth in the Russian 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 balanced state as a whole, and the groundwater runoff also keeps a constant state.

An ancient river way lies in the frontier of the piedmont alluvial fan in the west of the China section. The shallow aquifer underlying this area accepts plentiful recharge, so it has a huge exploitation potential. Because the assemblage of rivers and marshes in the middle of the basin, both deep and shallow groundwater should be exploited so as to maintain a healthy environment and minimise impacts on these environmental assets.

A series of geological environmental problems occur during the exploitation of groundwater, such as draining of wells and the regional decline reduction in groundwater levels. In the China section of the basin the shallow aquifer is exploited, which results in regional decline in reduction of groundwater levels, with an annual average rate of decline being 0.5-1m. The reduction is as high as 2.2-2.8m in some places. The water level of the coalfields has declined sharply. Generally, the annual drawdown fluctuates from 2-3m, and in some years, it is as high as 4m. With the draining of the wells and the decline in groundwater levels, the wells near the residential are also drying up. All six water well fields of Jiamusi city, as well as the irrigation wells and enterprise-owned wells, exploit the pore aquifer in loose rock masses mostly most of the time. In 2000, there were 1,656 wells in Jiamusi City, with a total yield of $1.56\times108m^3$. At present, there are two depression cones (called the 'eastern depression cone' and the 'western depression cone' in the intensively exploited area, and the groundwater levels are declining 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, the section of marsh area in China part of the region was about 34,000km^2 . Today it has now decreased to 4,500km^2. Marsh is an important part of the environment related to groundwater. The Chinese government is adopting measures to reclaim wetland from tilth to protect and restore the marsh in this area.

6.1.6.6. 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 united communiqué of the ninetieth prime ministerial meeting between China and Russia, the two countries will continue to cooperate on joint monitoring of water quality of Transboundary Rivers, and will consider establishing an intergovernmental agreement on transboundary water resource protection.

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

In 2005, an accident in a petro-chemical plant in Jilin led to a major pollution incident on the Songhua River in China. The Chinese State Environmental Protection Administration (SEPA) invited an expert team of the United Nations Environment Programme (UNEP) on 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 2005, sampling and testing were undertaken at the border between China and Russia 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 was also carried out at the other monitoring points within China and Russia. The joint sampling at the pollution plume position was carried out in a timely manner. Through this process, China and Russia strengthened joint monitoring arrangements. China donated equipment and other materials (to assist Russia to respond to potential damage and future risks, including 6 pieces of monitoring equipment, 150 tonnes of activated carbon and 6 air compressors) to assist Russia in responding to potential damage and risks. 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 today, the Geological Survey Department of China has consistently sampled and tested the groundwater in the aquifer along the Songhua River from Jilin to Heilongiang. The dynamic monitoring indicates that the groundwater does not contain benzene, and that the middle Heilongjiang-Amur river basin has not been polluted by the accident that polluted the Songhua River.

6.2. Transboundary Aquifers of Greater Mekong River Basin

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The Greater Mekong River Basin is the longest river in Southeast Asia, the 7th longest in Asia, and the 12th longest in the world. It has a length of about 2,700 miles (4,350km). Rising in south-eastern Qinghai province, China, it flows through the eastern part of the Tibet Autonomous Region and Yunnan province, after which it forms part of the international border between Myanmar (Burma) and Laos, as well as between Laos and Thailand. The river then flows through Laos, Cambodia, and Vietnam before draining into the South China Sea south of Ho Chi Minh City (formerly Saigon). Vientiane (Viangchan), the capital of Laos, and Phnom Penh, the capital of Cambodia, both stand on its banks. About three-fourths of the drainage area of the Mekong lies within the four countries the river traverses on its lower course—Laos, Thailand, Cambodia, and Vietnam.

The Mekong River drains more than 313,000 square miles (810,000 square km) of land, stretching from the Plateau of Tibet to the South China Sea. The contrast between the physical conditions that prevail above and below the Mekong's descent from the Yunnan highlands divides it into two major parts. The upper Mekong flows 1,215 miles (1,955km) through a long, narrow valley comprising roughly one-fourth of the total area, cutting through the mountains and plateaus of south-western China. The lower Mekong, below the point where it forms the border between Myanmar and Laos, is a stream 1,485 miles (2,390km) in length draining the Khorat Plateau of north-eastern Thailand, the western slopes of the Annamese Cordillera in Laos and Vietnam, and most of Cambodia, before reaching the sea through the distributary channels of its delta in southern Vietnam.

In its upper reaches, the Mekong rises in the Tibetan Plateau between the Salween and Yangtze rivers; the streambed has cut deeply into the rugged landscape through which it flows. Along its course between Myanmar and Laos, the Mekong drains about 8,000 square miles (21,000 square km) of territory in Myanmar, comprising rough and relatively inaccessible terrain. In its more gentle lower stretches, where it constitutes the boundary between Laos and Thailand for a considerable distance, the Mekong inspires both conflict and cooperation among Cambodia, Laos, Thailand, and Vietnam.

6.2.1. Geography of Greater Mekong River Basin

The Mekong flows for almost 2,200km from its source and decreases in altitude by nearly 4,500 metres before it enters the Lower Basin where the borders of Thailand, Lao PDR, China and

Burma come together in the Golden Triangle. Downstream from the Golden Triangle, the river flows for a further 2,600km through Lao PDR, Thailand and Cambodia before entering the South China Sea via a complex delta system in Vietnam.

In Yunnan province, China (where the river is called the Lancang Jiang), the river and its tributaries are confined by narrow, deep gorges. The tributary river systems in this part of the basin are small. Only 14 have catchment areas that exceed 1,000km^2. In the south of Yunnan, in Simao and Xishuangbanna Prefectures, the river changes as the valley opens out, the floodplain becomes wider, and the river becomes wider and slower. The major concern here is soil erosion. s recently as 1998, up to 28 per cent of the Mekong Basin in Yunnan was classified as "erosion prone". Cultivation is now restricted in favour of reforestation.

Lao PDR lies almost entirely within the Lower Mekong Basin. Its climate, landscape and land use are the major factors shaping the hydrology of the river. The mountainous landscape means that only 16% of the country is farmed under lowland terrace or upland shifting cultivation. With upland shifting agriculture (slash and burn), soils recover within10 to 20 years but the vegetation does not. Shifting cultivation is common in the uplands of Northern Lao PDR and is reported to account for as much as 27% of the total land under rice cultivation (Lao Agricultural Census, 1998-9, 2000). As elsewhere in the basin, forest cover has been steadily reduced during the last three decades by shifting agriculture and permanent agriculture. The cumulative impacts of these activities on the river regime have not yet been measured.

Loss of forest cover in the Thai areas of the Lower Basin has been the highest in all the Lower Mekong countries over the past 50 years. On the Korat Plateau, which includes the Mun and Chi tributary systems, forest cover was reduced from 42% in 1961 to 13 per cent in 1993. Although this part of Northeast Thailand has an annual rainfall of more than 1,000mm, a high evaporation rate means it is classified as a semi-arid region. Consequently, although the Mun and Chi Basins drain 15% of the entire Mekong Basin, they only contribute 6% of the average annual flow. Sandy and saline soils are the most common soil types, which makes much of the land unsuitable for wet rice cultivation. However, in spite of poor fertility, agriculture is intensive. Glutinous rice, maize and cassava are the principal crops. Drought is by far the major hydrological hazard in this region.

In Cambodia, the agriculture sector accounts for half of the GDP and employs 80 to 85%of the labour force. Wet rice is the main crop and is grown on the flood plains of the Tonle Sap, Mekong and Bassac rivers. More than half of Cambodia remains covered with mixed evergreen and deciduous broadleaf forest, but forest cover has decreased from 73% in 1973 to 63% in 1993. Here the river landscape is flat. Small changes in water level determine the direction of water movement, including the large-scale reversal of flow into and out of the Tonle Sap basin from the Mekong River.

The Mekong Delta in Vietnam is farmed intensively and has little natural vegetation left. Forest cover is less than 10%. In the Central Highlands of Vietnam, forest cover was reduced from over 95% in the 1950s to around 50% in the mid 1990s. Agricultural expansion and population pressure are the major reasons for land use and landscape change. Both drought and flood are common hazards in the Delta, which many people believe is the most sensitive to upstream hydrological change.

6.2.2. Climatic Conditions of Greater Mekong River Basin

The Mekong's flow comes chiefly from rainfall in its lower basin, which fluctuates seasonally with the monsoon winds. Temperatures in the lower Mekong basin are uniformly warm throughout the year. Daily highs at Phnom Penh average 89°F (32°C), and lows average 74°F (23°C). In the upper basin, temperatures are moderated somewhat by altitude and generally are lower and exhibit more seasonal variation than those found farther south. In general, the temperature and precipitation in this basin vary greatly; the normal trend is that both temperature and precipitation increase from north to south. The entire basin comes under the influence of a south-west monsoon, and both dry and wet conditions during the year are most obvious. In general, the months between May-October constitute the wet season and November-April is the dry season. About 85% of the total precipitation in the basin is concentrated during the wet season. Heavy rains mainly happen in the mid period of the wet season.

In the Great Mekong River Basin the rainfall is unevenly distributed between seasons. The dry season (Nov-Apr, 6 months) will receive only less than 20% of the total rainfall and the wet (monsoon) season will receive more than 80%. The average monthly rainfall in the basin is listed below.

The rainfall distribution of Lancang - Mekong River Basin during the year Unit (mm)

Time(month)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lancang River Basin	Rainfall Volume	17.1	18.6	27.3	41.3	97.9	173.9	224.3	228.3	131.6	102.3	42.9	19.3
	Per	1.52	1.65	2.43	3.67	8.7	15.46	19.94	20.3	11.7	9.1	3.81	19.3
Under The Mekong River Basin	Rainfall Volume	8	15	40	77	198	241	269	292	299	165	54	14
	Per	0.5	0.9	2.4	4.6	11.8	14.4	16.1	17.5	17.9	9.9	3.2	0.8

6.2.3. Hydrological Regimes of Greater Mekong River Basin

The runoff is mainly from precipitation, followed by groundwater and snow melt. The runoff of the upper reaches of the river is mainly from groundwater recharge, followed by rain and snow melt water supplies. With the increase of precipitation, snow melt supply is reducing in the middle-reaches of the region. River runoff is from groundwater recharge and the precipitation supplies. Lower reaches are in the subtropical and tropical climate zones, and with abundant rainfall due to the monsoon, rain is the main supply of the runoff, which accounts for above 60% of annual runoff, followed by groundwater recharge. For many years, the average flow into the sea from Mekong River for has been 475×108m^3. The hydropower water reserves of the Great Mekong River Basin are 58 million KW.

The Mekong mainstream can be divided into six main reaches.

In dividing the river this way, geographers take into account a number of considerations, including:

- hydrological regime
- physiography
- land use
- existing, planned and potential resource developments

6.2.3.1. Lancang Jiang or Upper Mekong River in China: in this section, the major source of water flowing into the river comes from melting snow on the Tibetan Plateau. This volume of water is sometimes called the "Yunnan Component" and plays an important role in the low-flow hydrology of the lower mainstream. Even as far downstream as Kratie, the Yunnan Component makes up almost 30% of the average dry season flow. A major concern is that the on-going and planned expansion of dams and reservoirs on the Mekong mainstream in Yunnan could have a significant effect on the low-flow regime of the Lower Mekong Basin system.

6.2.3.2. Chiang Saen to Vientiane and Nongkhai: this reach is almost entirely mountainous and covered with natural forest, although there has been widespread slash and burn agriculture. There is little scope for wide scale permanent agricultural development and there are no plans for any major water resources developments. Pre-feasibility and feasibility studies of the hydropower potential here have focused on small run-of-river schemes for local needs. This may change, however, with recent interest in schemes in the Upper Nam Ou, the major tributary system, which could be developed to export power to China. On the Thai side, there are schemes to divert water out of the Mekong Basin to south-flowing basins. Although this reach could hardly be described as "unspoiled", the hydrological response is perhaps the most natural and undisturbed in all the Lower Basin. Many hydrological aspects of the Lower Basin start to change rapidly at the downstream boundary of this reach.

6.2.3.3. Vientiane and Nongkhai to Pakse: the boundary between Reach 2 and 3 is where the Mekong hydrology starts to change. Reach 2 is dominated in both wet and dry seasons by the Yunnan Component. Reach 3 is increasingly influenced by contributions from the large left bank tributaries in Lao PDR, namely the Nam Ngum, Nam Theun, Nam Hinboun, Se Bang Fai, Se Bang Hieng and Se Done rivers. The Mun - Chi river system from the right bank in Thailand also enters the mainstream within this reach.

It would be easier to measure impacts on mainstream hydrology from changes to the major left and right bank tributary systems by further dividing the river into subreaches upstream and downstream of where the Mun and Chi rivers meet the Mekong (the confluence). The hydrologies of these subreaches are distinct, as are the present status and future direction of their water resources development potential. The Mun and Chi rivers are highly developed low-relief, agricultural basins with low runoff potential and significant reservoir storage for dry season irrigation. The left bank Lao tributaries are in an accelerating phase of development in terms of water demand for agriculture and hydropower.

6.2.3.4. Pakse to Kratie: The main hydrological contributions to the mainstream in this reach come from the Se Kong, Se San and Sre Pok catchments. Together, these rivers make up the largest hydrological subcomponent of the Lower Basin. Over 25% of the mean annual flow volume to the mainstream at Kratie comes from these three river basins. They are the key element in the hydrology of this part of the system, especially to the Tonle Sap flow reversal. One of the major issues here is the potential impact on flow regimes that would result from hydropower regulation on the upper Se San in Vietnam.

6.2.3.5. Kratie to Phnom Penh: This reach includes the hydraulic complexities of the Cambodian floodplain, the Tonle Sap and the Great Lake. By this stage, over 95% of the total flow has entered the Mekong system. The focus turns from hydrology and water discharge to the assessment of water level, overbank storage and flooding and the hydrodynamics that determine the timing, duration and volume of the seasonal flow reversal into and out of the Great Lake.

6.2.3.6. Phnom Penh to the South China Sea: Here the mainstream divides into a complex and increasingly controlled and artificial system of branches and canals. Key features of flow behaviour are tidal influences and salt water intrusion. Every year, 35% to 50% of this reach is flooded during the rainy season. The impact of road embankments and similar infrastructure developments on the movement of this flood water is an increasingly important consequence of development.

Greater Mekong River Basin water resources approximate distribution

country	Basin area ($\times 10^4 km^2$)	Percentage of total area (%)	Average flow (m^3/s)	Percentage of total flow (%)
China	16.48	20.7	2410	14.5
Burma	2.4	3.1	300	2
Laos	2.02	25.4	5270	35.6
Thailand	1.84	23.1	2560	17.2
Cambodia	15.5	19.3	2860	19.3
Vietnam	6.5	8	1660	11.2

6.2.4. Hydrogeology of Greater Mekong River Basin

Groundwater is stored in different aquifers, and its location, depth, distribution, and run-off are affected by geological factors. Different characteristics of the geological structure result in different characteristics of the water and restrict the storage and movement of groundwater. The occurrence of groundwater in the whole basin is characterized by the karst water distribution along the Hengduan Mountains and Tanen Mountains. In China, it is widely distributed in the Sichuan-Yunnan region. Because of the control of the Jinghong in Yunnan province, China and the Chiang Raithe fault in Thailand, the area in the vicinity of Lincang develops south-western strip karst formations. The pore water is mainly distributed in the southern delta plain, plateau basin and intermountain valley. The fissure water is widely distributed in the centre of the basin.

In the upper reaches of Lancang the Mekong River has a north-south orientated cross-section due to the mountains fold belt, and the hydrogeological conditions are complicated. In the frozen soil region of the Tibetan Plateau above Duchang on the Lancang River, the glacial melt water recharges groundwater aquifers in the freeze-thaw season and the water level is increased while the water reduces in the frozen season.

In the middle and lower reaches of Lancang River, groundwater is mainly distributed in the magma and metamorphic rock structures, most of it and the water is mostly karst water. Granite bedrock fissure water is the most widely distributed in magma rocks. Fissures connect into reticular structures that have good storage conditions and permeability. Groundwater suffers serious loss due to topography. Topography controls the groundwater flow and the shallow aquifer mainly comprises of weathered and fissured rocks of metamorphic origin. Groundwater is mainly supplied by precipitation, and the discharge forms include spring runoff and underground discharge. The cause of the clastic rock pore fissure aquifers is complex. Lithofacies changes, the extent of crack development, the recharge of water, and hydrogeological structural features are all related to the tectonic belt. Clastic rock in the plateau includes sandstone, conglomerate, and shale etc. It has a very dense rock structure and because of its hardness, has a strong ability to resist wind . As a result, weathering fissures do not develop and the rock structure has a weak permeability. Sometimes, however, it can develop large cracks due to tectonic movement; which is conducive to groundwater ,recharge and water-rich areas appear. Pure carbonate rocks are distributed over a large area of Yunnan province in China. In these areas, the karst is developed and surface depressions, funnels, sinkholes, and dissolved cracks occur frequently, creating a good channel for rain and surface water recharge of groundwater. Groundwater mainly occurs in the cracks, caves and underground river systems rich in karst water. As a result of the fracture cutting, rock breaking and the development of joints and karst fractures, the hydraulic connection between aquifers is close. The discharge zone of groundwater is on the edge of the basin and the water often discharges to the surface in the form of an underground riversand springs. The group of carbonate rocks intercalated clastic rock and the group of clastic rocks intercalated carbonate rock also contain a small amount of groundwater, yet these formations often resist water and have little significance for the water supply of the basin.

So the characteristics of the enrichment of water are obviously caused by lithology. Relatively speaking, sand and conglomerate are good for the storage of water; shale, mudstone, and other clay-rich materials are not conducive to storage. In addition, rainfall, topography, and hydrological factors also have a large influence on water enrichment. The Yunnan-Guizhou Plateau district is a karst area and has abundant supplies of karst water, but the distribution of this water is uneven. This type of groundwater is mainly distributed in the layered hard carbonate rock group, and stored in karst underground river channels occurring in the Paleozoic and Lower Paleozoic carbonate rocks. The precipitation in this region is abundant. There is a wide distribution of carbonate rocks(the exposed carbonate rocks in Yunnan Province account for about 60% of the province's total area) which are generally thick with a pure lithology. Underground rivers with considerable flows develop pervasively in this region because they generally become a concentration of discharge points for local underground runoff. There is also pore water and fissure water in this region. The main distribution of pore water can be found in the mountain basins, valleys and at the edge zones of foothills. The Lacustrine is the main sediment type in the basins. The clay inter-bedded silt layers are accumulated, the thickness of which is larger and the water abundance is generally better. Fissure water occurs in the cracks of fractured rocks, metamorphic and magmatic rocks. The fissure water of metamorphic rock types mostly emerges in the form of a layer and the water abundance is medium, due to in-situ recharge and discharge. In the tectonic fracture zone, the groundwater is rich and discharges in the form of springs, so it is difficult to form a medium-sized water source. The igneous rocks mostly contain weathering fissure water, and the water abundance and rainfall has a close connection with the degree of rock weathering.

In the Korat Plateau in the middle reaches of the Mekong River, sand covers a large area. The rainfall is relatively high, but there is a limited quantity of shallow groundwater because of thin soil, fast water evaporation and infiltration, and poor water retention. The river in this drainage basin is generally "dendrite" and the river networks are the result of special natural processes. The Quaternary lacustrine sand and clay layers in the area stack alternately to form an aquifer with a multi-layered structure. The hydraulic connection between aquifers is close. As the river network develops, the groundwater becomes rich due to greater rainfall, abundant supply source, and good infiltration conditions.

A large area of Pliocene-Quaternary mafic basalt is in the vicinity of Salavan Naji, underlying Carboniferous. Early progeny ended Silurian-Devonian groove deposition, and folded under the Paleozoic strata. A number of areas produce phyllite and schist. The lower of Carboniferous is flysch, followed by a volcanic phase. Some parts of the late Carboniferous is continental sediment. Vast areas of increased erosion happened in the late Permian, resulting in unconformity between the Paleozoic and Mesozoic. The majority of rocks in the region are consolidated and semi-consolidated , magmatic rocks and metamorphic rocks. Most of the groundwater is fissure water and has a poor storage characteristics due to the poor degree of weathering and zoster distribution.

The lower reaches of the Mekong River plains mainly consist of Quaternary alluvial plains and deltas. The sedimentation of the river formed the plains and they have a large area. Alluvial plains are generally divided into three parts: the Piedmont Plain (the transitional zone of the mountains to the plains), the Central Plains (mainly alluvial deposits, often a number of rivers or water flows running through these), the Coastal Plain (alluvial - marine Plain, often characterised by ponds and coastal topography). Piedmont plains of alluvial–diluvia type run from Bandana Mountain to the Tonle Sap Lake. Groundwater is buried deep in comparison. Down to its the piedmont plains is the central plain, where the sediments are mainly alluvial deposits and also often have lake sediments, wind or marine sediment deposits. Continuing down is the coastal plain, which has very fine sediments and a great lake area. In the Ca Mau Peninsula and the surrounding areas, cyclical Haichao invasions often occurs and forms the cross-cutting phenomenon between the marine and alluvium layers. It is also has coastal sands or shell embankments. On both sides of the Mekong Delta is the insignificant linear mountain, dividing the majority of the plateau. It is associated with a low mountains yet it is close to a larger mountain range. The Mekong Delta is a relatively new alluvial plain, in the northern part of which is Tonle Sap Lake, and above it are older plains. Quaternary sediments are widespread, although thickness is variable (40-350m). The aquifer is formed by coarse granular rocky material which results in good permeability, smooth run-off and good recharge of water. The groundwater quality is generally good in the area.

Particularly in the Mekong Delta region, sediment thickness is large and it is highly conducive to the transport and enrichment of pore water. Beneath Quaternary sediments is a large area of basalt ageing from the late Pliocene to Quaternary. Mainly fissure eruption rocks are within the diabase-like structure. Cracks are generally less developed, with resulting in less water, and there is often a relatively impermeable layer of Quaternary loose material which provides a watertight effect at the bottom of the aquifer.

The entire basin's water supply is mainly derived from the karst areas, such as China's YunnanProvince, as well as Alluvial Fan Delta regions such as the Mekong River Delta and the Red River Delta. These areas account for 85% of the pore water basin-wide. The natural recharge areas modulus of pore water and karst water is generally 10 ~ 40 × 104m^3/km^2.a and the recharge rate is relatively large. However in the fissure water region, the relative proportion of water recharge is derived from a relatively small area. Therefore, the pore water volume accounts for 30% of recharge while the karst water volume accounts for 20% of recharge Bedrock fissure water is distributed in the lower reaches of the Mekong River and the surrounding areas and in larger, more developed tectonic fracture zone areas. Groundwater storage capacity on the large modulus of natural recharge in some areas, such as the Lincang - Jinghong area, and the Dali - Lao Cai area, is as high as 25 ~ 30 × 104m^3/km^2.a. In some areas, where there are no developed cracks, groundwater storage is smaller. The natural replenishment modulus is 5 × 104m^3/km^2.a in such areas. However, these areas occupy the majority of the basin area with fissure water supply accounting for 50% of the total amount of water resources.

6.2.5. Distribution of Groundwater Resources

According to the occurrence conditions and distribution of the Lancang-Mekong River Basin, the groundwater resources in the basin can be divided into: groundwater occurring in the plains and basins, groundwater in plateaus and mountains, groundwater in mountains and hills, and groundwater in freezing and thawing areas.

6.2.5.1. Groundwater in Plains and Basins: The main occurrence of groundwater is in rock formations with loose sediments and little consolidation. Groundwater is generally abundant, and it has particular importance to mining operations in these areas. It is located in the major plains, basins among the mountains, large plains and piedmont plains of inland basins. Areas include, including the Mekong Delta, Hanoi Delta, Vientiane Plain, Savannah plains, Pakistan plains, as well as the transitional plain to the eastern part of the mountain range on the eastern bank of the Mekong River in Cambodia. Natural supply resources are 81,078,000,000m^3/km^2.a, with exploitable resources of 56,423,000,000m^3/km^2.a. Natural recharge modulus reaches 30-50 × 104m^3/km_2.a. The groundwater type is generally pore water.

6.2.5.2. Groundwater in the Plateaus: The distribution of groundwater in the plateaus is more complicated, with groundwater mainly consisting of bedrock fissure water and karst water. The natural supply resources in the plateau are 38,646,000,000m^3/km^2.a, with exploitable resources of 28,153,000,000m^3/km^2.a. The natural recharge modulus is10-40×104m^3/km^2.a. The exploitable resources are is mainly located in major plateaus, including the Yunnan-Guizhou Plateau, Sichuan plateau Tong, Gan Dream Plateau, Plateau khorat, Kontum plateau and so on, among the valley terrain. The stratas exposed in these areas are from Cambrian to Quaternary.The hydrogeological conditions are more complicated. The natural replenishment modulus can be as high as 30×104 m3/km2.a in the areas where fractures have developed, whereas in areas where fractures have not developed the natural replenishment modulus can be less than 5×104m3/km2.a.

6.2.5.3. Groundwater in Mountains and Hills: Groundwater in mountains and hills is a combination of bedrock fissure water and pore water. Located in the east of Tanbang plateaus of Myanmar, the highlands of Shan State near the border between north of Thailand and Laos, and the mountains and basins in the very north of Laos, have a natural supply of water resources of 46,731,000,000 m3/km2.a, and the volume of resources available for exploitation is 32,169,000,000 m3/km2.a. Pore water is distributed in the mountain basins. Most of the basins belong to the Cenozoic, but have different structures. The deposits from the Tertiary or Quaternary have developed differently. The natural recharge modulus in these deposits is 20 - 50 × 104m3/km2.a.

6.2.5.4. Groundwater in Freezing and Thawing Areas: The distribution of groundwater in freezing and thawing areas runs from north-western Tibet to Linzhi, Mangkang, and Yushu. The unique geographical landscape of the region is a high mountain terrain and an extreme cold and dry continental climate. The elevation is about 5,000ml, and annual rainfall is less than 100mm. The rivers are very short and mostly closed flow. The soil is often frozen for more than 8 months a year. The types of phreatic water are the marshes, permafrost and glaciers. Phreatic water is controlled by the law of vertical zonation. In the freeze-thaw season, aquifers are rich in water, and natural supply resources are 26,266,000,000m3/km2.a, with exploitable resources of 18,926,000,000 m3/km2.a.
Groundwater is located in the basins and plains, mountains and hills, plateaus, and freeze-thaw areas. Groundwater in the basins and plains accounts for 42%of the total recharge, mountains and hills account for 24%, and plateaus account for 20%. The remainder is located in the freeze-thaw regions. ,It is clear that plains and basins account for the largest percentage of recharge, and have the largest storage area. Groundwater is broadly distributed in the mountains and hills in the inland area. Although the supply module is not high, the region has a large water reserves due to high rainfall and a large recharge area. In freeze-thaw areas, mainly in China's Tibet Plateau, the groundwater is rich in the thawing season and poor in the frozen season.

6.2.5.5. The Hydrogeochemistry of the Aquifers: In terms of the overall groundwater, the water quality of the Lancang-Mekong River Basin is good; the groundwater quality classification in most areas deems it fit for dinking. Relatively poor water quality is located mainly in Hanoi, the Mekong Delta, and the city of Luang Prabang in the vicinity of the east wing. Groundwater in this region can only be used for limited agricultural irrigation and industrial water. Groundwater pollution is very serious in some important cities such as Kunming, Hanoi and Vientiane. From the Lancang River in China to the Mekong Delta, the salinity of the water is high. Salinity is also an issue in the Lancang River Basin groundwater in China where salinity (in bicarbonate type water) is $\leq$0.5g/l. South of Vientiane, the groundwater varies in its chemical constitution frombicarbonate to bicarbonate-sulfate. This region is in the transition zone between fresh- and salty water. In the Mekong Delta, the chemical constitution of groundwater varies from bicarbonate-sulfate to sulfate, belonging to the chloride salt type.

The Lancang-Mekong River Basin is an alternating deposition with highly connected surface water and groundwater. As a result the water quality of surface water and the lithology of shallow water channels are important factors influencing the shallow hydrogeochemistry. The upper reaches of the main stream have good water quality, because of the type of rock types including:consolidated, semi-consolidated rocks, mainly sand shale, limestone and basalt, followed by gneiss. The PH value of groundwater is between 7.6-8.4 and salinity is between 1.57mg/l-6.8mg/1,which is typical of water with a low level of salinity. In terms of total hardness, the concentration of sulfate ions and chlorine ions are similar, and temporary hardness is mainly an issue in the main water body. There are thick masses of granite exposed on the surface in the middle reaches, underlain by sandstone and metamorphic rocks. The chemical constitution of groundwater varies from bicarbonate to bicarbonate-sulfate. Downstream, there are mainly Quaternary unconsolidated sediments, including the coarse sand and gravel layers. The PH values in Mekong groundwater are between 7.3-8.0, as a result of the presence of the bicarbonate ion water type (HCO_3^{2-}). The main ion in the outlet of the river is Ca^{2+}, and the main component of sealed salt water is NaCl, which was formed due to the transgression in the geological period.

In China, groundwater salinity is ≤0.5g/L, with the main type of water being bicarbonate fresh water. While the total hardness of the water in some important cities such as Kunming is significantly increasing, in other areas it is remaining stable. In terms of groundwater quality, the water in these areas is fit for dinking except for in Yunlong and Weixi. The amount of fluoride (F-)in Baoshan and Menghai groundwater is >1.0mg/L; the amount of iodide (I-) in Yongping and Pu'er groundwater is >1.0mg/L. The main forms of groundwater pollution in Jinghong City are volatile phenol (in terms of phenol)> 0.002mg/L, mercury (Hg)>0.001mg/L, and lead (Pd)>0.05mg/L.

Lancang River water quality deteriorates in the wet period, while water quality in the dry season only fluctuates slightly and is generally good. Water quality in the main stream, the middle reaches of the river and the tributaries have a smaller inter-annual change. They have basically remained stable with only light organic pollution and water quality in most years remainins between levels II-III. However, water quality in downstream areas has deteriorated with quality reaching level V in most years. Especially in wet periods, there has been a serious deterioration of water quality, with a failure to maintain the water quality standard of level III (which indicates serious pollution). An evaluation of the results of water quality in the main stream of the calendar year is shown below in Table.

Evaluation of the results of water quality in the main stream of the Lancang River

Year	the monitoring sections of upper reaches		the monitoring sections of middle reaches						Downstream monitoring sections			
	Yongbao Bridge		Jiajiu		Jinglin Bridge		Yakou		Banna		Ferry Han Meng	
	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
1987	IV	I	II	—	II	—	II	IV	II	II	—	—
1988	III	III	III	II	A	II	A	II	V	II	IV	—
1989	II	I	III	II	IV	III	III	II	A	II	V	—
1990	I	II	III	I	I	II	II	II	A	I	A	—
1991	IV	I	III	II	I	I	III	III	A	II	A	I
1992	II	II	IV	A	I	IV	II	III	—	—	V	I
1993	A	I	IV	II	IV	II	II	I	—	—	A	II
1994	III	I	II	III	IV	II	II	II	IV	II	A	II
1995	II	I	II	IV	II	IV	II	II	IV	I	III	IV
1996	III	I	IV	IV	III	II	II	I	A	II	A	IV
1997	II	I	II	II	III	II	II	II	A	II	A	II

Following Vientiane, there is a large distribution of fresh water in Thailand's central region, with underlying brackish or salty water. The rock structure is Precambrian structure in the eastern part of Vietnam, with underlying Mesozoic metamorphic and sedimentary rocks, Quaternary stratigraphy and various ages of granite intrusion. In this area, because of the rich morphemic water and the widespread growth of water regulations, the water salinity of most districts does not surpass 0.3g/l. However, it is possible in the areas dominated by calcareous rock to have salinity readings above 0.4-0.6g/l due to the presence of heavy carbonic acid, calcium chloride, sodium water and calcium bicarbonate magnesium water. The Menam basin is the area's largest basin, which dates from the Mesozoic Era and the old Tertiary Period-Neogene Period red stratum; above them, there is over 300m thickness of silting alleviation deposits below the Menam Rivers. Their hardness index does not surpass 0.5-0.8g/l due to the calcium bicarbonate content of the water. It is possible to form fresh water in the Quaternary Period stratum's old Tertiary Period-Neogene Period and in the Mesozoic Era deposit above some positions, while to form the bi-sulfuric acid-chlorination and the sodium chloride micro salty water and the salty hot confined water in the quite deep position. Horizontal and vertical zonality are visible in the groundwater hydrochemistry and the hardness index assignment. Supplies of calcium bicarbonate - magnesium water with a salinity of 0.05-0.15g/l is typical in the mountainous areas. But there is 0.5g/l heavy soda water and heavy carbonic acid - chlorination water formed due to domestic usage in the foreland. The Delta plain water is characterised by bicarbonate - calcium chloride - sodium - magnesium water, with a salinity of less than 0.6g/l. The groundwater hydrochemistry of the Hanoi rift valley is characterised by sodium bicarbonate fresh water and high levels of vertical zonality, making the salinity highly variable.

6.2.6. Transboundary Aquifers:

The Lancang - Mekong River is an international river, which flows through China, Myanmar, Laos,Thailand, Cambodia and Vietnam. The surface water and groundwater are closely linked. Groundwater is an important fresh water resource, and the transboundary aquifer is an important component of the groundwater system and the precious freshwater resources among the countries. Therefore, the study on transboundary aquifers is of important significance to the management of groundwater resources shared between countries. Through various hydrogeological parameters, five significant international transboundary aquifers have been identified and are described below.

6.2.6.1. The Lancang River Downstream Aquifer: This is a clastic rock fissure water aquifer shared by China and Myanmar, located at the juncture of Yunnan and Myanmar. The area of theaquifer is 39,508.5km^2, the part in China covering 31,167.5km^2, accounting for 78% of the area of aquifer. The annual rainfall is 1,000-1,500mm.The supply conditions are good and the natural supply module is between $10\times104m^3/km^2.a$ and $30\times104m^3/km^2.a$. The chemical types of the groundwater are mainlyHCO_3-CaMg and the salinity is 0.15 ~ 0.4g / l.

The main lithology of the strata in the area is acidic intrusive granite rocks of Triassic, shale folder clay limestone of Jurassic, calcareous shale and sandstone folder mudstone, conglomerate mudstone folder siltstone and fine sandstone of Cretaceous. The intrusive rocks are mainly distributed in the vicinity of Lincang and Jinghong and many fissures have developed. The largest fault is the South Lancang fault (a very deep fault) in the South Lancang fault zone and Wuliang Mountain fault zone. To thethe north of the South Lancang fault is the Lancang River Valley, and on the west of Lanping, and it is to the south of Yongping. The north of Yunxian, through Jinghong extends into the territory of Myanmar from the southwest. To the north of the Wuliang Mountain fault zone is Lanping, to the west of Zhenyuan and to the southwest of Simao. Due to the impact of the fault zone, the contact position of acidic intrusive rocks and the surrounding rock, the tectonic fissures are rich in groundwater supplies. The metamorphic rocks are distributed from the east of the Lancang River to the Zhenyuan-Simao area. The calcareous shale and argillaceous limestone of Jurassic are also widespread. Most of the rock has a dense structure, few development cracks, poor tensional, is resistant to weathering, and therefore has less developed fissures. As a result, the infiltration capacity and storage capacity for groundwater is relatively low .

6.2.6.2. Red River Upstream Aquifer: This aquifer is a transboundary aquifer shared by China and Vietnam, with a total area of 60,805km^2. The area of the section in China is 56,897km^2, and the runoff module of natural recharge is about $30\text{-}40\times104m^3/km^2.a$. For many years, the average annual rainfall was 1200 ~ 2000mm in the area has been 1,200-2,000mm, while the highest annual rainfall in some areas, such as the Lao Cai, is 3,200mm. There are mainly Triassic marine sedimentary rocks as well as Early Cambrian marine activities, which deposited debris and mud, including flysch rocks, in the area. The karst area is made up of solid thick-bedded limestone, dolomitized limestone, and calcareous dolomite. Triassic marine sedimentary rocks environments are made up of solid thick-bedded limestone, dolomitize limestone, and calcareous dolomite. Due to abundant rainfall and surface water, geomorphologically, the Fengcong-valley, the Fenglin-valley and the Gufeng valley plain developed. And underground karst holes of the event rate are 33%-50% of the underground area, resulted in well-developed karst groundwater. A large fault zone is located near Lao Cai due to the impact of crack development in the region, and groundwater is stored in the fissures. There is little development of clastic rock areas for the aquifers in water-rich regions with the worst structural cracks. Only the weathered cracks on the surface lead to the development of shallow unconfined aquifers. Groundwater occurs in the karst aquifers debris, cracks and construction crack. The underground river catchment area is generally 57-200km^2, and dry season flow is generally 50-500L/s. The depth of water is typically less than 30m. It is even less than 10m in some places and the annual variation of water level ranges between 10-20m.

6.2.6.3. The Midstream Mekong River Aquifers System: The aquifer is a transboundary aquifer through Thailand, Myanmar and Vietnam, and it belongs to fissure pore water in the plain and mountain basins. The area of the aquifer is 106815.75km^2. The section in Myanmar covers 77955.75km^2,accounting for 73% of the total area. The part in Thailand accounts for 21% and the part in Vietnam accounts for only 6% of the total area. The annual rainfall in the region is between 900mm and 1,600mm. Because the structure of the aquifer is complex and the supply conditions in different regions are relatively different, the differences between the amounts of groundwater available are also relatively large. The natural supply module is between 5× 104m^3/km^2.a and 40 ×104m^3/km^2.a. The aquifer is mainly affected by leaching and mixing, and groundwater is of the bicarbonate and sulfuric acidic types.

The stratas of the aquifer exposes continental classic sedimentary rocks of Jurassic, sandy conglomerate of middle and upper Cretaceous and the alluvial layer of Holocene. The continental clastic sedimentary rocks of Jurassic are scattered in the surrounding areas of Udon in Thailand, while a large number are distributed in the surrounds of the Phupan Mountains. The main lithologies are purple mudstone, calcareous mudstone, and folder sandstone. Few fractures develop in these areas and the sediments form a relative aquifuge with poor permeability. The red or brown gravel and sandstone of Cretaceous are widely distributed in the aquifer, with a thickness of 60m-300m and an average thickness of approximately 125m. The fissure water is mostly in a layered form, and the water abundance within the coarser rock particles is generally better. The flow path is not long with characteristics of in-situ recharge and in-situ discharge. The groundwater quality is local fresh water underlying brackish water. The alluvial material of Holocene is concentrated on both sides of the Mekong River and is the main alluvium, and the lithologies are sandy gravel layer, silt loam layer, salty sand and gravel interbedded. The rocks are composed of slate, siltstone, sandstone, and the rounding is good. The thickness of sediments changes and has a high variability of between 100m and 500m. Surface water availability and rainfall are relatively high resulting in a high recharge rate. The natural supply module in this area is up to 40 ×104m^3/km^2.a with an abundance of rich groundwater.

6.2.6.4. The Kele Plateau Aquifer: The aquifer, shared by Thailand and Laos, is a pore and fissure aquifer. The whole area is 95510.50km^2. The area within Thailand is 90837.50km^2, accounting for most of the aquifer. Laos accounts for a little area in the northeast. The mean annual precipitation in this region is about 1,000mm. The natural recharge modulus in most of the region reaches as high as 50×104m^3/km^2.a, and the local modulus is 50×104m^3/km^2.a along the bank of the Meng River and the Xi River. The groundwater is generally brackish to saline. Sulfate and chloride are the main chemical types of the groundwater.

The strata consist mainly of Cretacic limestone, rhyolite, silexite and Holocene loose sediment. The loose sediment of river and lake phrase distributes along the banks of the Xi River (Tributary River of Mekong River) and the Meng River, with gravel and clay as the main lithology. The main recharge sources are atmospheric precipitation and river water, the secondary is the lateral recharge from monotonic bedrock water. The natural recharge modulus is 30-50×104m^3/km^2.a for the wide recharge sources and the area has good infiltration conditions. The strata in other areas are Cretacic stratum, consisting of red, purple and gray sandstone, siltstone, and shale, sand limestone, and calcareous siltstone. The aquifer is bedrock fracture water with undeveloped fissures. The natural recharge modulus is 5~10×104m^3/km^2.a. To the east of the aquifer is Chang Shan Mountain, which has an elevation 2,000-3,000m. Its hydrogeological conditionsare complex, and the lithology is mixed rock, gneiss and slate. Quaternary basic basalt spreads around Ba se in Laos, with developed weathering fissures. The natural recharge modulus is 20×104m^3/km^2.a.

6.2.6.5. The Mekong River Delta Aquifer: The aquifer is shared by Cambodia and Vietnam, extending from Bian Dan Mountain in Cambodia to the Mekong River delta. It is a typical flood alluvial basin, which extends to the Changshan Mountain in Vietnam in the east, Oula Mountain in the west, and to Biandan Mountain in the north. The whole area of the aquifer is 223422.50km^2, and the section in Cambodia is 141337.75km^2, accounting for 63.3% of the total area. The length of the Mekong River in Cambodia is about 1,000km. The Tonle Sap Lake water system affluxes the Mekong River downstream. As the largest lake in Cambodia and also in the Indochina Peninsula, Tonle Sap Lake is a natural regulating reservoir of the Mekong River.

The annual precipitation in this region is between 1,200mm and 2,400mm, with the Mekong River delta having the highest precipitation. The aquifer consists of Quaternary sediment, with 100-1,000m in thickness. Biandan Mountain is accented intensely and the delta plain has been sunk by tectonic movement. As a result, very thick loose sediments were accumulated at the mountain front,forming splendid water-bearing media. The natural recharge modulus is 30~50×104m^3/km^2.a. The groundwater environment transits from brackish water to saline water. Hydrogeochemical processes such as leaching, mixing and condensing result in the transition in the chemical type of groundwater from bicarbonate, sulfate to sulfate, to chloride from north to south.

The lithology of Quaternary aquifer is silt, clay and small amounts of sandrock. A large amount of silt, and small amount of clay with fine sand is spread underneath. The upper part is covered by a silt seam with 15-50m in thickness. The stratigraphic profile along E—F—H profile line in Mekong River delta is seen. The mountain front is the groundwater recharge area, and the lower delta is the discharge area of groundwater. The aquifer graduates from coarse, thick and single layered to fine and multilayered.

The main recharge sources are precipitation, surface water, and bedrock fissure water. For example, the annual amount of precipitation on Ca Mau Peninsula is 1,800-2,400mm. The rainfall is so high that precipitation is the main recharge source in this region. Meanwhile, there are lots of rivers in the Mekong River delta, such as Tonle Sap Lake, Deep River, Saigon River, Hell River and some tributaries of Mekong River. Boulders and gravels are exposed from the top to the middle of the alluvial fan, which are good mediums for the vertical intake of atmospheric precipitation. The natural recharge modulus is 30×104m^3/km^2.a~50×104m^3/km^2.a. The lower delta has a good water storage capacity, as well as being a positive paretic zone.

The most important fresh water aquifer is the confined aquifer. In general, thin Holocene sediments generally formed not very thick phreatic aquifers. Extensive mid-Pleistocene aquifers from coarse to fine sand are spread in the north and south of the delta, with a common mineralization of <1g/l. The bottom Pleistocene aquifer, which contains boulders, gravel and sand, is a confined aquifer with good groundwater quality. This supplies 60% of the fresh water for the lower delta.

The values from the average runoff modulus method are larger than that from the rainfall infiltration method. The renewable water resources in water cycle are likely to be duplicated. 5 kinds of cross aquifers can be divided in Mekong River delta. The groundwater types are Quaternary loose sediments, pore water and bedrock fissure water. The pore water aquifers have a large water bearing capacity and receive supplies from Biandan mountain and other high mountains around. They have a natural recharge modulus of $30\sim50\times104m^3/km^2$.a and is an important water supply site in local places. The fissure water aquifer with metamorphic rock and intrusive rock developed little fissures and it is the local water supply aquifer. It has a natural recharge modulus of $5\sim20\times104m^3/km^2$.a. The Kele plateau aquifer is a fissure and pore aquifer. The fundamental state of the cross aquifers in Mekong River basin is seen. in table below.

The characteristics table of cross aquifers in Mekong River basin

Number	designation	countries shared	areas (km^2)	The type of aquifer
1	The Lancang River downstream Aquifer	China, Burma	39508.50	massive rock, single formation, fissured aquifer
2	Red River upstream aquifer	China, Vietnam	60805.0	Complex formation fissured karst aquifer
3	The Midstream Mekong River Aquifers System	Thailand, Laos	106815.75	double layer porous and fissured aquifer
4	The Kele plateau Aquifer	Thailand, Laos	95510.50	Multilayer structures fissured aquifer
5	The Mekong River Delta Aquifer	Cambodia, Vietnam	223422.50	Loose sediment, Multilayer structure, porous aquifer

6.2.7. Development and Utilization of Groundwater

Groundwater is an important component of water resources; it is an essential natural resource for human existence, life and production activities. In Lancang-Mekong River Basin, development and utilization of underground water has a long history. In inland especially during drought areas, groundwater is mainly used by residents for irrigation and for drinking. In major cities, such as Phnom Penh, the exploitation of groundwater is for urban water supply. According to the statistics of South Valley with 41 major cities, 20% of them rely on groundwater; 39% rely mainly rely on surface water with yet use groundwater as a supplement; and 41% rely only on surface water.

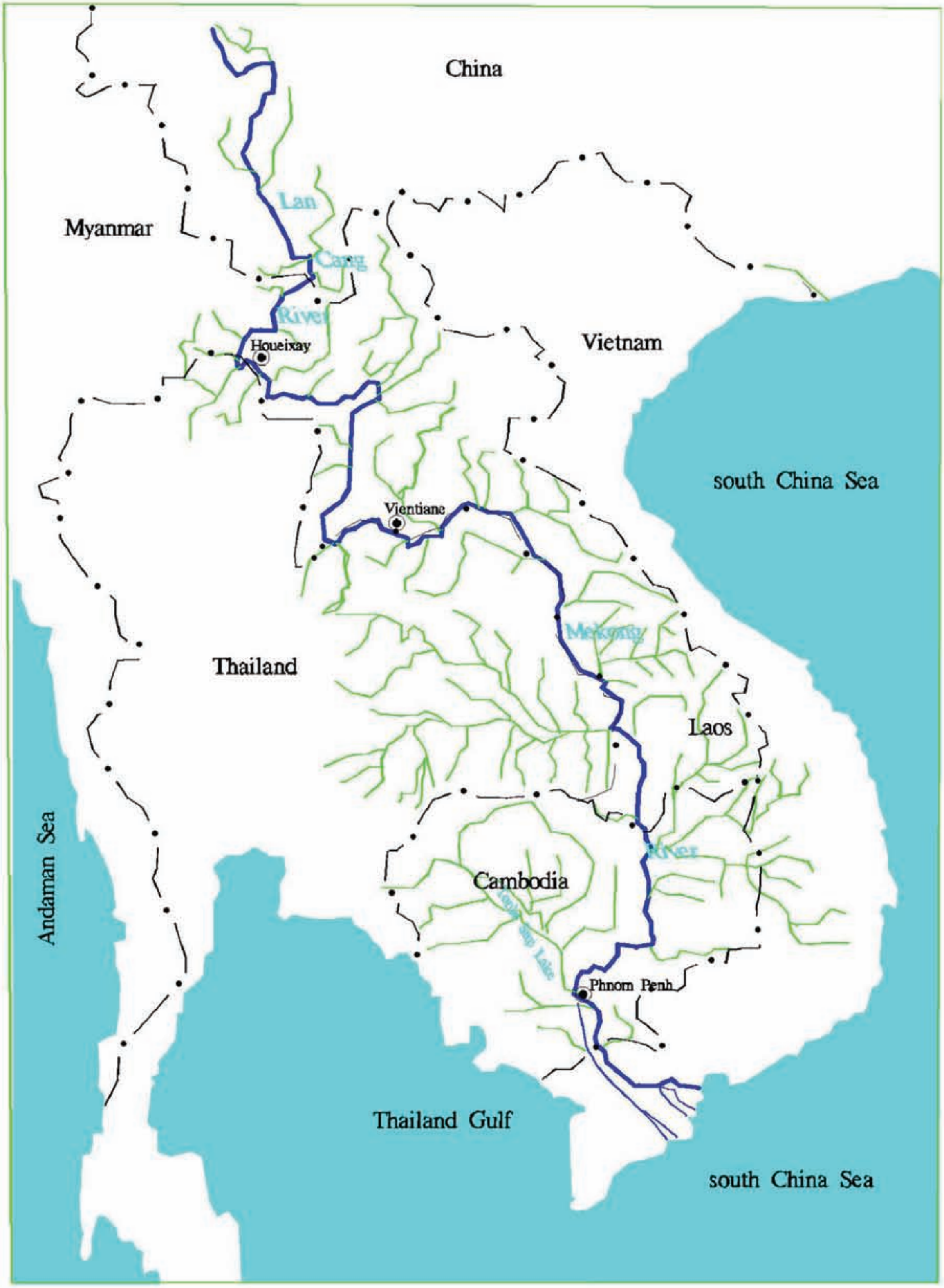
In Vietnam, groundwater is indispensable for urban water supply. In most areas, shallow groundwater is used for drinking, but in the main city shallow groundwater is not sufficient, so the depth of groundwater pumping had to be increased. In some cities, where the rate of groundwater extraction is much higher than the natural recharge rate (such as in Hanoi) the decline of groundwater levels is beginning to become evident.

Groundwater Pollution and Safety Development: Groundwater resources in the Mekong River Basin are relatively abundant, because of the abundant annual rainfall in the basin, and the melt water of snow in the upper reaches. Groundwater is closely linked to surface water and, in some areas, groundwater even recharges surface water. However, in recent years, water shortage problems have begun to become an issue, especially in the dry season and in regions experiencing drought conditions.

Sources of groundwater pollution can be divided into point sources, surface sources and the proliferation sources. Point sources refer to municipal solid waste landfill and accidents (for example, oil and septic tank leakage). Surface sources refer to the pollution of groundwater due to surface seepage. Irrigation water containing pesticides and fertilizers, unorganized rural wastewater, human and other wastewater percolate through the soil. Use of excessive amounts of chemical fertilizers and pesticides for farming has resulted in large quantities of toxic, as well as nutrient-rich (mainly nitrogen and phosphorus), chemicals infiltrating the groundwater through leaching. This has resulted in underground water pollution.

Low groundwater quality restricts the safe use of water by residents, and in many parts of Asia, the levels of arsenic and fluoride contamination in groundwater is high. In Yunnan Province in China, Menghai and Baoshan, the fluoride content is greater than 1.0mg/L in some areas. However, this issue can be resolved through proper management and by searching for alternative water sources, or by the removal of arsenic through treatment. Optimal allocation of water resources to maximize the economic, social and environmental benefits includes two aspects: firstly, the development process achieves the optimal allocation of water resources; and secondly, the process of using water resources achieves the optimal allocation of water resources. Optimal allocation of water resources can guide and restrict the use of water to adjust the industrial structure and regional distribution. Especially in arid and semi-arid dry areas, water resources allocation must be based on the layout of the development of the industrial structure and the scale of land resource development.

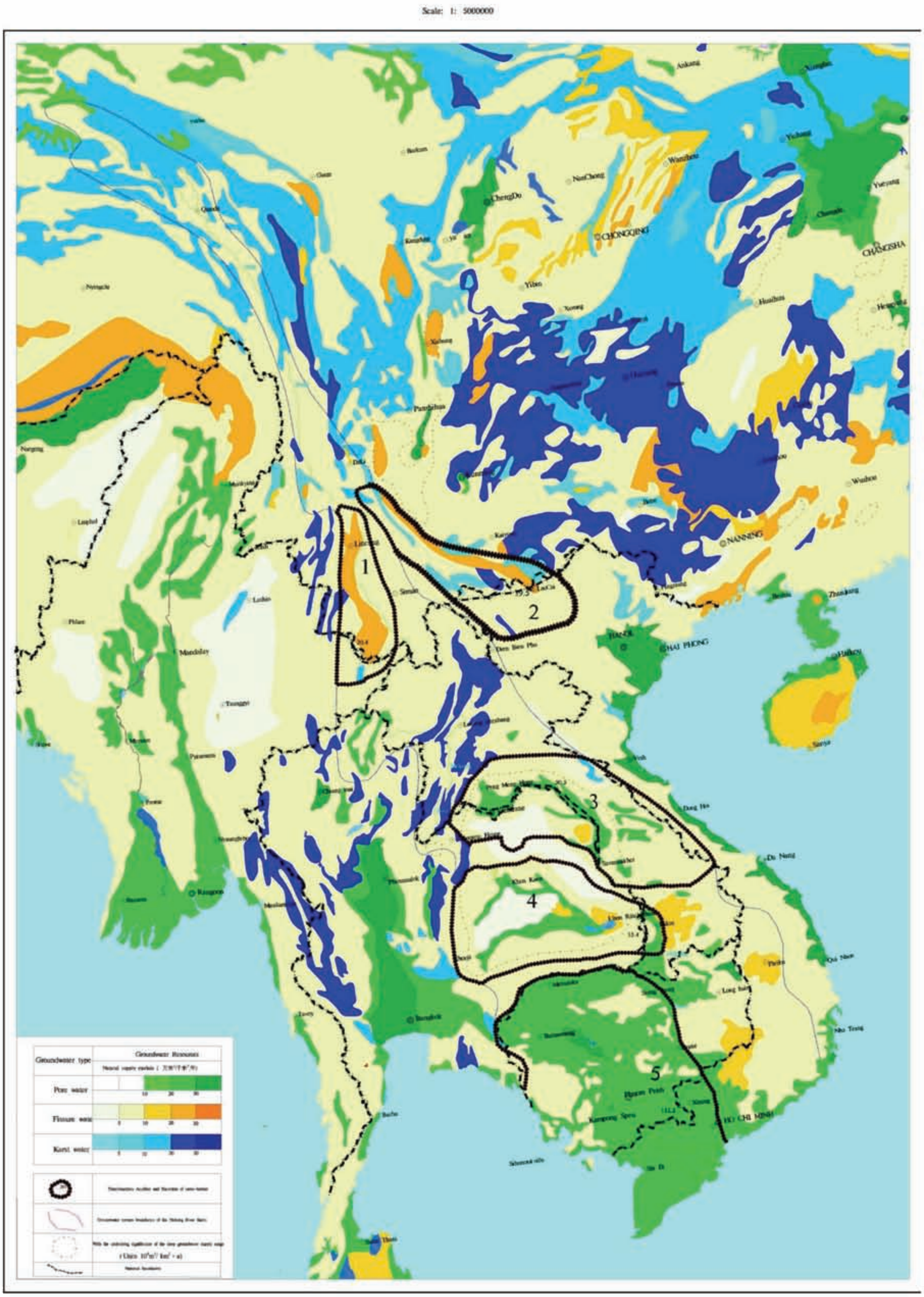
Greater Mekong River



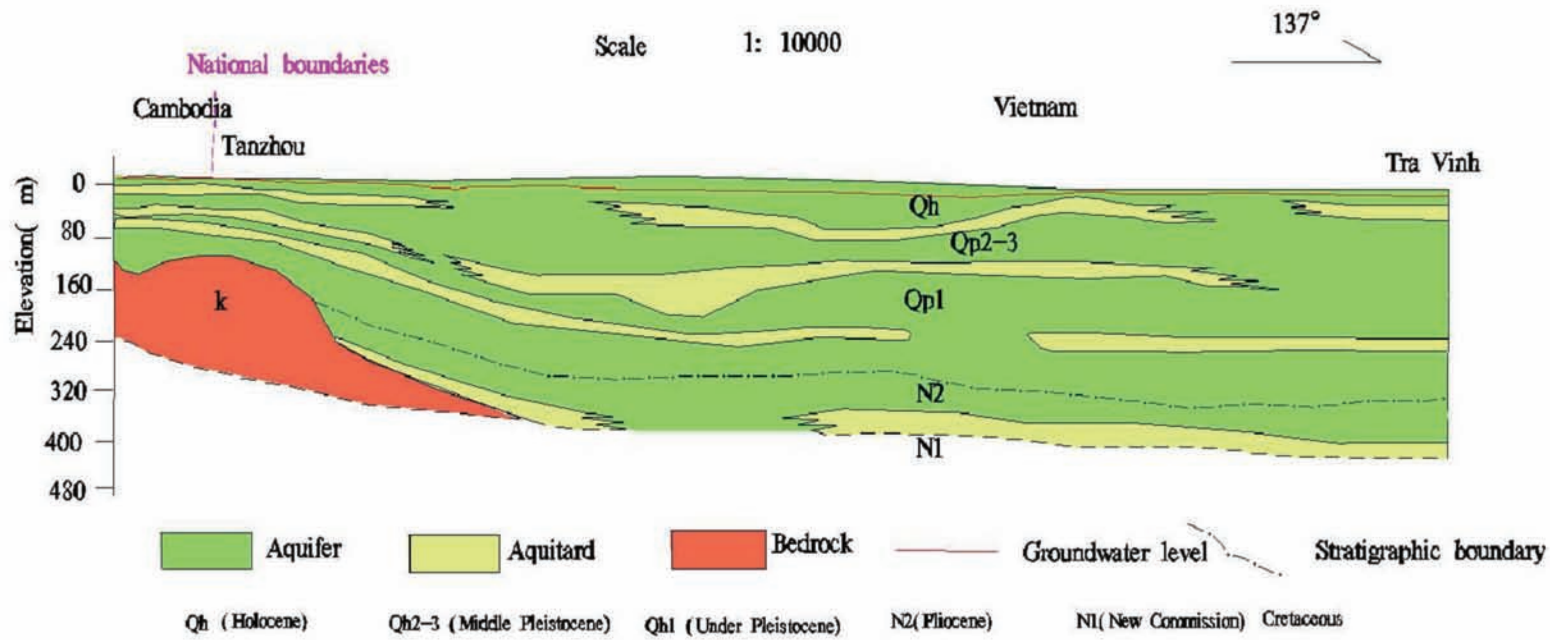
Greater Mekong River Dendrite

Scale: 1: 5000000

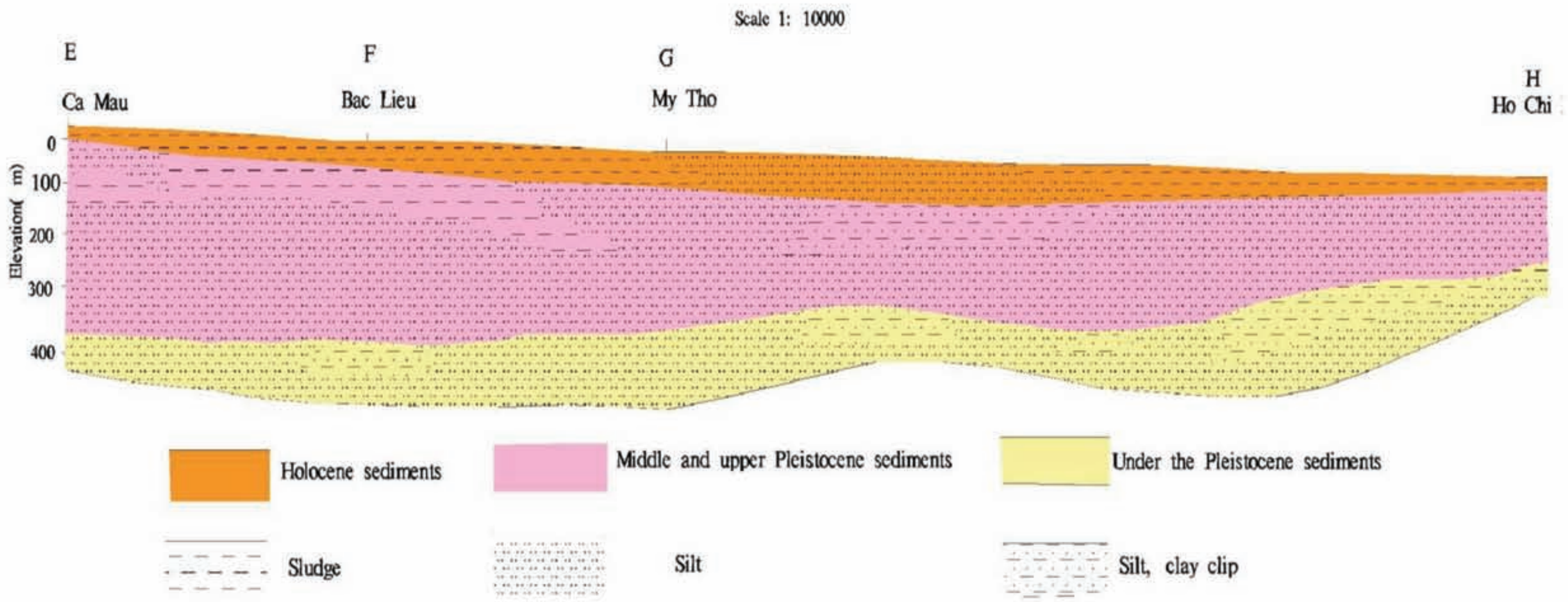
Hydrogeology of Greater Mekong River Area



Transboundary Aquifers of Greater Mekong River Basin



Hydrogeological Profile of Mekong River Delta



Hydrogeological Profile of Mekong River Delta

6.3 Transboundary Groundwaters of Central Asia

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6.3.1. Introduction

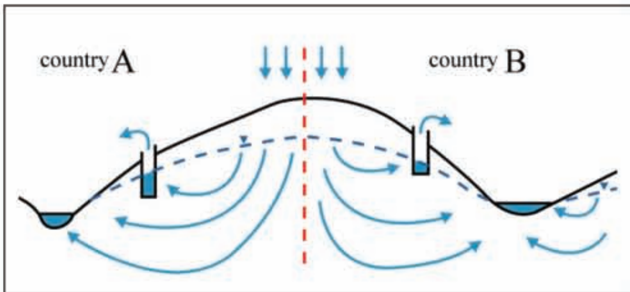
This preliminary inventory and assessment sets out the scale and scope of the transboundary groundwater bodies in Central Asia. It describes the importance of transboundary groundwaters in supporting human uses; examines the pressure factors on these groundwater bodies; and provides information on status, trends and impacts in relation to both water quantity and quality. The assessment also provides some preliminary indications of the management measures being taken, planned or needed to prevent, control or reduce any transboundary impacts on groundwaters. This chapter draws on and summarises an assessment of transboundary groundwaters of the Caucasus and Central Asia undertaken by the United Nations Economic Commission for Europe (UNECE, 2007) in which a questionnaire was designed and used to collect relevant information from the countries in the region. The assessment was based on knowledge at that time, much of which was incomplete and needs to be confirmed and completed by further studies. Transboundary aquifers in Central Asia are to be assessed again in the autumn of 2010 in the framework of the second Assessment of Transboundary Rivers, Lakes and Groundwaters under the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

The methodology for the assessment of groundwaters broadly follows the Driving Forces-Pressures-State-Impact-Responses (DPSIR) framework adopted by the European Environment Agency (UNECE, 2006) to describe i) the pressures acting on groundwaters resulting from human activities, ii) the status in terms of both quantity and quality of groundwaters, iii) the impacts resulting from any deterioration in status and iv) the responses in terms of management measures that have already been introduced and applied, need to be applied, or are currently planned.

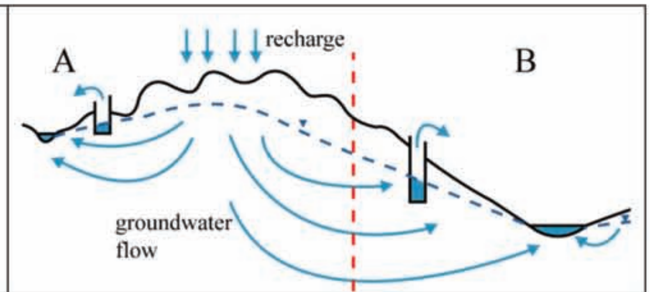
During the time of the Soviet Union, basin plans were developed by regional institutions for the transboundary basins of Central Asia. These included inter-republic and multi-sectoral aspects, as well as allocation of water for various uses. Since independence more than a decade ago, the countries in the region, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, have been striving to develop fair and rational bases for sharing and using their water resources. These countries have faced extreme economic inefficiencies and ecological damage in their efforts to undertake the transition to market economies. In the whole region, improving water quality and increasing water quantity to meet basic human needs in these environmentally damaged and economically depressed areas can be recognized as an urgent and priority task. Agricultural expansion and population growth over the past three decades have placed a great strain on the water resources of the region.

6.3.2. Characterising Transboundary Groundwaters

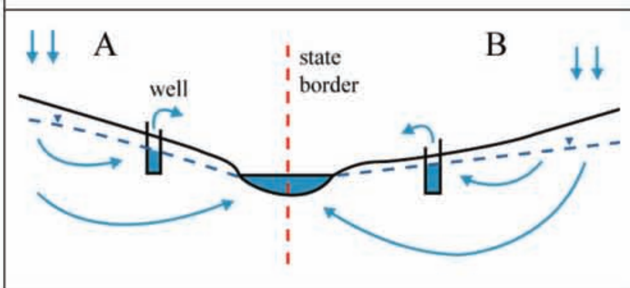
To enable transboundary aquifers to be compared and information to be collected in a consistent way by questionnaire, transboundary groundwaters were classified according to the general conceptual models and types shown in Figure 6.3.1. Thus, in the Central Asia region, 13 aquifers with significant resources were reported as transboundary, bordering or shared by two or more countries. However, not all were reported by both countries sharing them. The assessment has shown that although several of the types of transboundary situations shown in Figure 6.3.1 were identified, the dominant aquifers are composed of sequences of young alluvial sediments associated with the large river basins. A general summary of the information on aquifer types, sizes, connection with surface water resources and geology of the aquifers is given in Table 6.a.



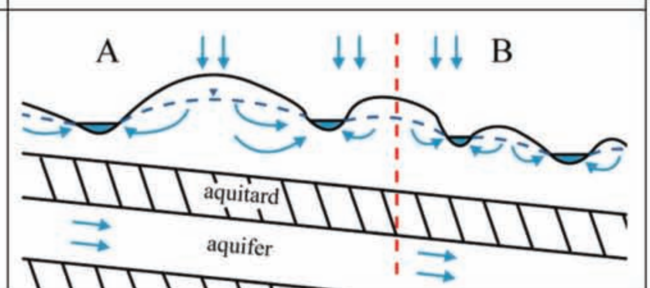
(1) State border follows surface water catchment and groundwater divide, little transboundary groundwater flow.



(2) Surface water and groundwater divides separate from state border, recharge in one country, discharge in adjacent.



(3) State border follows major river or lake, alluvial aquifer connected to river, little transboundary flow



(4) Large deep aquifer, recharged far from border, not connected to local surface water and groundwater.

Figure 1: Types of transboundary groundwaters (UNECE, 2007)

Table 6.a Transboundary groundwaters identified in the Central Asia region

No[1]	Aquifer	Countries	Type/link with surface water	Lithology/ age	Thickness (mean-max, m)	Extent (km^2)
1	Osh Aravoij	UZ/KG	n.a./shallow/deep/ medium	Sandy gravel		
2	Almoe-Vorzin	UZ/KG	n. a. /medium			
3	Moiansuv	UZ/KG	n.a./shallow-deep/ strong-medium	Boulders, pebbles, loams, sandy, loams	150 -300	1,760
4	Sokh	UZ/KG	n. a./probably shallow/strong			
5	Pretashkent	KZ/UZ	4/deep/weak	Sand, clay	200 -320	20,000

6	Chu Basin	KG/KZ	4/deep/weak	Sand, clay, loams	200 -350	
7	Birata-Urgench	TM/UZ	3/shallow/strong	Sand, loams	10 -50	60,000
8	Karotog	TJ/UZ	2/shallow/moderate			328
9	Dalverzin	UZ/TJ	2/shallow/moderate			
10	Zaforoboi	TJ/UZ	2/shallow/moderate			
11	Zeravshan	TJ/UZ	2/shallow/moderate			88
12	Selepta-Batkin/Nai-Icfor	KG/TJ	2/shallow/moderate			891
13	Chatkal-Kurman	KZ/UZ	4/ deep/weak	Sand, clay		20,000

[1] Aquifers numbered on Figure 6.3.2

All of the 13 identified transboundary aquifers are composed of Quaternary or Neogene sediments. The predominant lithological types are gravel, sand, clay, and loams. The aquifers vary considerably in size, and the extent of the groundwater bodies (in one country) varies greatly, reaching 60,000km2 in Turkmenistan (Table 6.a). For those aquifers for which information was provided, the mean thickness ranges between 10 and 200 m and maximum thickness between 50 and 350m, depending mainly on stratigraphy and age. These aquifers represent large volumes of groundwater storage and significant groundwater resources, which play an important role in the region.

On the basis of the conceptual sketches in Figure 6.3.1, the aquifers identified in the assessment can be divided into two groups. The first represents deeper groundwater in aquifers which have only weak or moderate links with local surface water systems and are recharged far from the border region (Type 4). Only in one case is the state border coincident with the watershed and the recharge zone. The second group represents shallow groundwater flowing from neighbouring countries towards a transboundary river (Type 3). The state border follows major rivers and the aquifers are directly connected to surface waters. From the information available, it is clear that the degree of connection between groundwaters and surface waters is an important consideration for their integrated management, and the assessment confirms these strong linkages for many of the transboundary groundwaters. The locations of the transboundary groundwater bodies identified in the region are shown in Figure 6.3.2.

Figure 2: Location of transboundary groundwater bodies in Central Asia (map: International Groundwater Resources Assessment Centre)

6.3.3. Groundwater Uses and Functions

Groundwater resources are important in total water usage and all of the aquifers are utilized for drinking water, although the proportion of the total used in this way varies between 10% in Turkmenistan and 100% in Kazakhstan. In seven of the transboundary aquifers (1, 3, 4, 6, 7, 9 and 12 in Table 6.a) the proportion of drinking water use is less than 50% and in four cases (aquifers 5, 8, 11 and 13) it reaches more than 75%. However, there are differences in reported groundwater use between neighbouring countries for the same aquifer. For instance, while in Kazakhstan groundwater from the Pre-Tashkent aquifer was reported to be used predominantly for drinking water purposes, in Uzbekistan it was reported to be used only as a source of mineral water.

Other possible uses include the significant abstraction of groundwater for agriculture reported in four aquifers (1, 2, 3 and 6 in Table 6.a) and for maintaining baseflow and springs in three aquifers (1, 2 and 3). Other widely reported uses in the region include small amounts for industry and spas. The strong linkages of the alluvial aquifers to rivers and lakes were confirmed, and the consequent need to protect the ecosystems of these associated surface waters was emphasized in the case of Kyrgyzstan (Chu basin).

6.3.4. Pressure Factors on Transboundary Groundwaters

It is logical to expect that human activities in the region might have an impact on both transboundary groundwater quantity and quality. The alluvial settings of the aquifers are likely to be at risk of pollution from agricultural and industrial activities, since groundwater resources are used for these purposes, as indicated by the responses from the countries in the region. Furthermore, inefficient irrigation systems and mismanagement of irrigation water diversions have resulted in elevated salinity levels in soil and water and in overall environmental degradation. However, recent monitoring data from these groundwater bodies is very scarce or in some cases no monitoring activities are currently performed. Therefore, any assessment of pressure factors on transboundary aquifers is currently very limited.

Within the overall picture of groundwater utilization, abstraction for irrigation has comparable significance to that for drinking water. The Central Asian countries are significantly dependent on irrigated agriculture, and both water quantity and quality have emerged as issues in the development of these countries. Many of the aquifers are utilized for irrigation. The percentage of total abstraction for irrigation is comparable with that for drinking water which is not surprising as agriculture is the largest water consumer in the region and a major employer of the region's workforce. However, the poor condition of the irrigation infrastructure and poor agricultural practices jeopardize water and land resources. This is especially the case for aquifers with a very high percentage of abstraction for agriculture, such as aquifer no 3 which in Uzbekistan has 50-75% of its total abstraction being used for agriculture. The economic difficulties in the region have suppressed both the usage of water for irrigation and the application of fertilizers and pesticides. With the expected economic growth and the need to increase crop production, agricultural pressure factors are expected to become more important in the future.

Industrial pressure factors on transboundary aquifers in the region are rather limited. For industry, water is modestly utilised from only five of the aquifers at a rate of less than 25% of the total groundwater abstraction (aquifers 2, 3, 6, 7 and 12). For mining, only two cases were recorded, both with less than

25% of total abstraction (aquifers 1 and 6), and for thermal spa two cases with less than 25% were reported (aquifers 6 and 7). Occurrences in groundwater of heavy metals and organic substances were reported by several countries. However, precise and recent data from monitoring programmes are not available. Country reports were mainly dependent on expert judgement based on the existing industrial activities in the aquifer recharge areas. Livestock watering is reported as a minor (less than 25%) but widespread water use in much of the region, although the responses did not report the type of the animal production (extensive or intensive) in the aquifer areas. Confirmatory evidence of these pressures would normally come from pollution by pathogens and nitrogen, but there are no data from which to quantify this pressure factor on the transboundary aquifers in the Central Asian region.

Type of use	Percentage of total groundwater abstraction (aquifers numbered as in Table 6.a)			
	< 25%	25-50%	50-75%	> 75%
Drinking water	3, 6, 7, 9	1, 4, 12	2, 10	5, 8, 11, 13
Irrigation	1, 6, 7	2, 12	3, 7, 10	9
Industry	2, 3, 6, 7, 12			
Mining	1, 6			
Thermal spa	6, 7			
Livestock	1, 2, 3, 6, 7			

6.3.5. Status, Trends and Impacts of Groundwater Quantity and Quality

From the responses by countries in the region to the transboundary aquifer questionnaire, differences in the significance that countries give to groundwater resources can be recognised. For example, mountainous countries such as Kyrgyzstan and Tajikistan expressed less interest in groundwater as both surface water and groundwater resources are available. In general, most human activities provide some pressures on groundwater systems, and could potentially affect both water quantity and quality. However, the lack of effective, sustainable and comprehensive groundwater monitoring programmes in most countries in the region creates obstacles to current and future evaluation of groundwater quality and quantity in the aquifers.

6.3.5.1. Groundwater quantity

As mentioned above, groundwater abstraction for water supply and irrigation was identified as the main use of groundwater in the region. Questions on water quantity impacts were oriented towards two areas, i) identifying impacts on groundwater levels and ii) identifying the type and scale of problems associated with groundwater abstraction from the aquifer.

No information was provided concerning trends in groundwater level despite the fact that most countries have already established groundwater quantity monitoring networks. This may be an indication that groundwater level decline is not an issue in the region. Most of the impacts on quantity status of groundwater were reported to be local. However, some countries also recorded more widespread impacts in the form of reduction in borehole yields and spring flow and from pol-luted water being drawn into aquifers. These impacts were characterized as moderate in some aquifers in Turkmenistan and Uzbekistan and severe in some aquifers in Kazakhstan and others in Uzbekistan and Turkmenistan. The main types of quantity impact caused by over-exploitation of groundwater resources occur as reduction of borehole yields and of baseflow and spring flow (aquifers 3, 5, 7, 8, 9, 10, 11, 12 and 13), polluted water being drawn into an aquifer (1, 2, 3, 6 and 7) degradation of ecosystems (3 and 6), and salt water upconing (6 and 7). Information on groundwater quantity problems is summarized in Table 6.c.

Table 6.c Reported groundwater quantity problems

Problem	Increasing scale of problem →			
	1. Local and moderate	2. Local but severe	3. Widespread but moderate	4. Widespread and severe
Increased pumping lifts or costs		7	7	
Reduction of borehole yields	3, 8, 12, 13		7	5
Reduced base flow and spring flow	9, 10, 11			3, 7
Degradation of ecosystems	3, 6			
Sea water intrusion	-	-	-	-
Salt water upconing	6	7		
Polluted water drawn into aquifer	1, 3, 6		2, 7	
Land subsidence	-	-	-	-
Decline of piezometric level				5

6.3.5.2. Groundwater quality

Most countries in the region reported problems with groundwater quality. The assessment of groundwater quality impacts indicated occurrences of seven groups of pollutants: salinization, nitrogen substances, pesticides, heavy metals, pathogens, organic compounds, and hydrocarbons. Aquifer 5 was the only one with no indications of groundwater quality impacts reported. In seven aquifers (1, 2, 3, 4, 7, 8 and 12), at least one type of pollution was recorded as being caused by human activities. In two cases (6 and 7), a natural origin for the observed salinization was indicated.

Agriculture was recognized as the most common cause of pollution, impacting five aquifers with nitrogen substances, pesticides and hydrocarbons (1, 2, 7, 8 and 12). The level of reported agricultural pollution ranged from “moderate” to “serious”. This is probably a direct result of current agriculture practices in the region, as old-fashioned technologies and methods for farming are still applied.

Industrial sources cause groundwater contamination by heavy metals, industrial organic com¬pounds and hydrocarbons. Heavy metals also originate from ore mining (aquifers 1, 2 and 7). The level of impact by these

Table 6.cc Reported groundwater quality problems

Problem	Nature of problem		Typical range of concentration
	Natural origins	From which human activities	
Salinization	6 and 7	Irrigation: 4 and 12	1.00 - 3.00 g/l
Nitrogen species		Agriculture: 2, 7, 8 and 12	Values are not available
Pesticides		Agriculture: 1, 2 and 7	Values are not available
Heavy metals		Industry: 1 Ore mining: 2 and 7	Values are not available
Pathogens		Sewer leakage: 7	Values are not available
Industrial organic compounds		Industry: 7	Values are not available
Hydrocarbons		Agriculture: 1 and 2: Industry: 3 and 7	0.2 - 0.0015 mg/l
Radioactive elements		Disposal of waste products of extractive enterprises: 1 and 2	Values are not available
Sulphate and hardness		3 and 9	Values are not available

pollutants on water quality varies between "slight" and "serious". Other contaminants influencing four aquifers (1, 2, 3 and 9) include radioactive elements originating from the disposal of waste products of extractive enterprises, sulphate and hardness. Groundwater quality problems in the region are summarized in Table 6.c.

Countries in the region reported different pictures with regard to transboundary impacts on groundwater quantity and quality. From this preliminary evaluation there is little evidence of declines in groundwater levels caused by human activities in neighbouring countries. Only in two cases were transboundary quantity impacts observed (aquifers 1 and 5) and there was no clear link between types of aquifers and water quantity impacts. However, from the point of view of quality, the present situation seems to be more serious, and most countries indicated significant impact on groundwater quality caused by human activities in the neighbouring countries. This assessment should be understood as a very preliminary one, because the assessment of transboundary impacts can be influenced by many factors, especially data availability, and for this reason probably does not reflect the real situation in the region.

6.3.6. Management Responses

The assessment of the current situation in the region is not very optimistic, since most of the basic measures related to sustainable water management have not been implemented so far or are being used insufficiently, or remain to be approved or introduced. Although only a few of the necessary measures are in place, it was nevertheless indicated that currently only a few measures are being planned for future implementation (e.g. increasing efficiency of groundwater use and integrated river basin management, good agricultural practices, data exchange between countries). If this picture reflects the real situation, future perspectives for management of groundwater resources in the region are not bright.

In some countries, certain management measures have already been implemented and have proved to be effective. In almost all cases some level of groundwater quality and quantity monitoring has been introduced, and in some cases was reported to be effective (e.g. aquifers 2, 4, and 6). However it was widely recognized that monitoring was inadequate and needed to be improved (e.g. in Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan). As a consequence partly of the inadequate monitoring activities, there is a lack of proper water assessment and planning activities for the transboundary aquifers in the majority of the responding countries. A similar situation was identified in the delineation of protection zones and vulnerability mapping. These were occasionally reported as being used and used effectively (aquifers 3, 5, 6 and 13), but otherwise needing to be improved. In the majority of the aquifers management of abstraction by licensing is being used, but was generally considered to be insufficient where it was being applied, and the abstraction needed to be better monitored.

To protect groundwater quality, the most widely reported tasks that need to be undertaken were the treatment of urban and industrial wastewaters. Only two countries (Kyrgyzstan and Turkmenistan) reported these measures to be currently effective. In many instances, implementation or improvement of good agricultural practices is also needed, since no country reported that these were effectively implemented.

For the introduction or improvement of transboundary cooperation, management measures based on an integrated river basin approach need to be implemented (Table 6.d). In this regard, establishment of transboundary legal frameworks and institutions (e.g. agreements and joint bodies) was recorded as the main factor requiring improvement. Only Turkmenistan reported the existence of transboundary institutions. Data exchange is currently widely considered to be insufficient, and there is a need for exchange arrangements to be introduced.

Table 6.d Reported groundwater management measures

Management measures	Already used and effective	Used, but need to be improved	Need to be applied	Currently planned
Transboundary legal framework and institutions (joint bodies, agreements, treaties, etc.)	7	1, 2, 4	5	
Groundwater abstraction management by regulation (licensing, taxation)		5, 7	1, 2, 13	
Groundwater abstraction management by incentives or disincentives (subsidies, credits, energy prices, energy supply, etc.)		4, 5, 6	2, 7	
Increasing efficiency of groundwater use		4, 5, 6	1, 2	7
Monitoring of groundwater quantity	4, 6	1, 2, 5, 7, 10, 13	8, 9, 11, 12	
Monitoring of groundwater quality	2, 4, 6	1, 3, 5, 13	7, 8, 9, 11, 12	
Public awareness campaigns		7	1, 4, 5, 6	
Protection zones for public supplies	3, 5, 13	4, 6	7	
Vulnerability mapping for land use planning	5, 6, 13		1, 2, 3, 4, 7	
Good agricultural practices		7	1, 3, 4, 6	2
Groundwater integrated into river basin management		3, 4	1, 6	7
Wastewater reuse or artificial recharge		6, 7	3, 4	
Treatment of urban wastewater	6, 7		3, 4	
Exchange of data between countries		2	3, 6, 7	
Treatment of industrial effluents	6	7	1, 2, 3,	
Rendering of waste products and recultivation of ground			1	
Neutralization of radioactive elements and rehabilitation of territory				2

Water management in the countries of Central Asia is a complex and critical issue. The application of the principles of integrated water resources management (IWRM) in these countries will require groundwater to be integrated into river basin management planning. Sustainable transboundary cooperation will most likely be achieved by creating a basis for assessing the national and regional benefits from technical investments, but these must be complemented by supportive national policy and institutional reforms, as well as capacity- building to strengthen regional institutions.

6.3.7. Conclusions

Based on the responses from countries in the Central Asian region to the questionnaire on transboundary groundwaters, the following conclusions can be drawn:

- groundwater resources are very important in the region;
- groundwater is used in the region mainly for drinking water supply. Therefore, it is necessary to protect and improve both groundwater quality and quantity as a precondition for the sustainability of the environment and human security;

- along with agriculture, direct water abstraction for water supply is the main use of groundwaters in the countries of the region;
- the majority of the most basic measures to improve groundwater management have not yet been mplemented;
- only scarce data are available from transboundary groundwater monitoring programmes;
- there is a lack of water management planning for the transboundary bodies;
- implementation or improvement of good agricultural practices is needed;
- there is a need to establish transboundary institutions for proper cooperation and data exchange;
- water management is a critical and important issue in all countries in the region, but they are currently focusing on national rather than transboundary demands;
- there is a need for supportive policy and institutional reforms and capacity-building for regional or transboundary institutions;
- it is highly recommended that pilot projects be prepared for monitoring and assessmen of transboundary groundwaters in the region, and that the case studies be prepared with a focus on upgrading and building the capacity of the existing infrastructure for monitoring and assessmen of transboundary groundwaters.

References

UNECE (2006) Strategies for monitoring and assessment of transboundary rivers, lakes and groundwaters. ECE/MP.WAT/20, United Nations, Geneva.

UNECE (2007) Our waters: joining hands across borders. First Assessment of Transboundary Rivers, Lakes and Groundwaters. United Nations, Geneva

6.3.8. Preliminary Inventory of Aquifers in the Central Asian Region

Aquifer No. 1: Osh Aravoij		**Shared by: Uzbekistan and Kyrgyzstan**
Type 5, Medium links to surface water systems, groundwater flows from Uzbekistan to Kyrgyzstan		
	Uzbekistan	Kyrgyzstan
Area (km^2)		
Water uses and functions (percentage of total abstraction)	Drinking water supply (25-50%), irrigation, mining, livestock (<25%)	Drinking water supply (25-50%), irrigation
Pressure factors	Agriculture, industry, waste disposal	Agriculture
Problems related to groundwater quantity	Polluted water drawn into aquifer	Lack of relevant data to be quantified
Problems related to groundwater quality	Serious problems with pesticides, moderate problems with heavy metals, slight problems with hydrocarbons and radioactive elements	Lack of relevant data to be quantified
Transboundary impacts	Decline of groundwater level, groundwater pollution	Lack of relevant data to be quantified
Groundwater management measures	Need to be improved: transboundary institutions, monitoring of groundwater quantity and quality, need to be applied: abstraction management, efficiency of use, mapping, good agricultural practices, integrated river basin management, treatment of industrial effluents, data exchange	Need to improved: transboundary institutions, monitoring of groundwater quantity and quality
Status and what is most needed	Improvement of the monitoring of groundwater quantity and quality	Improvement of the monitoring of groundwater
Future trends and prospects	Expected pressure on the water resources due to economic growth and climate change	Expected pressure on the water resources due to economic growth and climate change

Aquifer No. 2: Almoe-Vorzin		**Shared by: Uzbekistan and Kyrgyzstan**
Type 5, Medium links to surface water systems, groundwater flows from Uzbekistan to Kyrgyzstan		
	Uzbekistan	Kyrgyzstan
Area (km^2)		
Water uses and functions (percentage of total abstraction)	Drinking water (50-75%), irrigation (25-50%), industry, livestock (<25%)	Drinking water supply (25-50%), irrigation
Pressure factors	Agriculture, mining, waste disposal	Agriculture
Problems related to groundwater quantity	Polluted water drawn into aquifer	Lack of relevant data to be quantified
Problems related to groundwater quality	Nitrogen species, pesticides, heavy metals, hydrocarbons	Lack of relevant data to be quantified
Transboundary impacts	Groundwater pollution	Lack of relevant data to be quantified
Groundwater management measures	Effective: quality monitoring Need to be improved: quantity monitoring, transboundary institutions, data exchange Need to be applied: abstraction management, mapping, treatment of industrial effluents	Need to be improved: transboundary institutions, monitoring of groundwater quantity and quality
Status and what is most needed	Good agricultural practices, neutralization of radioactive elements	Enhancement of monitoring programme
Future trends and prospects		Improvement of the monitoring of groundwater quantity and quality

Aquifer No. 3: Moiansuv		**Shared by: Uzbekistan and Kyrgyzstan**
Type 5, Strong, medium links to surface water system, average thickness 50 m		
	Uzbekistan	Kyrgyzstan
Area (km^2)	1,760	Not identified yet
Water uses and functions (percentage of total abstraction)	Irrigation (50-75%), drinking water, industry, livestock (<25%)	Drinking water supply, irrigation
Pressure factors	Industry	Agriculture
Problems related to groundwater quantity	Reduction of borehole yields, degradation of ecosystem, polluted water	Lack of relevant data to be quantified
Problems related to groundwater quality	Hydrocarbons, sulphates	Lack of relevant data to be quantified
Transboundary impacts	Groundwater pollution	Lack of relevant data to be quantified
Groundwater management measures	Effective: protection zones Need to be improved: transboundary institutions, quality and quantity monitoring, integrated river basin management Need to be applied: mapping, good agricultural practices, treatment of urban and industrial wastewater	Need to improved: transboundary institutions, monitoring of groundwater quantity and quality
Status and what is most needed		Enhancement of monitoring programme
Future trends and prospects	Improvement of monitoring programmes for quality and quantity	Improvement of the monitoring of groundwater quantity and quality

Aquifer no. 4: Sokh		**Shared by: Uzbekistan and Kyrgyzstan**
Type 5, Strong links to surface water systems		
	Uzbekistan	Kyrgyzstan
Area (km^2)		
Water uses and functions		Drinking water supply, irrigation
Pressure factors	Irrigation	Agriculture
Problems related to groundwater quantity		Lack of relevant data to be quantified
Problems related to groundwater quality	Salinization (1-3 g/l)	Lack of relevant data to be quantified
Transboundary impacts	Groundwater pollution	Lack of relevant data to be quantified
Groundwater management measures	Effective: quantity and quality monitoring Need to be improved: transboundary institutions, abstraction management, protection zones, integrated river basin management. Need to be applied: mapping, good agricultural practices, urban wastewater treatment and reuse	Need to improved: transboundary institutions, monitoring of groundwater quantity and quality
Status and what is most needed		Enhancement of monitoring programme
Future trends and prospects		Improvement of the monitoring of groundwater quantity and quality

Aquifer No. 5: Pretashkent	**Shared by: Uzbekistan and Kazakhstan**	
Type 4, Large deep groundwater (artesian type)		
	Uzbekistan	Kazakhstan
Area (km^2)		
Water uses and functions	Mineral water and partly as drinking water source	Drinking water supply
Pressure factors	Not recognized	Water abstraction on both sides of the aquifer
Problems related to groundwater quantity	Not recognized	Reduction of borehole yields
Problems related to groundwater quality	There are no problems with pollution	There are no problems with pollution
Transboundary impacts	Not recognized	Decline of the groundwater levels were observed
Groundwater management measures	Licensing of groundwater abstraction and monitoring programme in place. Urgent need to establish transboundary institutions and data exchange	Licensing of the groundwater abstraction and monitoring programme in place. It is urgently needed to establish the transboundary institutions and data exchange
Status and what is most needed	Enhancement of monitoring programme	To enhance monitoring programme and assessment methods as mathematical modelling for making water balance
Future trends and prospects	Increased economic activities and climate change can have a pressure on the groundwater resources	Increased economic activities and climate change can have a pressure on the groundwater resources

Aquifer No. 6: Chu Basin	**Shared by: Kyrgyzstan and Kazakhstan**	
Type 4, Quaternary sand and gravel, weak links to surface water systems, groundwater flow from Kyrgyzstan to Kazakhstan		
	Kyrgyzstan	Kazakhstan
Area (km^2)		
Water uses and functions (percentage of total abstraction)	Drinking water, irrigation, industry, mining, livestock, thermal spa (<25%)	Drinking water 50%, irrigation 50%
Pressure factors	Water abstraction	Water abstraction
Problems related to groundwater quantity	Degradation of ecosystems, salt water upcoming	None
Problems related to groundwater quality	Salinization	None
Transboundary impacts	None	Not quantified yet
Groundwater management measures	Effective: quantity, quality monitoring, mapping, urban and industry wastewater treatment. Need to be improved: transboundary institutions, abstraction management, protection zones. Need to be applied: good agricultural practices, integrated river basin management, data exchange	Effective: quantity, quality monitoring Need to be improved: transboundary institutions, abstraction management Need to be applied: good agricultural practices, integrated river basin management, data exchange
Status and what is most needed	Enhancement of monitoring programmes	Enhancement of monitoring programmes
Future trends and prospects	Lack of data and information for making proper predictions	Lack of data and information for making proper predictions

Aquifer No. 7: Birata-Urgench		Shared by: Uzbekistan and Turkmenistan
Type 3, Quaternary sand and loam, groundwater flow from Uzbekistan to Turkmenistan		
	Uzbekistan	Turkmenistan
Area (km^2)		
Water uses and functions	Drinking water supply	Drinking water supply
Pressure factors	Water abstraction	Water abstraction
Problems related to groundwater quantity	Widespread/moderate reduction of borehole yields, widespread/serious reduction of baseflow and spring flow	Widespread/moderate reduction of borehole yields, widespread/serious reduction of baseflow and spring flow
Problems related to groundwater quality	Salinization (natural origins and irrigation) from wastewater and drainage water	Salinization (natural origins and irrigation) from wastewater and drainage water
Transboundary impacts	Need to be investigated	Need to be investigated
Groundwater management measures	Joint quantity and quality monitoring, data exchange	Joint quantity and quality monitoring, data exchange
Status and what is most needed	Improvement of groundwater monitoring programmes	Improvement of groundwater monitoring programmes
Future trends and prospects	Lack of information for making trends prediction	Lack of information for making trends prediction

Aquifer No. 8: Karotog		Shared by: Tajikistan and Uzbekistan
Type 2, Moderate connections with surface water bodies		
	Tajikistan	Uzbekistan
Area (km^2)	328	Necessary to be corrected
Water uses and functions	Drinking water supply	Drinking water supply
Pressure factors	Water abstraction	Water abstraction
Problems related to groundwater quantity	Change of water resources at the limit of sustainability	Change of water resources based on the water abstraction on the Tajikistan
Problems related to groundwater quality	Negligible local contamination by nitrate (agriculture)	Negligible local contamination by nitrate (agriculture)
Transboundary impacts	Necessary to be investigated	Necessary to be investigated
Groundwater management measures	Joint monitoring of the groundwater	Joint monitoring of the groundwater
Status and what is most needed	Enhancement of monitoring networks for groundwater	Enhancement of monitoring networks for groundwater
Future trends and prospects	Not sufficient information to make predictions	Not sufficient information to make predictions

Aquifer No. 9: Dalverzin		Shared by: Uzbekistan and Tajikistan
Type 2, Moderate connections with surface water bodies		
	Uzbekistan	Tajikistan
Area (km^2)		
Water uses and functions	Irrigation	Drinking water supply and irrigation
Pressure factors	Water abstraction	Water abstraction
Problems related to groundwater quantity	Water resources are recharged in the course of year	Water resources are recharged in the course of year
Problems related to groundwater quality	Moderate increase in mineralization and hardness	Moderate increase in mineralization and hardness
Transboundary impacts	Necessary to be investigated	Necessary to be investigated
Groundwater management measures	Monitoring of the groundwater status	Monitoring of the groundwater status
Status and what is most needed	Enhancement of the representative monitoring network of transboundary waters	Enhancement of the representative monitoring network of transboundary waters
Future trends and prospects	Lack of information for making predictions and trends	Lack of information for making predictions and trends

Aquifer No. 10: Zaforoboi		Shared by: Tajikistan and Uzbekistan
Type 2, Moderate connections with surface water bodies		
	Tajikistan	Uzbekistan
Area (km^2)		
Water uses and functions	Drinking water and irrigation	Drinking water and irrigation
Pressure factors	Water abstraction	Water abstraction
Problems related to groundwater quantity	Natural resources are recharged in the autumn and winter period	Natural resources are recharged in the autumn and winter period
Problems related to groundwater quality	No contamination	Moderate pollution
Transboundary impacts	Necessary to be investigated	Necessary to be investigated
Groundwater management measures	Existing groundwater monitoring network needs to be improved	Groundwater monitoring network needs to be improved
Status and what is most needed	Enhancement of the representative monitoring network of transboundary waters	Enhancement of the representative monitoring network of transboundary waters
Future trends and prospects	Lack of information for making predictions and trends	Lack of information for making predictions and trends

Aquifer No. 11: Zeravshan		**Shared by: Tajikistan and Uzbekistan**
Type 2, Moderate connections with surface water bodies		
	Tajikistan	Uzbekistan
Area (km^2)	88	To be corrected
Water uses and functions	Drinking water supply	Drinking water and technological water
Pressure factors	Moderate water abstraction	Moderate water abstraction
Problems related to groundwater quantity	Change of water resources at the limit of natural sustainability	Change of water resources at the limit of natural sustainability
Problems related to groundwater quality	Significant effect of industrial activities on the territory of Tajikistan	Lack of data for evaluation
Transboundary impacts	Necessary to be investigated	Necessary to be investigated
Groundwater management measures	Need to organize complex monitoring programme	Existing groundwater monitoring programmes
Status and what is most needed	Enhancement of the complex monitoring network for transboundary waters	Development of complex monitoring network for transboundary waters
Future trends and prospects	Lack of information for making and predictions and trends	Lack of information for making predictions and trends

Aquifer No. 12: Salepta- Batkin/Nai-Icfor (Syr Darya)		**Shared by: Kyrgyzstan and Tajikistan**
Type 2, Moderate connections with surface water bodies		
	Kyrgyzstan	Tajikistan
Area (km^2)		891
Water uses and functions	Irrigation and drinking water	Irrigation, drinking water and technological water
Pressure factors		Water abstraction
Problems related to groundwater quantity	Over exploitation registered	Water abstraction on the territory of Kyrgyzstan
Problems related to groundwater quality	Contamination by nitrates and salinization	Increased mineralization, hardness and sulphates
Transboundary impacts	Necessary to be investigated	Necessary to be investigated
Groundwater management measures	Special monitoring is not performed	Monitoring is incomplete
Status and what is most needed	Enhancement of the complex monitoring network for transboundary waters	Enhancement of the complex monitoring network for transboundary waters
Future trends and prospects	Lack of information for making predictions and trends	Lack of information for making predictions and trends

Aquifer No. 13: Chhatkal-Kurman		**Shared by: Kazakhstan and Uzbekistan**
Type 4, Weak link to surface waters, groundwater flow from Kazakhstan to Uzbekistan		
	Kazakhstan	Uzbekistan
Area (km^2)	20,000	
Water uses and functions (percentage of total abstraction)	Drinking water (100%)	Drinking water (100%)
Pressure factors	Water abstraction	Water abstraction
Problems related to groundwater quantity	Reduction of borehole yields, decline of groundwater level	Reduction of borehole yields, decline of groundwater level
Problems related to groundwater quality	None	None
Transboundary impacts	Decline of groundwater level	Decline of groundwater level
Groundwater management measures	Effective: protection zones, mapping Need to be improved: quantity and quality monitoring, abstraction management. Need to be applied: transboundary institutions	Enhancement of monitoring programmes
Status and what is most needed	Joint monitoring programme	Joint monitoring programme
Future trends and prospects		Lack of information to make predictions

6.4. Transboundary Aquifers of India – A Pilot Case from Indus River Basin

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6.4.1. Introduction

Bounded by the Himalayas to the north, the Indian continent stretches southwards to the Tropic of Cancer, and tapers off into the Indian Ocean between the Bay of Bengal to the east and Arabian Sea to the west. The transboundary aquifers originate in the Himalayas and pertain to the Indus and Ganges basins; the Indus basin shares transboundary aquifers with China, Pakistan and Afghanistan, and the Ganges basin with Nepal, Bangladesh and Myanmar. The map below, derived from World Hydrogoleogical Map, depicts the transboundary aquifers of India (Figure 1).

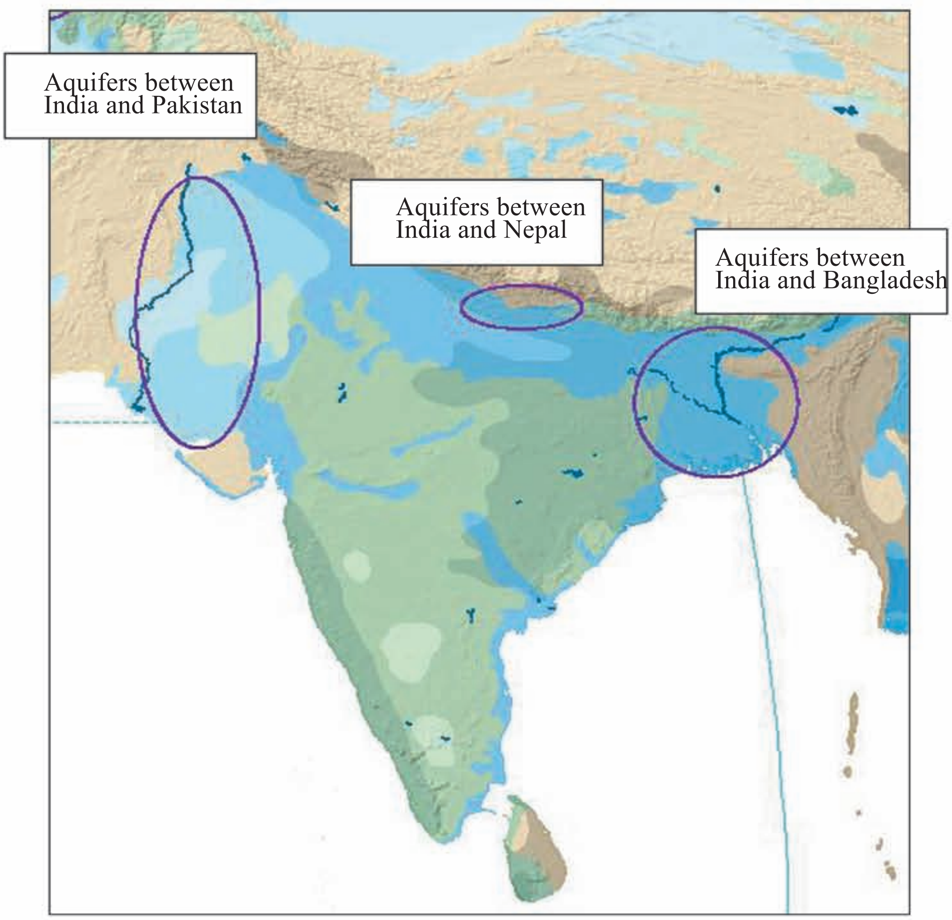

Figure 1: Transboundary Aquifers of India

6.4.2. Indus Basin

The Indus basin has a geographical area of 1.16 million sq km, 28% of which is in India (i.e. 0.32 million sq km) and more than 50% is in Pakistan (figure 2). In the Indian part of the Indus Basin, high mountain ranges cover 85% (i.e. 272,280 sq.km), and foothills and plain areas cover only 15%. The rainfall varies from 2,400mm in the northeast to a low of 200mm in the southwest. The average monsoon runoff is estimated to be 58,640 MCM. The Indus plains have a close network of canals, with the net irrigated area of 5.80 million hectares and a net area sown of 9.59 million hectares. The ground water potential for irrigation is estimated to be 5,428 MCM/year.

India and Pakistan share the Indus River water under the terms of the Indus Water Treaty, but at the time, it was not considered necessary to include groundwater, as its development was much lower during 1950 than it is today. Now, however, groundwater development has increased significantly, with the operation of more than 0.15 million structures and the exploitation of 70% of the dynamic potential and also the deep aquifer zones (the cumulative pumpage of which has not been quantified). It has, therefore, become imperative to study transboundary aquifers in detail and share the information for their better management and utilization.

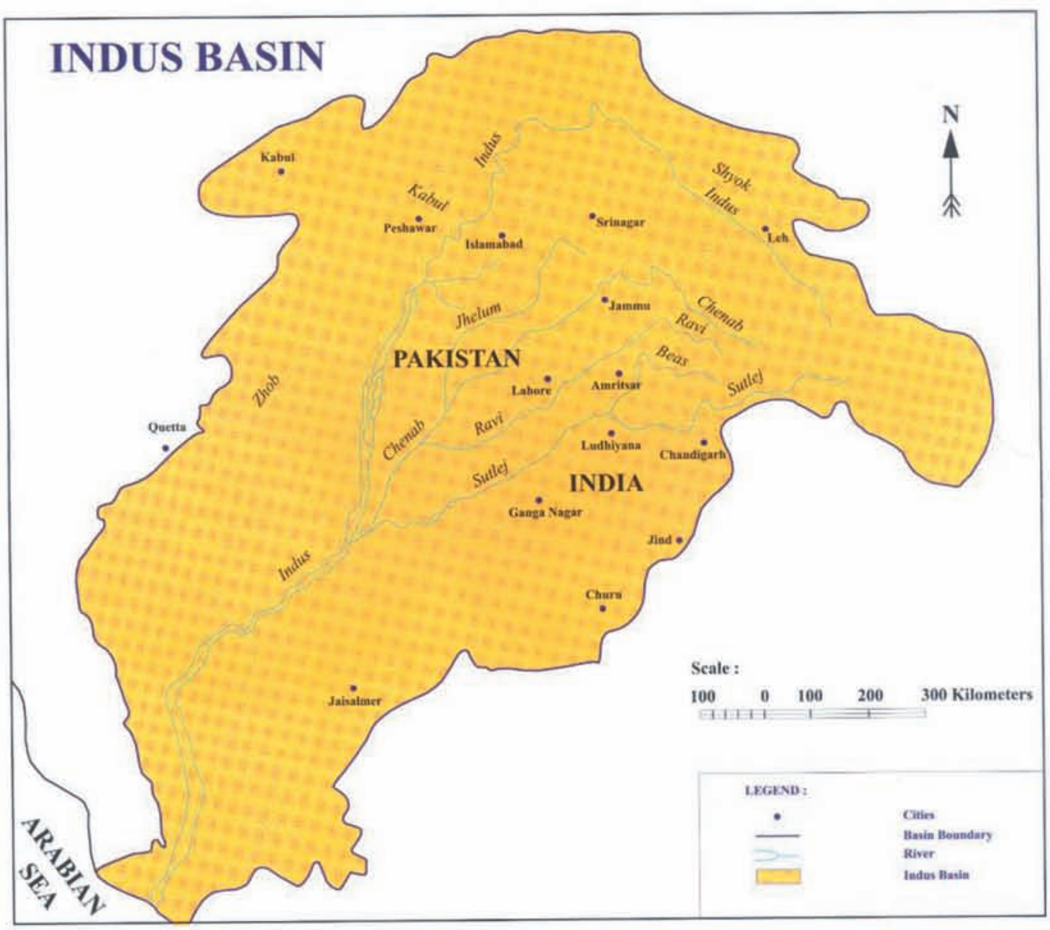

Figure 2 Indus Basin Map

6.4.3. Geological Framework of Indus Basin

The deep aquifers of the Indus basin are a multi-aquifer system and are of the Tertiary to Mesozoic period, but their contribution across the border with Pakistan is not known. The alluvial aquifers predominate in the Recent to Quarternary sediments, whereas aquifers in sandstone and limestone belong to the Cenozoic – Mesozoic age. Aquifers are present within fracture zones in the Precambrian quartzites (Aravalli group).

In the part of the Indus basin exposed in Rajasthan, the rocks are mostly of limestone and sandstone of Tertiary and Mesozoic periods. The geological succession in the Indus basin is given in Table 1.

Table 1: Regional Geology showing succession of different rock formations in Indus basin

Era	Period	Formation (Thickness)
Quaternary	Recent, Sub-recent	Desert sands, sand dunes and Alluvium
	to Pleistocene.	Summer formation.
Tertiary	U. Paleocene to Lower Eocene.	Bandah Limestone (75 m) Khuiala Limestone (100 m) Sanu Sandstone (75 m)
Mesozoic	Lower Cretaceous	Abur Limestone (66 m) Parihar sandstone (300 m)
	Jurassic	Badesar sandstone (65 m) Baisaki shales (165) Jaisalmer limestone (150 m) Lathi sandstone (450 m)
Paleozoic	Cambria	Jodhpur group (240 m)
Proterozoic	Pre-Cam	Malani Ingneous suite (Granites and Rhyolites)

6.4.4. Hydrogeology

The transboundary aquifer system is made of alluvial sediments mostly of different grades of sand with intervening layers of silt and clay. The ground water is fresh but in the south-western part of Punjab, the groundwater is brackish to saline and the area is waterlogged because of seepage from the network of canal systems.

Old alluvial soils: These soils are deep, calcareous, and generally saline and alkaline in nature, and highly stratified and variable in texture. These soils are predominantly coarse textured with very little clay content.

Sub-mountain soils: These soils are developed in mid to high altitudes in high mountain regions. They are yellow and brown to dark brown in color. The soils are very deep and well drained with moderate to low permeability.

Desert soils: These soils are present in Rajasthan and have aeolian sand which is pale brown to light yellow-brown in color. These are generally well drained and low in moisture holding capacity.

Calcareous slerozomic soils: These soils occur Rajasthan near the area adjoining Punjab, in the extreme southwestern part of Punjab, and the northwestern part of Haryana.

Brown hill soils (on sandstone & shale): These soils are formed at elevations ranging from about 300 to 1,500 m amsl in the areas of moderately undulating regions. These soils are shallow and embedded with stones.

Mountain meadow soils: These are exposed only in the high mountain ranges of Jammu and Kashmir.

Alluvial soils (recent): The alluvial soil cover is found in the alluvial parts of Punjab, Haryana and the outer plains of Jammu.

Skeletal soils: These soils are developed in high altitude areas between 2,400from 2400 to 7,200 m amsl. These areas are dotted with deep gorges and desert plateau. These soils constitute an appreciable spread of mountain meadow and brown hills. These are developed in the parts of Leh and Kargil districts of Jammu and Kashmir.

6.4.5. Aquifer Systems

The Indus basin represents a multi-aquifer system, with different aquifers ranging in age from pre-Cambrian to recent deposits. The groundwater exploration in different parts of the basin revealed a configuration of different aquifer zones. The sub-surface lithological data collected from exploratory drilling and other state tube-wells have been synthesized for the preparation of different lithological cross sections as, which are presented below.

6.4.5.1. Jhelum Sub Basin

The geological cross section along Chandhara in the east to Kuchpura in the west has revealed the sub-surface geology down to a depth of 122.83 m.bgl (Figure 3). A major aquifer running along the section consists of medium to coarse sand. The other major water bearing formation consists of gravel and coarse sand. The maximum thickness of the aquifer material is in the central portion of the section and decreases and splits in two different layers inter-spaced by clay towards the east.

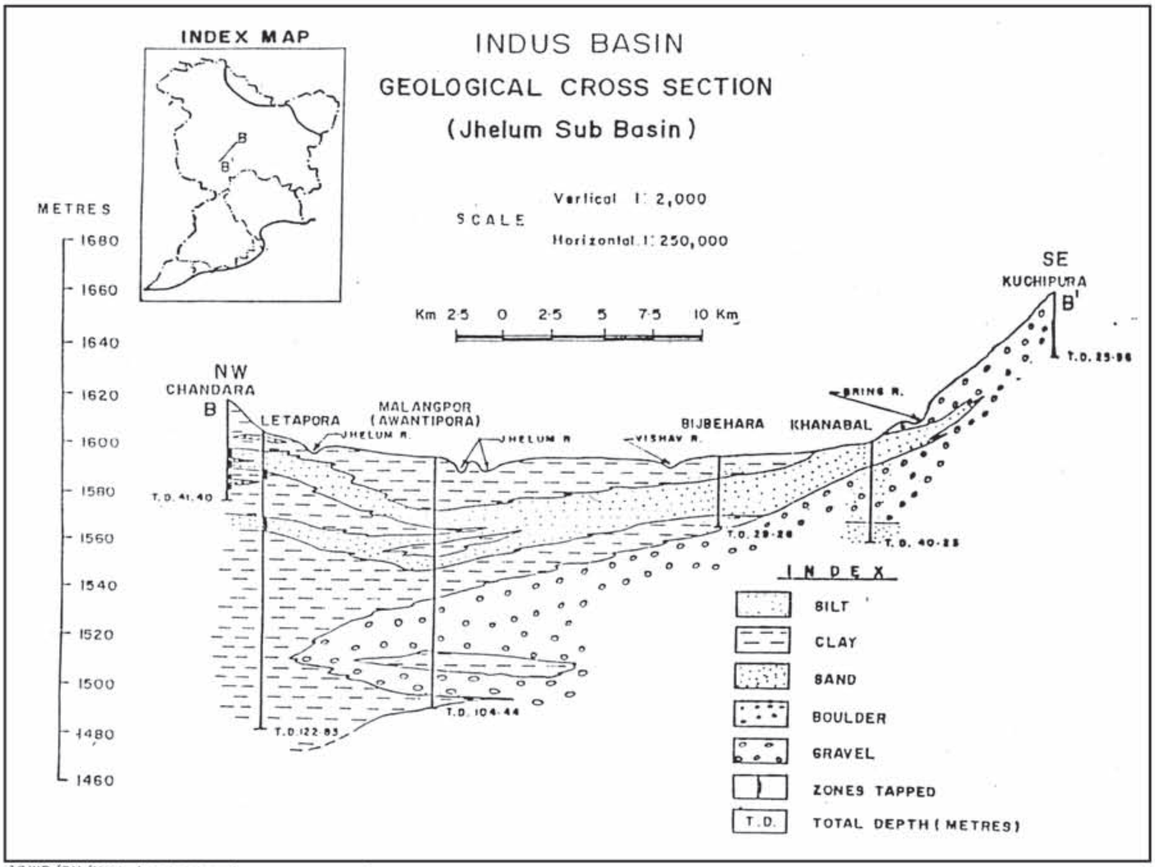

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Figure 3: Lithological cross section of Jhelum sub basin (after CGWB)

6.4.5.2. Chenab (Chandrabhaga) Sub Basin

A geological sub-surface cross section along Jourian in the west to Sungal in the east in the Chandrabhaga sub-basin (Jammu Province) has revealed an aquifer about a 100m thick with intervening clay layers (Figure 4). This aquifer comprises of sand, boulder, and conglomerate. The tube-wells drilled in the area mostly draw water from this aquifer.

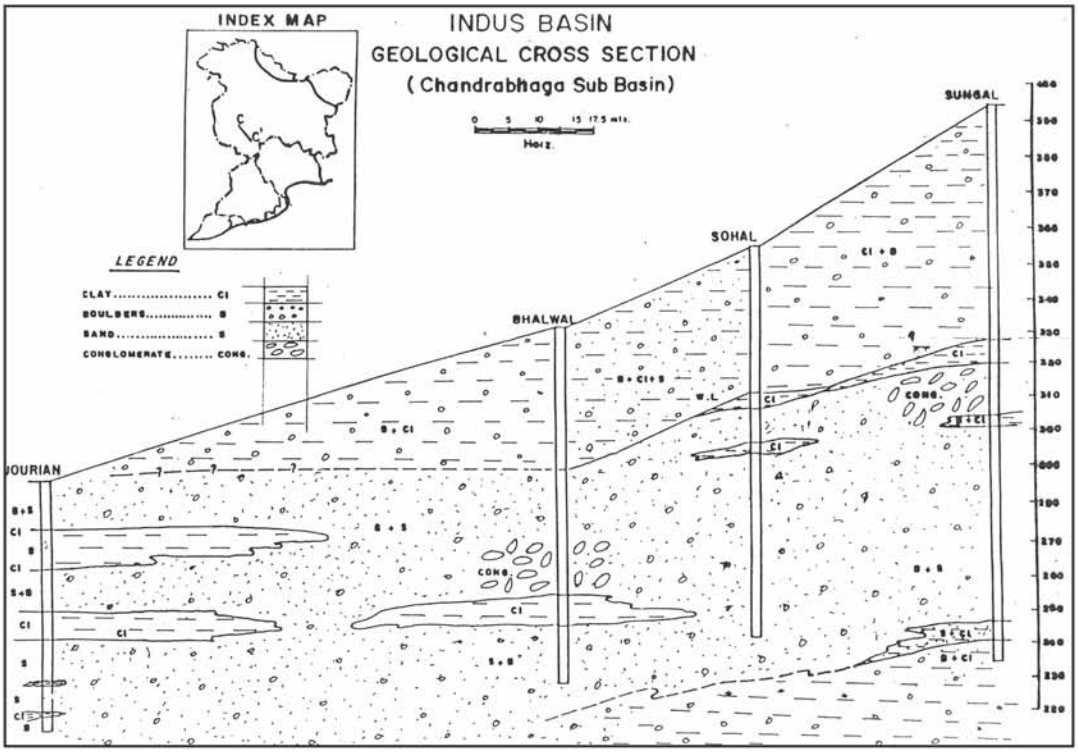

Figure 4 - Lithological cross section of Chenab (Chandrabhaga) Sub Basin (after CGWB)

6.4.5.3. Beas Sub-Basin

The section is drawn parallel to the right bank of the Beas River and extends between Jaunke and Beas (Figure 5). It reveals the presence of seven to nine thick permeable granular zones down to a depth of 300-500 m.bgl. All the aquifers have a large lateral extent and are separated by 5 to 18m18 m of thick clay beds. A thick clay zone occurs between 450 & 496 m bgl at Jamarai. The aquifer material is composed of fine to medium sand, and the aquifer extending down to 200m depth consists of fine sand and silt. The first aquifer is under phreatic conditions and extends down to 50m in the northwestern part of the section and extends down to 42m in the southwestern part. The deeper aquifers are under semi-confined conditions.

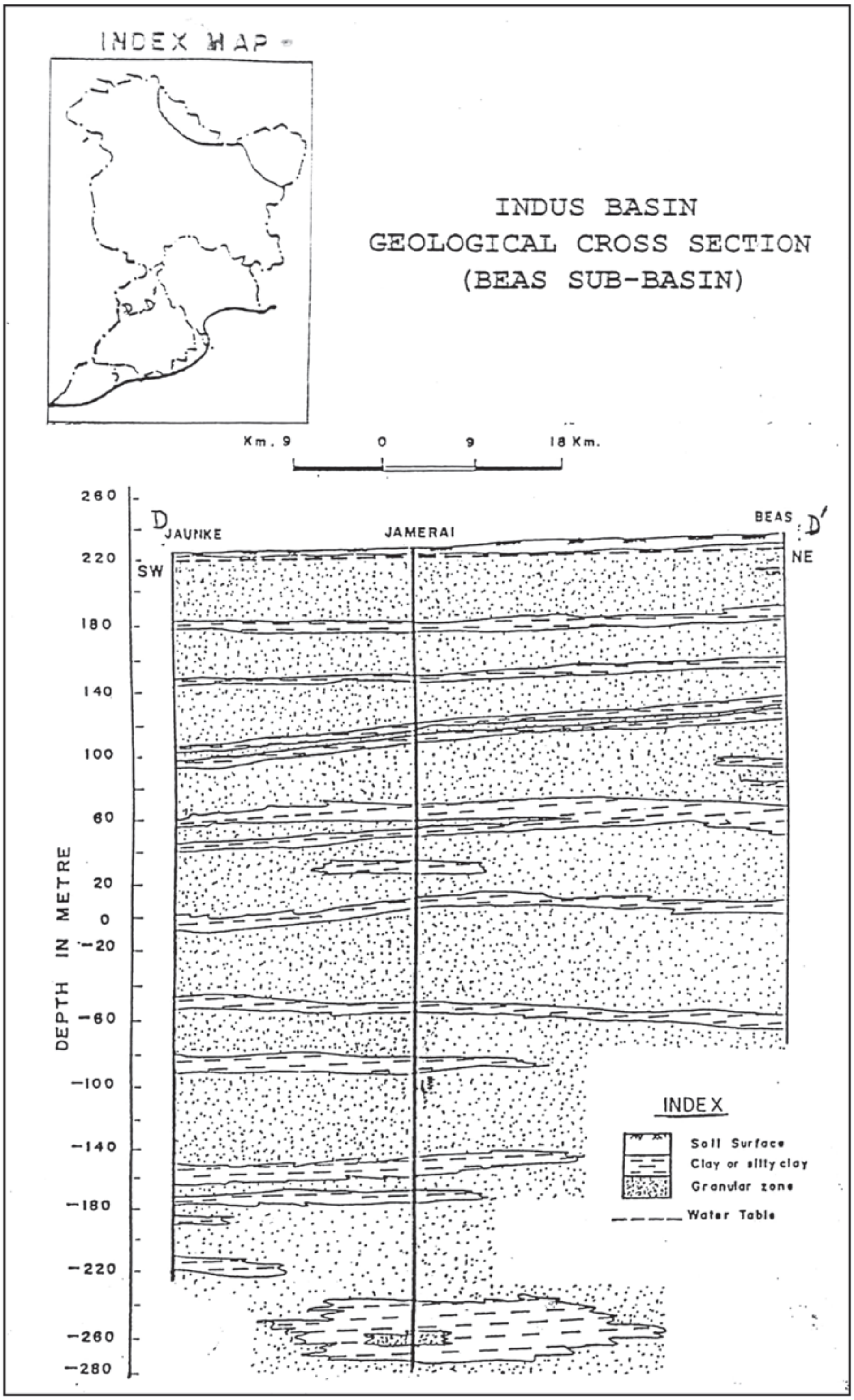

Figure 5: Lithological cross section of Beas Sub Basin

6.4.5.4. Satluj Sub-Basin

The section (Figure 6) covers the Satluj sub-basin of the Nalagarh Valley of Himachal Pradesh. The uppermost layer is clayey and its thickness is about 10m. Below this clay layer, a single aquifer comprising sand, gravel, and pebble and boulder exists. Boulders exist in the northeastern part and extends down to 50m i.e. drilled depth. In the southwestern part, the same aquifer has bifurcated into two and is separated by a clay lens. The thickness of the aquifer is at its maximum in the northeastern part and decreases towards the southwestern area. In the central part, the cumulative thickness of the saturated granular zone is 20m. The aquifers in the area have a high potential.

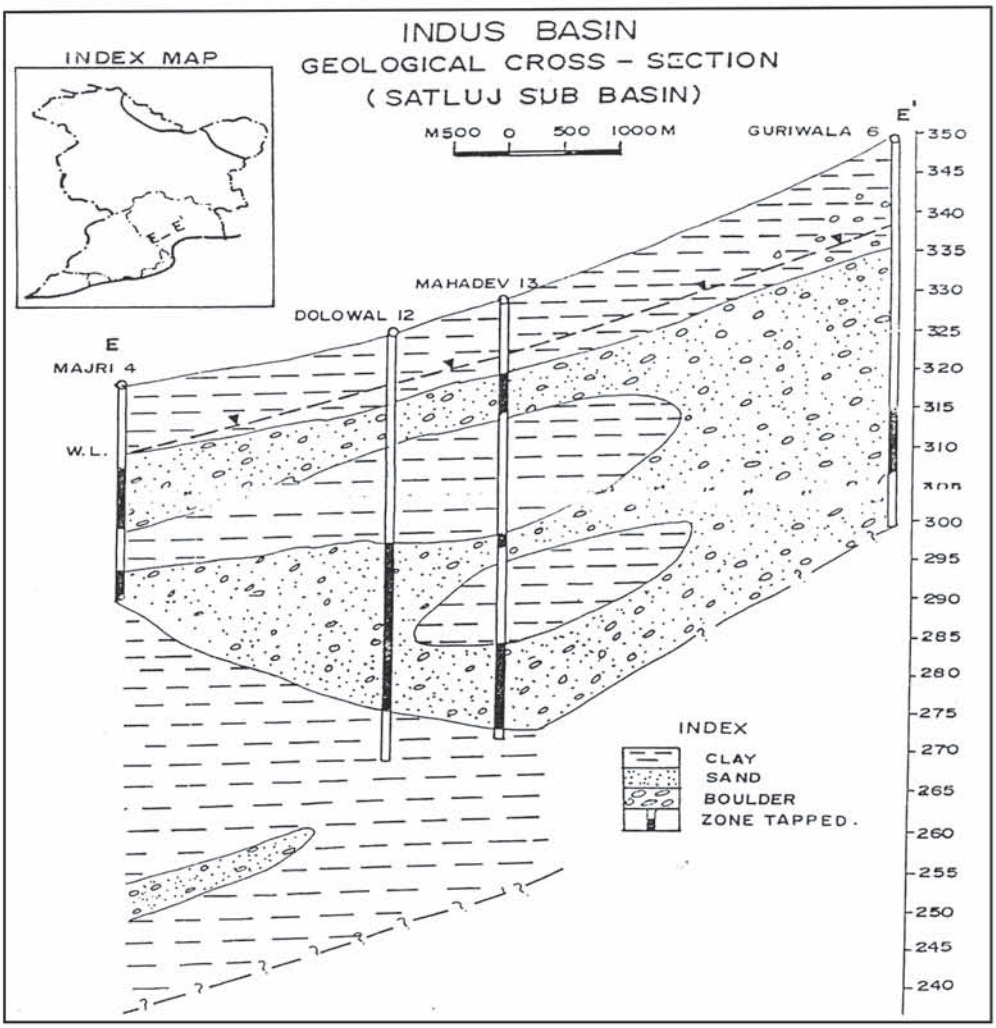

Figure 6 Lithological cross section of Satluj Sub Basin (after CGWB)

6.4.5.5. Ghaggar Sub-Basin

A geological cross-section is drawn from Dera (Punjab) to Anupgarh (Rajasthan), as shown in Figure 7. The aquifers of the Ghaggar sub-basin primarily consist of quaternary alluvial sediments. In the western part of the sub-basin these are associated with the underlying Nagaur and Jodhpur sandstone of Tertiary age. The quaternary alluvium exhibits two different types of sediments. The extreme eastern part, which is around 2 to 10 km wide, is comprised of Kandi belt. The Kandi belt corresponds to the coalescence of alluvial fans deposited by the mountainous rivers at their entry into the plains. It consists mainly of coarse, clastic deposits comprising of medium to very coarse sand and sub-angular to sub-rounded gravels, pebbles and cobbles of varied nature. Lenticular intercalations of silty or sandy clay, clayey silt and clay are rare and generally less than 3m thick.

The quaternary alluvium in the plain adjoining to Kandi belt is fluviatile. It consists of medium to very fine grained sand intercalated with clayey material. The thickness of fluvial deposits is over 400m.

In the upper part of the sub-basin the aquifer is phreatic, and thickness is up to 110m. In the lower part, the aquifer system it is confined by clay or silty beds of large areal extent. At places where the confining bed are too thin (less than 4m), semi-confining conditions also occur. The thickness of a the confined aquifer is less than 100m in the southwestern part of the sub-basin, while it is more than 400m in the northwestern and northeastern parts.

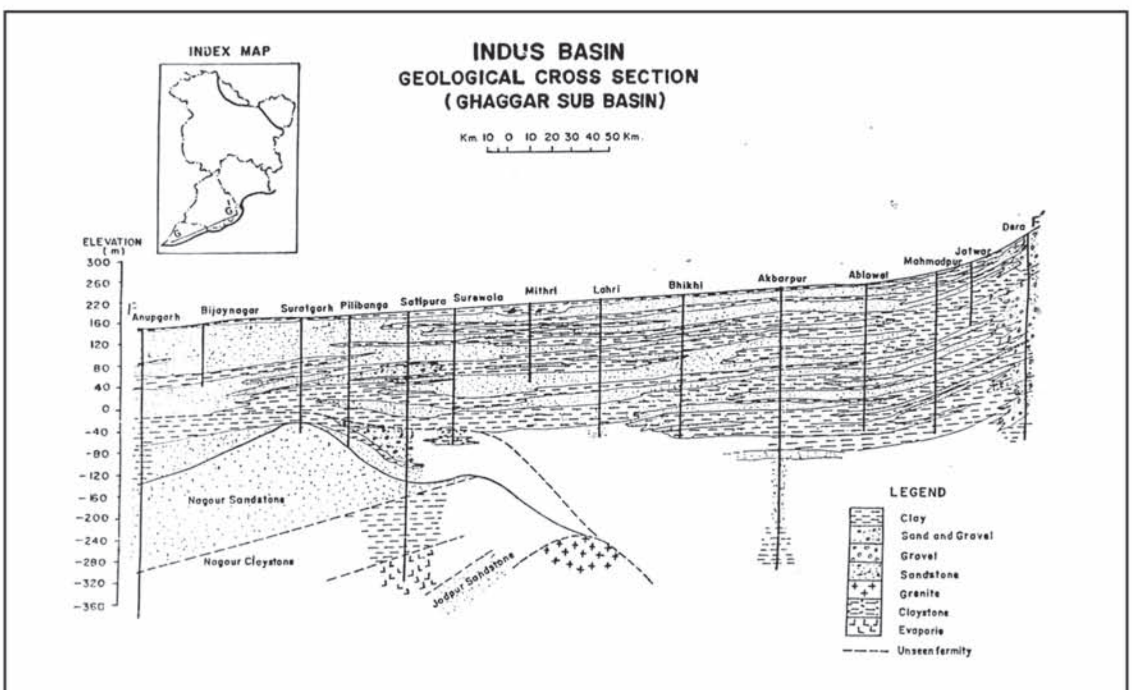

Figure 7 Lithological cross section of Ghaggar sub basin (after CGWB)

6.4.6. Groundwater Potential, Development and Management

The geological formations range in age from pre-Cambrian to Quaternary deposits (recent) and thus constitute different aquifer systems with different potentialities. The groundwater potential of the mountain areas (about 85% of the basin area) has not been estimated, but in the 15% of the foot hills and plain areas, the dynamic (annual replenishment) groundwater potential of the unconfined system is estimated to be 26.5 BCM and the status of its development is monitored (Table 2). The in-storage potential is estimated to be1,338 BCM up to the explored depth of 350m. The saline aquifers cover an area of about 25,100 sq.km, and have an estimated potential of 1.07 BCM of the shallow unconfined aquifer.

Table 2: Ground water assessment and development status for Indus Basin, India

S. No.	State/District	Geographical Area Falling In Indus basin (sq.km.)	Annual Gross Recharge (MCM)	Net Draft (MCM)	Area covered (sq.km.)	Potential (MCM)	Water logged area (sq.km.)
			Fresh Ground water		Saline Ground water		
1	JAMMU KASHMIR	117683	4425.6	40.3	NIL	NIL	NIL
2	HIMACHAL PRADESH	47436	247.72	49.3	NIL	NIL	321
3	PUNJAB	50362	18192.27	16101.95	2980	4162	5525
4	HARYANA	14679	3645.83	2067.85	3750	5430	4350
5	RAJASTHAN	14624	603.96	210.09	18347	1158	1171
6	CHANDIGARH(UT)	114	0.023	0.018	NIL	NIL	NIL

Use of groundwater is necessary to meet irrigation demand, (which uses 90% of the resource). The resulting decline in water levels is being reduced through the practices of MAR and regulatory measures. The saline ground water resources have been developed on a limited scale, for use in conjunction with surface canal water. Based on the surface water availability and sub-surface storage, it is estimated that feasible groundwater storage is 29,800 MCM. The non-committed run-off of about 2,100 MCM has been planned for MAR in creating sub-surface storages to check the declining trends in water levels and reduce energy costs. A number of recharge structures have already been constructed.

6.4.7. Problems Related to Transboundary Aquifers

India has a long border with Pakistan and the transboundary aquifers are of different geological ages, and of variable groundwater quality and hydrogeological conditions. In the Indus basin, most of the precipitation is on the Indian side, and the groundwater flows towards Pakistan. Both sides have a close network of canals for irrigation, and areas are affected by water-logged conditions and inland salinity etc. It is suggested that any future study of the transboundary aquifers should not be restricted to the fresh aquifers but should also include saline aquifers and should deal with problems like pollution and water-logging. Moreover, India has begun implementing large MAR schemes and has made them mandatory for industries and urban/infrastructure developers. It has also constituted an authority to regulate the development of groundwater resources. Such actions, however, are not being envisaged in the transboundary countries. It is suggested that the guidelines for managing such problems/issues be incorporated in the Draft Articles on the Law of Transboundary Aquifers (Eckstein, 2007). Moreover, it is important to spell out the extent (i.e.distance from the international boundary) to which the aquifers are determined to be transboundary and the depth for their development. The Indus basin has complex aquifer systems and hydrogeological conditions. Groundwater is intensively exploited and the area is superimposed with a network of canal systems, etc. Therefore, these factors pose some questions for further consideration in the study of transboundary aquifers.

6.5. Transboundary Aquifers of Mongolia

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6.5.1. Geography

Mongolia is located inland in Northeast Central Asia, between China and Russia. It forms the transition zone between the great Siberian taiga and the Central Asian desert. Forest cover is limited to the Khangai, Khuvsgul and Khentii mountainous regions in the north, while bluffs are found in the Mongolian Altai and Gobi Altai mountains. High plateaus of the Gobi Desert and steppes cover the eastern and southern areas. The total territory of Mongolia is 1,564,000 km^2 and the average elevation is 1,580m above sea level. There is a great morphological diversity ranging from hilly and flat plains to high alpine mountains. Gentle morphological elements generally predominate. About 80% of the territory is situated at elevations than of above 1,000 metres above m.s.l. (Figure-1)

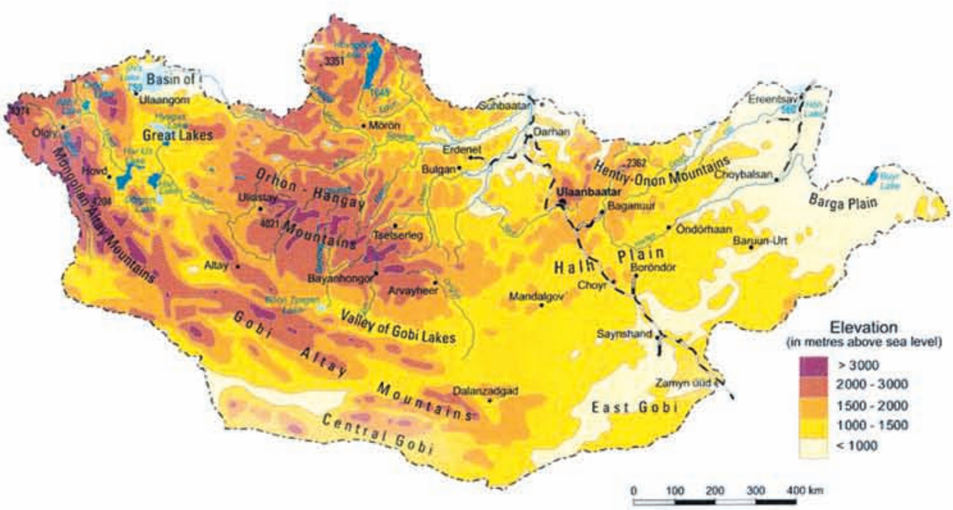

Fig-1. Orography map of Mongolia (After National Atlas of Mongolia,1990)

There are elevations of over 4,000 metres above m.s.l along the main drainage divides in the western part of the country. Altitudes of below 600m occur at the northeastern border of the country near Ereentsav. The main mountain ranges are the Mongolian Altay, Orkhon–Hangay, Khentii–Onon and Khubsugul Mountains. The main lower topographical elements are the Basin of Great Lakes, the Valley of Gobi Lakes, the Khalkh plain, the Barga Plain and the Gobi Desert.

6.5.2. Climate

Due to its inland location and mountainous surroundings, the main climate of the country is continental, harsh and arid. Important characteristics of the climate are long winters, short summers, large fluctuations of both daily and seasonal temperatures, and a low distribution of precipitation with about 85% of the precipitation falling in the summer. The precipitation, on average, is about 300-350mm in the Khangai, Khentii, and Khuvsugul mountain ranges; 250-300mm in Mongol Altai and forested areas; and 50-150mm in the Gobi Desert area. The main annual precipitation range is less than 50mm in the southern and southwestern Gobi and over 400mm in the mountainous area of northwestern Mongolia.

6.5.3. Water Resources

The total water resources of the country are estimated at 38.8km^3 and potentially accessible water resources are estimated at 34.29km^3. Surface water resources are estimated at 28.22km^3 and groundwater resources at 6.07km^3. There are over 4,100 rivers, approximately 3,500 lakes, 6,900 springs (including over 120 mineral water springs with supposed medicinal properties) and 240 glaciers.

Distribution of water resources by water basins : Mongolia is divided into three ocean basins in Central and Eastern Asia, namely the:
Northern Arctic Ocean Basin
Pacific Ocean Basin
Central Asian Internal Drainage Basin

Water resources are unevenly distributed, not only over the territory of the country, but also in time. Due to the mountainous conditions, almost all rain-fed rivers run to the Arctic and Pacific Ocean basins, and most of the surface runoff (~70%) flows out of the country. A small portion flows into the Central Asian Internal Drainage Basin within Mongolia. Mongolia is a country through which the world watershed line crosses. (Janchivdorj and Odontsetseg 2005) (Fig-2)

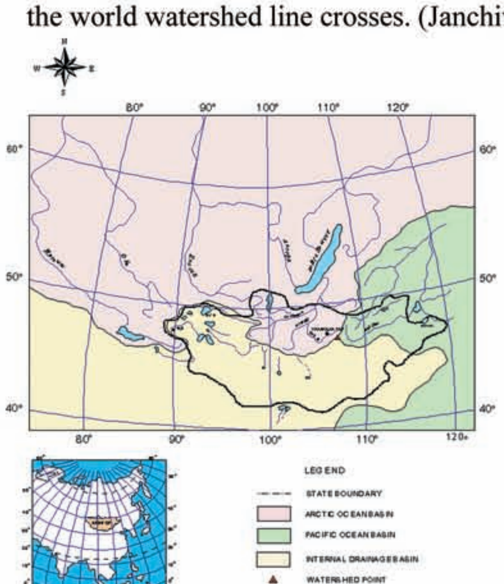

Fig-2.The regional pattern and watershed point in territory of Mongolia. (Janchivdorj and Odontsetseg 2005)

The Central Asian Internal Drainage Basin, which includes arid and semi-arid regions, covers 68% of the total territory of Mongolia. Perennial rivers and streams with permanent flow are very rare in these areas. Accessible water resources in the Gobi and steppe regions are scarce and they are generally unsuitable for drinking purposes due to high mineral content and/or unacceptable hardness. It is estimated that about one-third of the population of Mongolia lives in this area.

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6.5.4. Geology

The geology of Mongolia reflects the development of Central Asia between the cratons formed at the end of the Archean: the Siberian craton in the north and the Tarim, North China and Sino-Korean craton in the south. The whole territory of Mongolia was consolidated and belonged to the Late Paleozoic Pangean supercontinent. Further development from the Mesozoic to Cenozoic is characterized by orogenesis, magmatism and sedimentation-particularly in southern and eastern Mongolia.

The total development is divided into two parts: from Precambrain up to the end of the Permian, i.e. up to the formation of the hard crust and the Mesozoic and Cenozoic. During the Mesozoic and Cenozoic, the recent territory of Mongolia was in a platform geodynamic situation where the formation of different overlapping structures was caused mainly by destruction of the previous continental crust. The formation of large basins mainly occurred in the southern megablocks, but also in parts of the central megablocks.

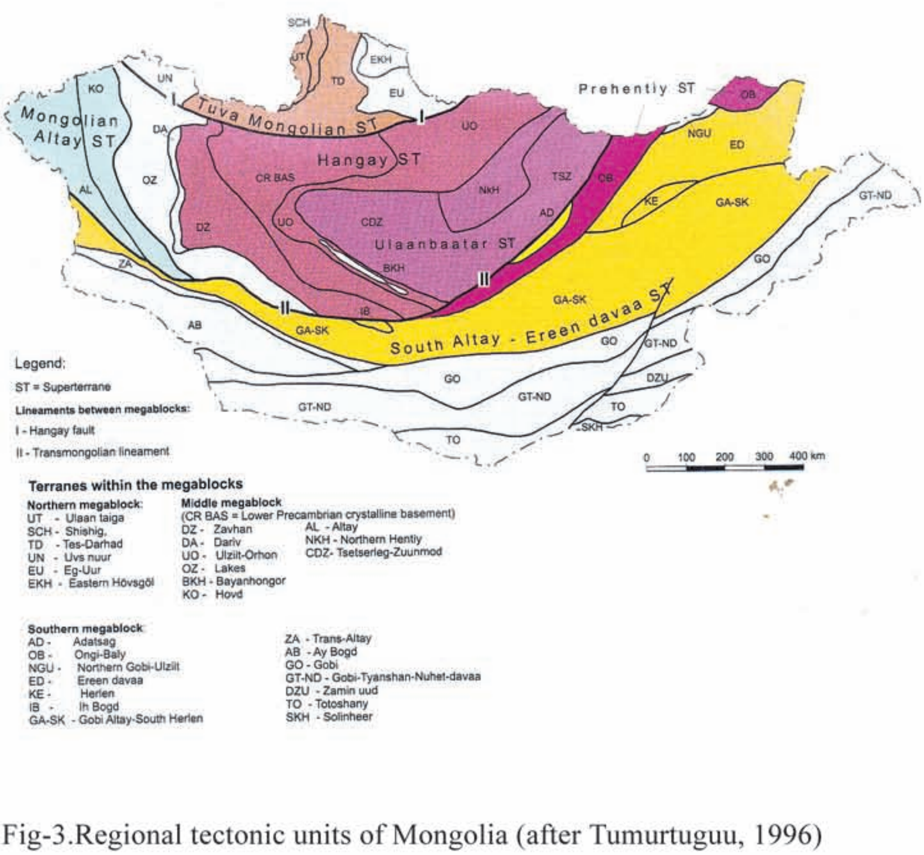

Fig-3.Regional tectonic units of Mongolia (after Tumurtuguu, 1996)

6.5.5. Characteristics of the Main Transboundary Aquifers of Mongolia

In Mongolia most of the groundwater and surface water flows over the country borders because it is a highly elevated country. In 1975, Mongolian scientists determined that over 200 trans-boundary water basins were located within the territory of Mongolia. Since then, there has been a lack of research studies on the theme of Mongolian transboundary water basins due to limited financial investment opportunities.

The map of Mongolia below shows that there are 3 groundwater circulation types in different geological deposits and rocks (map Fig-4).

- pore aquifers consisted from alluvial, eolian , proluvial-deluvial and other genesis of Quaternary age
  and also Neogene, Paleogene, Cretaceous ages
- pore-layer water in sedimentary rocks of Triassic-Jurassic ages
- fissure water in tectonic faults of intrusive, extrusive and metamorphic hard rocks of different ages

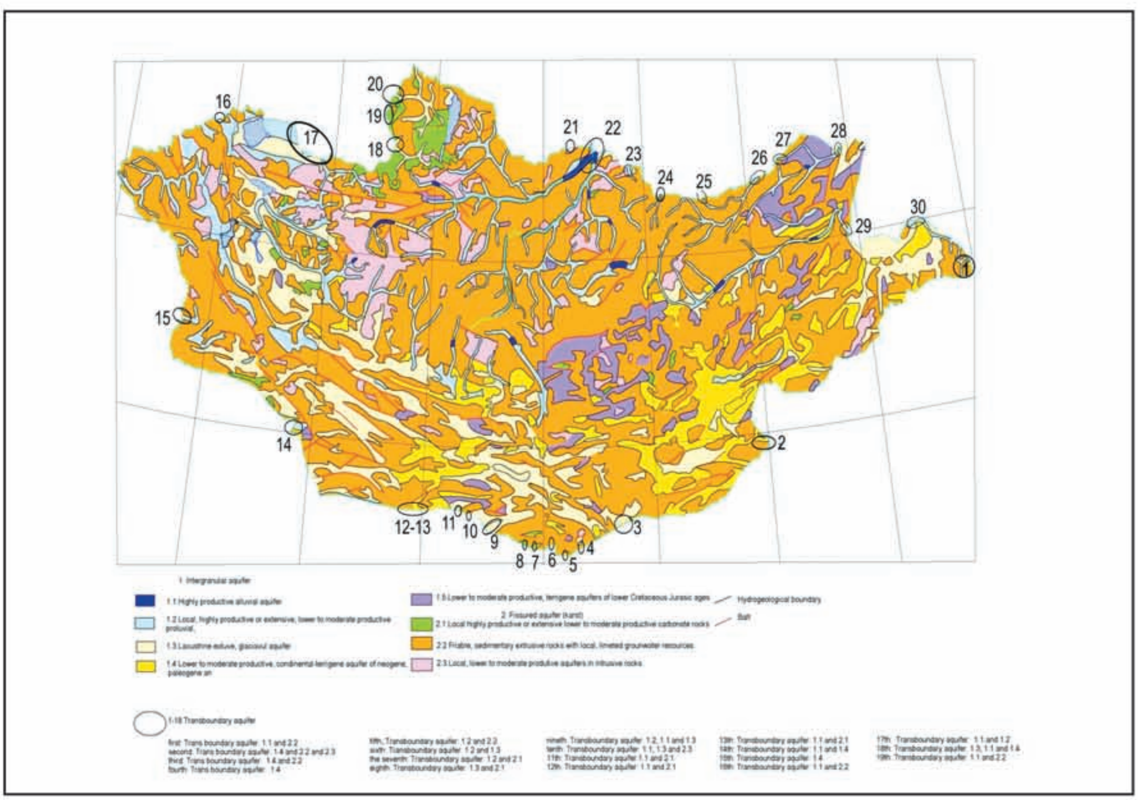

Fig-4 Main Transboundary Aquifers of Mongolia

The length of the boundary line between Mongolia and China is 3,700km and between Mongolia and Russia it is 2,600km.

1.1 Highly productive alluvial aquifer
1.2 Local highly productive or extensive, lower to moderate productive proluvial
1.3 Lacustrine eoluve, glaciavul aquifer
1.4 Lower to moderate productive, continental-terrigene aquifer of neogene, paleogene
1.5 Lower to moderate productive, terrigene aquifer of lower cretaceous Jurassic ages
2.1 Local highly productive or extensive, lower to moderate productive carbonate rocks
2.2 Friable, sedimentary extrusive rocks with local, limited groundwater resources
2.3 Local, lower to moderate productive aquifers in intrusive rocks

Groundwater aquifers with a high capacity are located only in the valley valleys of the larger river basins, and are extremely sparse. Relatively new aquifers with little to no recharge dominate in the dry Gobi steppe zone of Mongolia.
The recharge of water resources is mainly due to precipitation (Institute of Water Policy 1996), with 70-80% of surface water and precipitation contributing to recharge in each year. 70% of the total runoff flows out of the Mongolian border and tributaries leading to the Arctic Ocean basin and the Pacific Ocean basin.
At the present stage of hydrogeological study, researchers have distinguished 30 areas of Mongolia which could be classified as trans-boundary aquifers.

Number of aquifer	Name of transboundary aquifer system	The name of the province and soum	Countries sharing this aquifer system	Extension (km^2)	Type of aquifer system
1	Numrug river basin	Dornod province Sumber soum	Mongolia, China	6832.5	Highly productive alluvial aquifer and friable, sedimentary extrusive rocks with local, limited groundwater resources
2	Zamiin-Uud basin	Dornogobi province Erdene soum	Mongolia, China	6823.8	Lower to moderate productive, continental-terrigene aquifer of neogene, paleogene and friable, sedimentary extrusive rocks with local, limited groundwater resources and local, lower to moderate productive aquifers in intrusive rocks
3	Tsagaan khadnii sair	Umnugobi province Khanbogd soum	Mongolia, China	2319.8	Friable, sedimentary extrusive rocks with local, limited groundwater resources,
4	Ulaan tsaviin sair	Umnugobi province Nomgon soum	Mongolia, China	2580.03	Friable, sedimentary extrusive rocks with local, limited groundwater resources, Lacustrine eoluve , glaciavul aquifer
5	Orvog gashuunii sair	Umnugobi province Nomgon soum	Mongolia, China	3010.04	Friable, sedimentary extrusive rocks with local, limited groundwater resources
6	Khar balgas (gashuunii) sair	Umnugobi province Nomgon soum	Mongolia, China	1720.02	Friable, sedimentary extrusive rocks with local, limited groundwater resources
7	Onch khairkhanii sair	Umnugobi province Khurmen soum	Mongolia, China	2150.03	Friable, sedimentary extrusive rocks with local, limited groundwater resources
8	Tsagaan uuliin sair	Umnugobi province Khurmen soum	Mongolia, China	2408.03	Friable, sedimentary extrusive rocks with local, limited groundwater resources
9	Nariin suhait (Huhulzuh gobi basin)	Umnugobi province Noyon soum	Mongolia, China	4300.05	Lower to moderate productive, continental-terrigene aquifer of neogene, paleogene and friable, sedimentary extrusive rocks with local, limited groundwater resources
10	Tsagaan bulag basin	Umnugobi province Gurvan tes soum	Mongolia, China	2322.03	Lower to moderate productive, continental-terrigene aquifer of neogene, paleogene
11	Khuvdiin bayan burdiin sair	Umnugobi province Gurvantes soum	Mongolia, China	2236.03	Lower to moderate productive, continental-terrigene aquifer of neogene, paleogene

12	Khatan suudliin sair	Bayankhongor province Bayan undur soum	Mongolia, China	2064.02	Lacustrine eoluve, glaciavul aquifer
13	Dankhan khudgiin sair	Gobi-Altai province Erdene soum	Mongolia, China	2752.03	Lacustrine eoluve, glaciavul aquifer
14	Dayshigiin khudgiin sair	Gobi-Altai province Altai soum	Mongolia, China	2838.03	Friable, sedimentary extrusive rocks with local, limited groundwater resources, Lacustrine eoluve, glaciavul aquifer
15	Bulgan river basin	Khovd province Bulgan soum	Mongolia, China	9617	Local highly productive or extensive, lower to moderate productive proluvial and friable, sedimentary extrusive rocks with local, limited groundwater resources
16	Uureg lake basin	Uvs province Sagil soum	Mongolia-Russia	10516.2	Friable, sedimentary extrusive rocks with local, limited groundwater resources and Local highly productive or extensive, lower to moderate productive proluvial
17	Tes river basin (Uvs lake)	Uvs province Zuungobi soum	Mongolia-Russia	7960	Local highly productive or extensive, lower to moderate productive proluvial and lacustrine eoluve, glaciavul aquifer
18	Delger big river basin	Khubsugul province Bayanzurkh soum	Mongolia-Russia	22813	Lacustrine eoluve, glaciavul aquifer and lower to moderate productive, continental-terrigene aquifer of neogene, paleogene and Local highly productive or extensive, lower to moderate productive carbonate rocks
19	Bus river basin	Khubsugul province Renchinlkhumbe soum	Mongolia-Russia	1022.45	Local highly productive or extensive, lower to moderate productive proluvial and carbonate rocks
20	Shishhid river basin	Khubsugul province Renchinlkhumbe soum	Mongolia-Russia	18338	Lacustrine eoluve, glaciavul aquifer and local highly productive or extensive, lower to moderate productive carbonate rocks
21	Zelter basin	Selenge province Tsagaan nuur soum	Mongolia-Russia	5599	Friable, sedimentary extrusive rocks with local, limited groundwater resources
22	Hiagt river basin	Selenge province Altanbulag soum	Mongolia-Russia	1168.0	Local highly productive or extensive, lower to moderate productive proluvial and highly productive
23	Tsuh river basin	Selenge province Eruu soum	Mongolia-Russia	3974.4	Highly productive alluvial aquifer and Lacustrine eoluve, glaciavul aquifer and local, lower to moderate productive aquifers in intrusive rocks
24	Minj river basin	Khentii province Batshireet soum	Mongolia-Russia	5100	Highly productive alluvial aquifer and local highly productive or extensive, lower to moderate productive carbonate rocks
25	Balj river basin	Khentii province Binder soum	Mongolia-Russia	9094.5	Highly productive alluvial aquifer and local highly productive or extensive, lower to moderate productive carbonate rocks
26	Onon river basin	Khentii province Dadal soum	Mongolia-Russia	4465.94	Highly productive alluvial aquifer and local highly productive or extensive, lower to moderate productive carbonate rocks
27	Duch river basin	Dornod province Chuluutkhoroo soum	Mongolia-Russia	1075.83	Highly productive alluvial aquifer and lower to moderate productive, continental-terrigene aquifer of neogene, paleogene
28	Ulz river basin	Dornod province Chuluutkhoroo soum	Mongolia-Russia	17930.5	Lower to moderate productive, continental-terrigene aquifer of neogene, paleogene
29	Herlen river basin	Dornod province Choibalsan soum	Mongolia, China	11208	Highly productive alluvial aquifer and local highly productive or extensive, lower to moderate productive proluvial
30	Halh gol river basin	Dornod province Sumber soum	Mongolia, China	7690	Highly productive alluvial aquifer and Lacustrine eoluve, glaciavul aquifer and lower to moderate productive, continental-terrigene aquifer of neogene, paleogene

6.5.6. Groundwater recharge

Recharge in the Gobi region comes from infiltration of rainwater which percolates in the upper (shallow) aquifers after which it is discharged to springs, feeds vegetation, wadis or temporary lakes or is abstracted by shallow wells. A small portion percolated to deeper aquifers, but their size is largely unknown. The deep aquifers are the permeable rock sections from which groundwater can be abstracted (like in the Hunii Goloi aquifer) and contain mostly fossil water.

Quaternary alluvial sediments of the main rivers are being used as sources for centralized community water supply in many places. Usually the wells pump groundwater flows from elevated areas towards rivers. When the pumping rate exceeds the groundwater flow, the cone of depression extends towards the river, eventually inducing stream infiltration. These conditions are persistent in valley sections with high abstraction near urban centers, because the rate of the groundwater recharge is generally low and the relevant basin too small. In such cases, the most critical phase is during the months of March and April when the runoff reaches the annual minimum and many rivers are still frozen. In these circumstances, the alluvial aquifer is the only source of supply, usually with steadily falling groundwater levels and decreasing water quality.

Quaternary proluvial sediments near mountain ranges in the southern part of the country are the main sources of supply for many villages and small towns and, to a great extent, also for the watering of animals. Within reach of many shallow wells, the average recharge does not meet the requirements and in some cases there are additional losses by the seeping of groundwater from proluvial sediments into deeper aquifers. The best recharge conditions usually prevail in the foothills at the lower end of valleys, which are dry most of the time. A great majority of rainfall occurs as heavy local storms, often exceeding 20mm and resulting in short and muddy floods. When the stream reaches the plain, the water spreads and infiltrates the proluvial sediments.

Eolian sands are of minor importance for the economy of the country, but nomadic people and wild animals depend, at least occasionally, on this type of aquifer. Dune sands are well sorted with most grains in the 0.05-0.5mm size range. Small rain showers usually evaporate on reaching the ground. Recharge is mainly by local storms but very likely also by condensation from moisture - although probably to a much lesser extent. Withdrawal is primarily from springs and shallow wells.

Cretaceous sandstones and sands are widespread in central and southern Mongolia, mainly in the form of shallow basins or in almost horizontal positions. In many places this aquifer is covered by less permeable strata. Recharge is therefore extremely variable, predominantly occurring from rainfall in the outcrop areas, and in some places also from ephemeral streams.

6.5.7. Groundwater Use

The comparison between vegetation zones and the density of human population and livestock shows that vast steppe areas and even parts of the desert are populated, albeit sparsely, and used seasonally for livestock farming.

The main water use sectors in Mongolia are drinking water, agricultural water demand (livestock and irrigation) and industrial water. Minor water use sectors are tourism water use and water for green areas. Environmental water demands (base flow to rivers and wetlands, water for wild life and water for green belts) are important functions but difficult to estimate due to lack of data and information.

6.5.8. Drinking water supply

By the year 2004, 66% of the Mongolian population was receiving water from a piped water supply system (30% from a house or yard connection and 36% from public standpipes). The remaining 34% was provided from non-piped water supply systems including 24% by water delivery trucks and 9% from natural springs, ponds, snow and rivers (Table 6). These percentages have changed in past years due to rapid urbanization and the building of over 10,000 apartments. The data in Table 6 show a large difference between the daily consumption from piped supply and from non-piped supply sources.

6.5.9. Agricultural water use

Groundwater, surface water, snow and glacier water are used for livestock water supply. By 2005, there were 30.4 million head of livestock in the country, but by 2006, the head of livestock had increased up to 34.9 million and total water use of livestock was estimated at around 80 million m3/year.

6.5.10. The Properties of Groundwater in the Northern Borders of Mongolia

The groundwater recharge of this area comes from the surrounding high mountains and precipitation. In addition, there is a dominant distribution of inter granular-fissure groundwater is distributed predominantly in the northern border area of Mongolia. The distinguishing feature of groundwater in the northern border area is that both the quaternary aquifer's groundwater and river water flow in the same direction through the larger river valley. The research results have shown that the thickness of the aquifer and yield is uneven. Permafrost distribution is mostly greater around the Khubsgul mountain area, and the significance of the utilization of groundwater which is located in the upper or lower permafrost of (crack) inter granular fissures is mostly lower. The dominant hydrogeological formation in the northern part of Mongolia, particularly around the Khubsugul mountain area, is limestone from the Paleozoic period. The capacity of the groundwater aquifer is relatively high in this area. Triassic-Jurassic era volcanic rock is the dominant hydrogeological formation in the Selenge, Kherlen, Onon, Tes Ulz river basin's valley, and the main type of groundwater aquifer is fissure sub-surface water (Tsevegmed 1965). The lithology of the groundwater aquifer layer mainly consists of fissured porphyrite andesite, and andesite-basalt. The specific yield of the well, which was determined by survey investigation, was found to be 0.003-1.7 l/sec (MAS, 1986).

6.5.11. The Property of Groundwater in the Eastern Borders of Mongolia

The Dornod flat, east part of Sukhbaatar and Dornogobi province are situated within the eastern borders of Mongolia. Artesian aquifers are predominant in this area and are mostly distributed within the Paleozoic and Mesozoic intrusive rock types. The quaternary neogenic aquifer is located in the wide valley between small mountains of this zone.

The lithology of groundwater aquifer layers mainly consist of whetstone effusive rock, conglomerate, sand gravel and water impenetrable clay layer with a greater thickness (Jadambaa, 2007). The majority of the groundwater recharge is supported by filtration of precipitation and faraway groundwater flows and, as a result, the water interchange procedures are long-term. In addition, the hydration conditions and water storage properties of the above aquifers are uneven. The groundwater aquifers mostly appear below 50-100m in this zone.

Extrusion properties and yields of these aquifers are uneven but despite this, people in the area have relied on these water sources for a very long time.

6.5.12. The Property of Groundwater in the Southern Borders of Mongolia

The hydrogeological formation is from Jurassic period intrusive rock and predominantly distributes the artesian water of cretaceous era rock in the wide valley between the small mountains of this zone. Fissured conglomerate, coal, clay loam schist, argillite, conglomerate and effusive rock can be found in water storage deposits. The groundwater aquifers appear at a depth of 40-120m, the yields are uneven and the drawdown is high. The water mineralization and hardness are high due to the hydration property. Water storage is weak and the water penetrates in the water cycle slowly over the long term. Many small dry stream beds with quaternary deposits are located in the south on the Mongolian border (MAS, 1986). Only during periods of heavy rain and flash flooding does the runoff and surface water flow appear in the dry stream beds, because precipitation is the main source of recharge. The runoff flows out of Mongolia into the territory of China. The flow recharge of those dry stream beds is groundwater flow which comes from small mountains with break offs located in this area.

6.5.13. The Property of Groundwater in the Western Borders of Mongolia

The main hydrogeological formation in this area is volcanic rock of the Paleozoic period. Fissured porphyrite and andesite are included in the water storage lithologies. In the fissured volcanic rock formation, phreatic water predominates; is dominant and sometimes has a head. The valleys in this area are formed between high mountains and the water in these formations appears in springs under the face of the mountain laps. The groundwater aquifer appears below 36-80m and the yield is 0.1-3.6 l/sec at which results in a drawdown of 0.6-1m. The majority of groundwater recharge is supported by precipitation and groundwater flow which comes from the high mountains located in the area (Jadambaa, 2007). The hydration condition is uneven and the water storage capacity is medium and weak.

6.5.14. Main International Transboundary Groundwater Aquifers in Mongolia

At the present stage of hydrogeological study, 30 areas of trans-boundary aquifers have been distinguished.

1. Numrug River basin:

located near the source of the Halh River valley on the eastern transboundary territory of Mongolia between Mongolia and China. The source of aquifer starts from behind the Great Khyangan mountain range which is located in the territory of China. The elevation is 1,720m. One of the main tributaries of the Numrug River, the Galdastay, starts at the border area of Mongolia and China. The name of this river is Galdastay and it flows through to the western part of Modtoi khamar uul. The main aquifers of this basin consist of alluvial deposits of the present Quaternary age and also of extrusive and hard bedrocks with essentially limited groundwater resources. The type of aquifer systems in the first basin are: highly productive alluvial aquifers and friable, sedimentary extrusive rocks with local, limited groundwater resources, and lacustrine eoluve. There are also glaciavul aquifers with low to moderate productivity and continental-terrigene aquifers of neogene and paleogene. Groundwater recharge is 10-20mm/year.

2. Zamiin–Uud basin:

located near Zamiin-Uud in the southern part of Mongolia, with a distribution of low to moderate productivity aquifers in sediments of Upper Cretaceous and from Eocene to Pleistocene ages. One of the southern frontiers of Mongolia, - Zamiin-Uud - is located on the south-eastern edge of the basin of the same name, the direction of which is north-east to south-west. The Zamiin-Uud groundwater basin includes the following dry valleys which are similar to the Goby steppe: Hooloin gashuun, Elegnii Baruun tal, Bultger flat, Zanguutin hooloi, Zanguut flat, Biluut dry streambed, Borhoin flat, and the surrounding hilly mountains. The eastern part of the basin is indicated by the state boundary between Mongolia and China; the southern edge is intersected by a watershed through hills with an altitude altitudes of 1,129m: 1129m (Huh del), 1,076m (Sats ovoo), 1039m (Uizen tolgod), 994m (Burhtiin undur had); the western and north-western edges are intersected by watersheds through the Melzen hills, Hamarin shar ovoo (1,095m), Baga Bogd Uul (1,053m), and by the south range of Dalai sand mass. Within the Zamin-Uud groundwater basin 240 water points were recorded, which equates to one well for each 106km2. Within the Zamin-Uud groundwater basin the following aquifer types were found:

1. Present Quaternary lacustrine aquifer with very limited to limited groundwater resource productivity
2. Undefferentiated Upper Quaternary - Present Quaternary alluvial- proluvial aquifer also with very limited to limited groundwater resources productivity
3. From these 5 aquifers and water-bearing zones the most important for water supply is the Upper Cretaceous aquifer with a limited to moderate groundwater resources productivity
4. Water-bearing zone in fissured intrusive rocks with very limited productivity of groundwater resources
5. Water-bearing zone in hard bedrocks and metamorphic rocks with very limited productivity of groundwater resources

From these five aquifers and water-bearing zones important for water supply, only the Upper Cretaceous aquifer had limited to moderate groundwater resources productivity. This aquifer consists of sand, sandstone and conglomerate. This aquifer was studied in the central, western and eastern parts of Zamin-Uud village. For example, in 2007 "Usjuulagch" Limited Co. in Dornogoby aimag drilled one borehole in the Borhoin tal area which showed the possibility of distributing sufficient fresh groundwater (yield 6.0 L/s, drawdown about 20 m) to meet the needs of Zamin-Uud village. In 1990, in the Chumugtein Hooloi area, an aquifer was opened with a depth of 59-70 and 82-87m, a yield of 1.5 L/s which contained water with TDS-1.7g/l. In 2004 in the north-east of Zamin-Uud an aquifer was opened with a yield of 15.0L/s, but it was not of a sufficient standard to be used as a drinking water supply.

3. Tsagaan khad dry streambed:

This place is located in the south-eastern part of the Galba Gobi of Mongolia in the territory of Umnugobi Province, in the province of Khanbogd soum, in the western part of Aguut Mountain. The peak elevation of this mountain is 1,877m. The location coordinates are 42o 32I 51.6II 107o 34I 06.6II. The average elevation of this area is 1,000-1,500m. The Tsagaan khad is a dry streambed with a temporary groundwater flow and an area of 0.7 ha. Subsurface water level is 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The aquifer system of this place is made of friable, sedimentary extrusive rocks with local, limited groundwater resources. Recharge is and a recharge rate of 5mm/year.

4. Ulaan tsaviin dry streambed:

This place is located in the south-eastern part of the Borzon gobi of Mongolia in the territory Umnugobi, province, of Nomgon soum, in the south-eastern part of the Khalzan Mountain. The peak elevation of this mountain is 1,457m. The location coordinates are $42^{\circ}\ 15^{I}\ 19.0^{II}$ $105^{\circ}\ 46^{I}\ 38.0^{II}$. Elevation is 1,000-1,500m in this area. The Ulaan tsaviin dry streambed has a temporary groundwater flow and an area of 4-5ha. Subsurface water level is 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The aquifer system of this place is made of friable, sedimentary extrusive rocks with local, limited groundwater resources, and lacustrine eoluve, glaciavul aquifers. Groundwater and a groundwater recharge rate of 5mm/year.

5. Orvog gashuun dry streambed:

This place is located in the southern part of the Borzon gobi of Mongolia in the territory Umnugobi province, of Nomgon soum. Orvog gashuun bor tolgoi is located in this area. Its peak elevation is 802m. The location coordinates are $41^{\circ}\ 43^{I}\ 16.0^{II}$ $104^{\circ}\ 54^{I}\ 36.0^{II}$. Elevation is 1,000-1,500m in this area. The Orvog gashuun dry streambed has a temporary groundwater flow and an area of 6-7ha. Subsurface water level is 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The aquifer system of this place is made of friable, sedimentary extrusive rocks with local, limited groundwater resources. Recharge is and a recharge rate of 5mm/year.

6. Khar balgas gashuun dry streambed:

This place is located in the southern part of the Baruun tsokhio mountain ranges in the territory Umnugobi in the province, Khurmen soum. Ohi Khyangan Mountain is located in this area, with a peak elevation of 1,315m. The location coordinates are $42^{\circ}\ 02^{I}\ 52.4^{II}$ $104^{\circ}\ 20^{I}\ 24.4^{II}$. Elevation is 1,000-1,500m in this area. The Ulaan tsaviin dry streambed has a te-mporary groundwater flow and an area of 0.7 ha. Subsurface water level is 0.4-2.of 0 m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The aquifer system of this place is made of friable, sedimentary extrusive rocks with local, limited groundwater resources. Recharge and a recharge rate of 5 mm/year.

7. **Onch khairkhanii dry streambed:**

This place is located in the territory of Umnugobi in the province, of Khurmen soum. Location coordinates are $42^{o}\ 03^{I}\ 26.36^{II}\ 104^{o}\ 22^{I}\ 40.76^{II}$. Elevation is 1,000-1,500m in this area. The Onch khairkhanii dry streambed has temporary groundwater flow and an area of 0.1 ha. Subsurface water level is 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The aquifer system is friable, sedimentary extrusive rocks with local, limited groundwater resources. Recharge is 5mm/year.

8. **Tsagaan uuliin dry streambed:**

This place is located in the territory of Umnugobi province near Khurmen soum and the south western part of Tsagaan sumiin tuuri. The coordinates of this place are $41^{o}\ 59^{I}\ 52.8^{II}\ 103^{o}\ 14^{I}\ 28.3^{II}$. Elevation is 1000-1500m in this area. This Tsagaan uuliin dry streambed has temporary groundwater flow and an area of 0.2 ha. Subsurface water level is 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The aquifer system of this place is made of friable, sedimentary extrusive rocks with local, limited groundwater resources and a recharge of 5mm/year.

9. **Nariin sukhait (Huhulzuhiin gobi basin):**

Nariin sukhait basin is included in the Khukhulzukh gobi basin. This basin area is located near the coal mining deposit of Nariin Suhait, where there is a limited groundwater resource productivity in the alluvial- proluvial aquifers and a moderate groundwater resource productivity in the coal-bearing Triassic or Jurassic aquifers. The yield of boreholes is 1-3L/s, with dewatering of water to quarries occurring at a rate of 4-5L/s. In this area more than 70 small or moderate discharge springs are located in the tectonic fault zones with lengths of 100km. Types of aquifer systems in the third basin are lower to moderate productivity, continental-terrigene aquifer of neogene, paleogene and friable, sedimentary extrusive rocks with local, limited groundwater resources. Recharge is 5mm/year. The types of aquifer systems in the third basin have a low to moderate productivity, and are: continental-terrigene aquifers of neogene, paleogene type, and friable, sedimentary extrusive rocks with local limited groundwater resources and recharge of 5mm/year.

10. **Tsagaan bulag:**

The surface water discharge appears only during heavy rain and it is very limited, making it difficult to find the groundwater resources in this basin area. The type of aquifer system in this basin is of low to moderate productivity, and is a continental-terrigene aquifer of neogene andpaleogene. The groundwater recharge is 5-10mm/year.

11. **Khuvdiin bayan burd dry streambed:**

This place is located in the territory of Umnugobi in the province of Gurvan tes soum, in the south-western part of Segstsagaan Bogd Mountain. The peak elevation of this mountain is 2,480m. The coordinates are $42^{o}\ 57^{I}\ 42.2^{II}\ 100^{o}\ 4^{II}\ 46.4^{II}$. Elevation is 1,000-1,500m in this area. The Khuvdiin bayan burd dry streambed has a temporary groundwater flow and an area of 0.4 ha. Subsurface water level is 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The type of aquifer system in this basin is of low to moderate productivity, and is a continental-terrigene aquifer of neogene and paleogene. Groundwater recharge is 5-10mm/year.

13. Dankhan khudgiin dry streambed:

This place is located in the southern part of the Bulgan khoshuunii mountain range of Mongolia and lies south-west of Khatan suudal flange, in the territory of Gobi-Altai province, Erdene soum. Location coordinates are $42^{o}\ 56^{I}\ 47.0^{II}$ $97^{o}\ 30^{I}\ 0.30^{II}$. The average elevation is 1,000-1,500m in this area. The Khatan suudal dry streambed has a temporary groundwater flow and an area of 20-30 ha. Subsurface water levels are 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The type of aquifer system in this basin is lacustrine eoluve, glaciavul aquifer and the groundwater recharge is 5mm/year.

14. Dayshigiin khudag dry streambed:

This place is located in the Nomgon gobi area of Mongolia, south west of the Atas mountain. This mountain has a peak elevation of 2695m. It is also located near the Gashuunii Baruun Mountain, which has a peak elevation of 1457m in territory Gobi-Altai province, Altai soum. South-west is the Atas Mountain with a peak elevation of 2,695m. The Gashuunii Baruun Mountain is also in this territory and has a peak elevation of 1,457m. Location coordinates are $44^{o}\ 30.0^{I}\ 09.91^{II}\ 95^{o}\ 5^{II}30.19^{II}$. The average elevation is 1,000-2,000m in this area. The Khatan suudal dry streambed has a temporary groundwater flow of 50-60 ha. Subsurface water levels are 0.4-2.0m in some areas of the Tooroin grove. The people of this soum use hand wells to supply livestock with water. The type of aquifer system in this basin is friable, sedimentary extrusive rocks with local, limited groundwater resources, lacustrine and lacustrine eoluve, glaciavul aquifers. Groundwater recharge is 5 mm/year.

15. Bulgan River basin:

This aquifer system is located in the south-western part of Mongolia in the valley formed by the Bulgan River. The source of this basin is the southern side of the Mongolian Altai mountain ranges and passes into the territory of the Khovd Province, of Bulgan soum, and turns towards west to contribute to the Chinese Urunguy River and Ulungur Lake. One aquifer consists of alluvial sand, gravel, sandy loam and the other is consisted of extrusive rocks and bedrocks. Test wells drilled for the water supply in to supply the centre of Bulgan sum had yields ranging from 1.3 to 2.7L/s at drawdowns of 16.4 and 1.3m respectively. The thickness of the alluvial deposits varies between 12 and 40m; being 36m on average. The type of aquifer system in this fifth basin are locally highly productive or extensive, lower to moderately productive proluvial and friable, sedimentary extrusive rocks with local, limited groundwater resources. Groundwater recharge is 5mm/year. The type of aquifer systems in this fifth basin are local highly productive or extensive, lower to moderately productive proluvial and friable, sedimentary extrusive rocks with local, limited groundwater resources and a groundwater recharge of 5mm/year.

16. Uureg Lake basin:

This place is located in the southwestern part of the Baruun Tagna mountain ranges of Mongolia in the territory of Uvs province, Sagil soum. Elevation is 2,000-3,000m in this area. The source of the Uureg Lake is the Kharsh River, which originates from the Tsagaan shiveet Mountain. The long-term mean discharge module is 0.5-5 $l/s/km^2$ and surface runoff is 16-158mm in the basin area. The type of aquifer system in this basin is friable, sedimentary extrusive rocks with local, limited groundwater resources and local highly productive or extensive, and low to moderately productive proluvial. The groundwater recharge is 20-50mm/year.

17. Tes River valley:

The Tesiin gol is the primary source of the Uvs Nuur Lake. The Uvs Nuur Lake is the terminal basin for the Uvs Nuur Basin, which covers an area of 71.5km² and represents one of the best-preserved natural steppe landscapes of Eurasia. The border between Mongolia and Russia runs through the northern periphery of the basin. The Tes river valley was formed by the importation of sand and pebble, gravel boulder, sandy loam and clay loam with alluvial and alluvial proluvial deposit origin and sandy loam gravel loam by water, and eolian sands by the wind. In addition sand and rock waste and gravel with deluvial and proluvial origin are located in this basin. The spring transpired in the Tes River basin valley and discharge was 14.7 l/s. The spring flows to the Tes River basin valley and the average discharge is 14.7 l/s. The types of aquifer systems in this basin are local highly productive or extensive, with low to moderately productive proluvial and lacustrine eoluve, glaciavul aquifers. The groundwater recharge is 5mm/year.

18. Delger Big River basin:

the Delger Big River is located in Khuvsgul Province in northern Mongolia. Together with the Ider River, it is one of the sources of the Selenge River. The source of the river is the Ulaan Taiga range close to the Russian border. The main Delger Big River basin has high discharge losses within the basin area due to limestone deposits. Discharge occurs at a relatively higher level than other rivers during the scarce water period in the basin area. Long-term permafrost broadens the basin area. The types of aquifer systems in this basin are lacustrine eoluve, glaciavul aquifer with a low to moderate productivity, continental-terrigene aquifer of neogene, paleogene which are local highly productive or extensive, and low to moderately productive carbonate rocks. Groundwater recharge is 10-20mm/year.

19. Bus River basin:

The Bus River begins at an elevation of 3,000m at the Belchir Mountain and flows past the border areas of Mongolia and Russia to contribute to tributaries of the Shishkhed River near the western part of Khalzan Mountain. This basin area is located in the territory of Khubsugul province in Tsagaan-uul soum. The types of aquifer system in this basin are local highly productive or extensive and low to moderately productive proluvial and carbonate rocks. Groundwater recharge is 50-200mm/year.

20. Shishkhed River basin:

The Shishkhed River begins at the Tsagaan Lake and its tributaries are the Tengis and Ikh Jimst Rivers. Shishkhed River is the source of the Yenisei Big River and begins at the northern side of the Khubsugul Ulaantaiga mountain range. It passes many lakes of Darkhad khotgor. The length of the river is 296km within the territory of Mongolia. Distributed in the Shishkhed river basin are 1) Limited local, highly productive aquifers or extensive aquifers with low to moderate productivity, which are mainly represented by fissured carbonate rocks and coal-bearing terrigenous deposits and 2) Rock with local, limited groundwater resources. There are alluvial sediments of this type in the river valleys of Shishkhed gol. Proluvial sand, gravel and sandy loam with local, limited groundwater resources occur mainly in the groundwater transition zones. The people of Renchinlkhumbe soum of Khubsugul province use groundwater resources for domestic water supply. The aquifer of this groundwater resource is located over the permafrost at the base of the mountain. This aquifer does not freeze in winter because the groundwater flow rates are relatively high. The types of aquifer system in this eighth basin are the Lacustrine eoluve, glaciavul aquifers which arelocally highly productive or extensive, and low to moderately productive carbonate rocks. Groundwater recharge is 50-100mm/year.

21. Zelter River basin:

This place is located in the north-western part of the Buteel mountain ranges of Mongolia in the territory Selenge and province, of Tsagaan nuur soum. The elevation is 1,000m in this area. The source of this river is the Khujir River which starts behind the Buteeliin mountain ranges. The types of aquifer system in this basin are friable, sedimentary extrusive rocks with local, limited groundwater resource. Groundwater recharge is 20-100mm/year.

22. Suhbaatar cavity:

This extensive, very highly productive aquifer is located in the area of confluence of the rivers Orhon and Selenge in the transboundary area between northern Mongolia and Russia. It is cavity shaped and is located in the Selenge River's valley and near the Orkhon River, a tributary of the Selenge River. Paleogene Neogene and Quaternary deposits appear in the basin area. Water storage occurs in the Paleogene Neogene rocks and there is a clay layer dividing the aquifer. The water storage capacity of the alluvial deposits is high. The specific yield of the production well that is located in this basin area is 18 l/s at a 7m

groundwater drawdown. The groundwater quality is fresh and mineralization is 0.2-0.6 g/l. The component of the water is hydro-carbonate calcium magnesium and calcium sodium.

There are two systems for water supply in the town of Suhbaatar (on the boundary between Mongolia and Russia) - centralized and dispersed. Groundwater reserves for the water supply of this town are 7480.5m^3/day in category A and 1728.0 m^3/day in category B. A high discharge (300L/s) spring is located in the transboundary eolian aquifer near Lake Duruu between Mongolia and Russia. The types of aquifer system in this basin are locally highly productive or extensive, and low to moderately productive proluvial, highly productive alluvial aquifer and Lacustrine eoluve, glaciavul. Groundwater recharge is 50-200mm/year.

23. Tsuh River basin:

The Khuder River is one of the main tributaries of the Tsukh River. This river basin is located in the territory of Selenge province, in Khuder soum. The sources of the Tsuh River and Ereen River start at a 2,000m elevation. Other tributaries of the Tsukh River are the Uilga, Khatan, Great Ulelei, Khadantsaa, Ereen and Chagtaa Rivers. Types of aquifer system in this basin are highly productive alluvial aquifer and lacustrine eoluve, glaciavulrivers. The types of aquifers and systems in this basin are highly productive alluvial aquifers, lacustrine eoluve, glaciavul aquifers and local, low to moderately productive aquifers in intrusive rocks. Groundwater recharge is 20-100mm/year.

24. Minj River basin:

The Zakhar River is the main tributary of the Minj River and begins at the Khukh chuluu Mountain of the Baga Khentii mountain ranges. The peak elevation of Zakhar Mountain is 2,309m. Along the Khuder and Minj River valleys sand, gravel with clay layer with quaternary alluvial, and alluvial-proluvial origin is distributed. The types of aquifer systems in this basin are highly productive alluvial aquifers and local highly productive or extensive, or low to moderately productive carbonate rocks. Groundwater recharge is 50-100mm/year.

Possible groundwater resources in the Khuder and Minj River basin area (Dr. G.Tserenjav, 1997. Sc.Dr.N.Jadambaa and Dr. G.Tserenjav, 2001)

No	Basin name	Square	Exploitation resources 10*m^3/year
1	Minj	4916	61.4
2	Huder	5664	70.7

25. Balj River basin:

the Balj River starts from the Onon and Balj mountain ranges and the Khumul, Galttai, Bukhkhun and Khirkhon Rivers are tributaries of the Balj River. The types of aquifer systems in this basin are highly productive alluvial aquifers and local highly productive or extensive low to moderately productive carbonate rocks. Groundwater recharge is 50-100mm/year.

26. Onon River basin:

the Onon gol is a river in Mongolia and Russia with a length of 818 km length and a watershed area of 94,010 km². It originates at the eastern slope of the Khentii Mountains. The boundary of this river basin is included in the territories of Mongolia and Russia. It flows for 298 km and 29,070has 29070 km² of its basin is within Mongolia. Its confluence with the Ingoda River produces the Shilka River. The Mongolian portion of this river basin has relatively abundant groundwater resources and surface water resources. The majority of groundwater resources accumulate in the water storage formations of alluvial deposit in the river valley. The types of aquifer systems in this basin are highly productive alluvial aquifers and local highly productive or extensive, and low to moderately productive carbonate rocks. Groundwater recharge is 10-20mm/year.

27. Duch River basin:

the Duch River starts in the north-western part of the Lun Mountain and its peak elevation is 1,218m. Duch River is one of the main tributaries of the Ulz River. The types of aquifer systems in this basin are: highly productive alluvial aquifers and low to moderately productive, continental-terrigene aquifers of the neogene, paleogene. Groundwater recharge is 5-10mm/year.

28. Ulz River basin:

The sources of the Ulz River begin in the territory of Norvilon soum, of the Khentii province and flow over the Mongolian border form a tributary to the Tooroi Lake in Russia. This lake is involved with the outward flow to Mongolia's northern hydrogeological system. The Ulz River flows to the Russian border and contributes to the Tari Lake by manner of direct and diffuse flows. The total catchment area of Ulz River is 6,120km^2; and 5088km^2 of this area is located in Mongolia. The types of aquifer system in this basin are low to moderately productive, continental-terrigene aquifers of neogene, paleogene. Groundwater recharge is 5-20mm/year.

29. Kherlen River basin:

The Kherlen River basin's north-eastern boundary of groundwater is at the Onon Big River. The border of the Kherlen River's catchment area passes is on the peak of the eastern branch of mountains of the Khentii mountain ranges and extends to the border of China. The people of Dornod province use these groundwater resources to supply Dornod city with urban water. These groundwater resources are distributed in the porous water storage formation of alluvial deposits which are located on the southern terrace and flood plain zone of the Khrerlen River basin.

In the valley of Herlen gol, near the town of Choibalsan, there are twelve wells which have yields of between 8 and 50 l/s at a drawdown of 1-6m. The simultaneous pumping of four production wells produced a total yield of 157 l/s at a drawdown of between 3.6 and 4.8m. The other transboundary aquifers are arranged in river valleys on the north western plains of Mongolia. They consist of alluvial sand, gravel, lenses of sandy loam and clay, as well as permafrost deposits. The Kherlen River is a tributary of the Dalai Lakein China. The types of aquifer systems in this basin are: highly productive alluvial aquifers and local highly productive or extensive, low to moderately productive proluvial. Groundwater recharge is 50-200mm/year.

30. Khalkh gol River basin:

the source of the Khalkh gol River is the Numrug River which begins at the northern part of the Modtoi khamar mountain. This mountain has a peak elevation of 1,290m. One of the main tributaries of the Khalkh gol River begins in China. The total catchment area is 11,755km^2 and 7,440km^2 of this catchment area is located in Mongolia. The Khalkh gol River basin infuses shallow groundwater resources to the Buir Lake and residual deeper flow discharges to the Buir Lake. Deeper parts of the groundwater resources flow past the Dalai Lake to the Amur River where it becomes part of the Pacific Ocean basin. The types of aquifer system in this basin are: highly productive alluvial aquifers, lacustrine eoluve, glaciavul aquifers and aquifers with low to moderate productivity, and continental-terrigene aquifers of neogene and paleogene. Groundwater recharge is 5-10mm/year.

References

Hydro-geological map of Mongolia at scale 1:12 000 000, ÓÁ, 2006

Hydrogeological reports for 1976-2001yy. Geo-information Centre.

Groundwater Assessment in the Gobi Region of Mongolia Final Draft Report 25/01/2009

Groundwater map of Mongolia at scale 1:2500 000, Ministry of Nature and Environment of Mongolia and Institute of Meteorology and Hydrology, ÓÁ, 2006

Janchivdorj. L, Odontsetseg. D, 2005, Water Resources of Mongolia –Utilization and Management Challenges, International Symposium of the Association of Academies of Sciences in Asia on Science and Technology of Water, October 2005, Seoul, Korea

Tsevegmed, N., 1965, Physical Geography of Mongolia, UB

Ministry of Water Husbandry, 1975, General scheme-map for the complex utilization of water resources Mongolia and its protection, Volume-IV, UB,

Mongolian Academy of Sciences, 1986, General scheme-map for the complex utilization of water resources of Selenge River basin and its protection, UB

Jadambaa N., 2007, Groundwater Resources of Mongolia and its Regularity 2007, Mongolian Academy of Sciences, UB

Mongolian Academy of Sciences 1986, General scheme-map for the complex utilization of water resources of small rivers basin of north part of the Gobi region and its protection, Volume-1, UB

6.6. IWRM: Managing the Groundwater Component in Malaysia

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ABSTRACT

Integrated Water Resources Management (IWRM) is a participatory planning and implementation process which provides the mechanism for decision makers to determine how to meet society's long-term needs for water while maintaining essential ecological services and economic benefits. It is the process of balancing the demand for water with the constraints of the resource by promoting sustainable development, protecting the environment and fostering economic growth. Groundwater is an integral part of the IWRM.

Malaysia is rich in water resources and receives an average annual rainfall of 3000mm. Water resources development has been the basis of the socio-economic development of the country over the past decades. Population growth, the expansion of urbanisation, industrialisation and irrigated agriculture, and climate change are imposing rapidly growing demands and pressures on Malaysia's water resources. Water management is becoming increasingly complicated due to the concentration of populations in urban areas, commercial activities, the growth of industries around the cities and towns. These factors are leading to increasing water consumption, increasing water pollution, and increasing land use conflicts.

In Malaysia, because of the omnipresence of surface waters and the efficiency of the authority in providing public water supply, groundwater is widely undervalued, inefficiently extracted and inadequately protected. However, the increasing demand for water due to the expansion of urban populations, and industrial and agricultural sectors has increased the need for groundwater as a supplemental water source. The increased demand for, and use of, groundwater resources requires proper assessment, planning, development and sustainable management.

The best approach in ensuring a sustainable national water sector through the development of groundwater should be through the implementation of sound water policy and management practices. Sustainable water management could be accomplished through the conjunctive use of surface and groundwater. Conjunctive use is an effective tool for increasing the overall water supply. Monitoring and evaluation must also be undertaken to ensure that future groundwater issues are not overlooked or misunderstood.

Maintaining the delicate and sustainable balance of demand and supply of water is a critical element of any sound water management strategy.

6.6.1. INTRODUCTION

Integrated Water Resources Management (IWRM) is a participatory planning and implementation process which provides the opportunity to meet society's long-term needs for water while maintaining essential ecological services and economic benefits. It is the process of balancing the demand for water with the constraints of the resource by promoting sustainable development, protecting the environment, promoting democratic participation, improving human health and fostering economic growth. Worldwide, water policy and management are beginning to reflect the fundamentally interconnected nature of hydrological resources, and integrated water resources management is emerging as an accepted alternative to the sector-by-sector, top-down management style that has dominated in the past (USAID, 2004).

Since the readily available surface water resources are being depleted, the costs of development are increasing over time, and projects are often faced with strong opposition from environmentalists, the efficient development of water resources requires forward planning based on an assessment of long term needs and the sustainability of the environment. The direct issues facing the national water sector are: water availability, water supply and water pollution. The indirect issues are: floods and other water related hazards such as landslides and land subsidence. Both direct and indirect issues need to be addressed in a comprehensive manner in order to achieve a sustainable national water sector. It could be undertaken through IWRM. This paper gives an overview of the sustainable development of water resources in Malaysia while focusing on the role of groundwater in terms of water availability and improving the national water supply sector.

Although groundwater has been utilised since early historic times, humans have paid more attention to the visible sources of flowing and standing waters in the form of rivers and lakes. In addition to being 'out-of-sight and out-of-mind', groundwater is generally harder to put to use than surface water. Groundwater is present under every point of the land’s surface, although it is not always available in adequate quantities, or in a form or depth suitable for use. In many countries, groundwater is a key natural resource supporting economic and social development. However, in Malaysia, the presence of perennial rivers and the abundance of rainfall have meant that surface water resources have been exploited, leaving the groundwater systems relatively 'untouched'. Less than two per cent of the national water use originates from groundwater resources. The use of groundwater for domestic purposes is mainly confined to rural areas where there is no piped water supply, and where groundwater is abstracted from dug wells and well points. In Kelantan, large capacity municipal wells exist which provide 70% of the public water supply in the form of groundwater. Other states that have developed groundwater on a limited scale for public water supply are: Pahang (Nenasi), Selangor (Olak Lempit), Perlis (Arau) and Sarawak (Miri).

Despite the generally abundant quantities of surface water available to meet demand, water shortages have occurred fairly frequently in Malaysia. The reasons behind these water shortages have been numerous and complex but they give weight to the argument in favour of utilising groundwater resources to augment surface water supplies during these periods.

Integration between the use of surface water and groundwater is needed to ensure the sustainable utilisation of the both water resources. Groundwater is definitely capable of playing a bigger role in supplementing the water requirements of the country.

The National Water Resources Council (NWRC) initiated the formulation of a National Water Policy (NWP) and became a mechanism for Federal-State Government cooperation on water related matters. The NWRC acts as the central body responsible for co-ordinating the planning, development and management of water resources and water supply in the country. The formation of the NWRC represents a major step forward in overcoming the problems associated with the fragmentation of water related institutions and activities, in particular, the tendency towards the development of the same water source for different uses within an interdependent system.

6.6.2. GROUNDWATER RESOURCES

6.6.2.1 Introduction

The presence of plentiful perennial rivers and the abundance of rainfall in Malaysia have meant that surface water resources have been exploited, leaving the groundwater systems relatively ‘untouched’. One of the reasons for lack of groundwater development in Malaysia is the failure to recognise the vast potential of this ‘invisible’ water resource.

Currently, groundwater is only being significantly utilised for public water supply in Kelantan and Perlis. Other states which supplement their water supply with groundwater are Terengganu, Pahang, Sarawak and Sabah. In Kelantan, about 70% of the total water supply in the state is derived from groundwater, primarily in the Kota Bharu areas. However, rural population depends very much on groundwater for their daily requirements by obtaining it from shallow dug wells.

Less than 2% of the present water use in Malaysia is derived from groundwater resources. The use of groundwater for domestic purposes is mainly confined to rural areas, where there is no piped water supply. However, in Kelantan, groundwater plays very important role in supplying more than 70% of the public water supply system.

The increasing demand for water has increased the need for a more systematic and sustainable exploitation of groundwater. Demand comes from:

- rapid increases in population growth
- industrial or agricultural expansion
- deterioration in the quality of surface waters, and
- low flow of surface sources during prolonged periods of drought.

There are a number of the reasons for the lacking of extensive groundwater development in Malaysia:

- the failure to recognise the vast potential of the groundwater resources
- the misconception that groundwater exploitation is not sustainable
- the lack of full assessment of groundwater resources
- the lack of local expertise in the field of groundwater
- the lack of groundwater awareness.

An awareness of the interdependence between surface and groundwater is therefore and essential element towards resolving water resources issues and it will promote a far less fragmented approach towards establishing integrated water resources planning, development and management.

‘The fundamental importance of water of an acceptable quality as a primary resource has long been recognised, but the economic advantages of groundwater over surface water in many situations still have to be put across to politicians, administrators and water engineers alike: none of us must miss an opportunity to do just that’ (Llamas, et al., 1992).

6.6.2.2 Groundwater resource utilisation in Malaysia

In Malaysia, groundwater accounts for more than 90% of the freshwater resources. The total water available for use could be approximated as the sum of 10% of the surface runoff and the volume of groundwater recharge. Table 1 shows the summary of the water resources in Malaysia.

Table 1. Water resources in Malaysia (after Azuhan, 1999)

Water resources	**Quantity (billion m^3)**
Annual rainfall	990
Surface runoff	566
Evapotranspiration	360
Groundwater recharge	64
Surface artificial storage	25
Groundwater storage	5000

The development of groundwater resources for water supply to cater for overall needs (immediate, emergencies and future) should be carried out in orderly manner with proper policies and strategies in place. The main potential uses for groundwater are:

·Potable water supply
·Industrial use, and
·Irrigation water.

6.6.2.3 Current trends

6.6.2.3.1 Peninsular Malaysia

At present about 60% of the groundwater exploited is for domestic use, 35% for industrial use and 5% for agricultural use. Areas where groundwater is abstracted or has been previously abstracted for domestic purposes include Kota Bharu (100,000m^3/day), Kuala Terengganu (16,000m^3/day), Arau (6,000m^3/day), Sg. Ular, Pahang (5,000m^3/day), Rompin (2,000m^3/day) and some small areas in Pahang, Kedah and Langkawi.

For industrial purposes, groundwater is mainly utilised for cleaning, washing and cooling. Major industrial areas such as Shah Alam and Bukit Raja in Kelang use groundwater substantially for their operations. Groundwater utilisation for agricultural purposes is not very well developed and it is normally confined to isolated agricultural areas or areas outside the main irrigation schemes. Nevertheless, groundwater is being extensively used by the Agricultural Commodities Centre in Rhu Tapai, Terengganu, and in aquaculture farm in Pekan, Pahang.

6.6.2.3.2 Sarawak

Groundwater may be tapped from the alluvial aquifer (sand and gravel) or hard rock aquifers (sedimentary rocks or limestone) as shown by Figure 1. underlain extensively by alluvial materials of sand, gravel and clay. In some coastal plains and inland valleys, peat distribution is significant and groundwater has also been abstracted from these areas. In Miri, groundwater has been utilised significantly from wells in the sandstone to supplement the public water supply. Groundwater may be tapped from various aquifers (Figure 2).

6.6.2.3.3 Sabah (and Labuan)

In comparison to Peninsular Malaysia and Sarawak, groundwater development in Sabah has so far been insignificant. The main abstraction of groundwater is from shallow dug wells in villages; however, tube wells have been constructed to exploit the groundwater resources in Sandakan and Labuan. Groundwater may be tapped from various rock formations (Figure 3).

Figure 1: Simplified Hydrogeological Map of Peninsular Malaysia

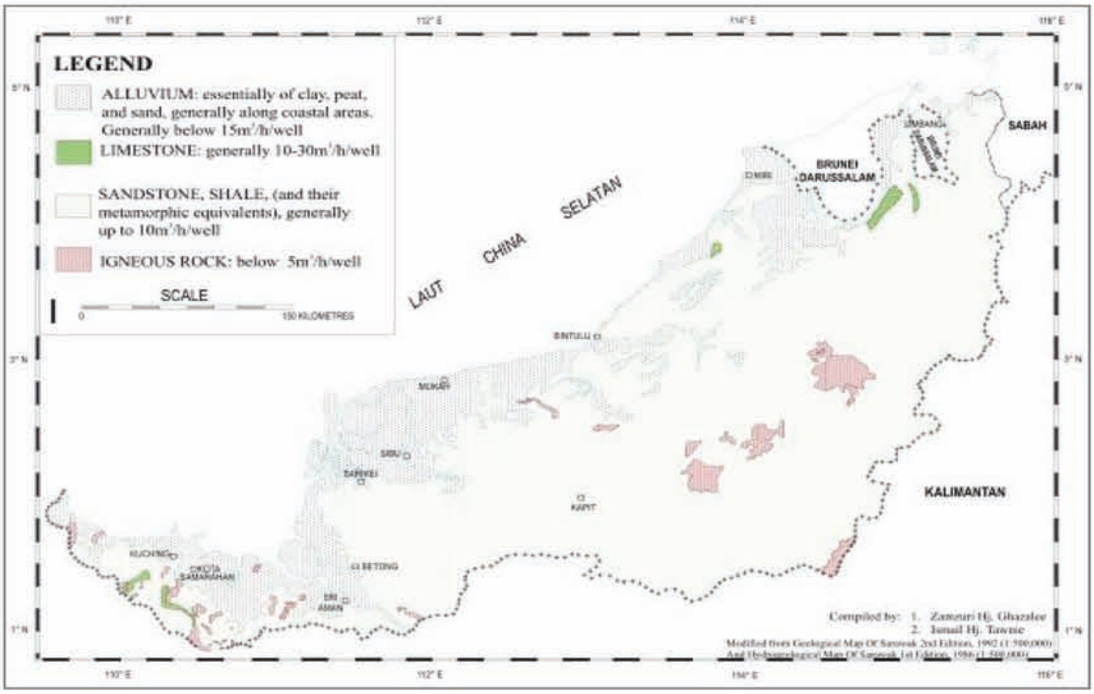

Figure 2: Simplified Hydrogeological Map of Sarawak

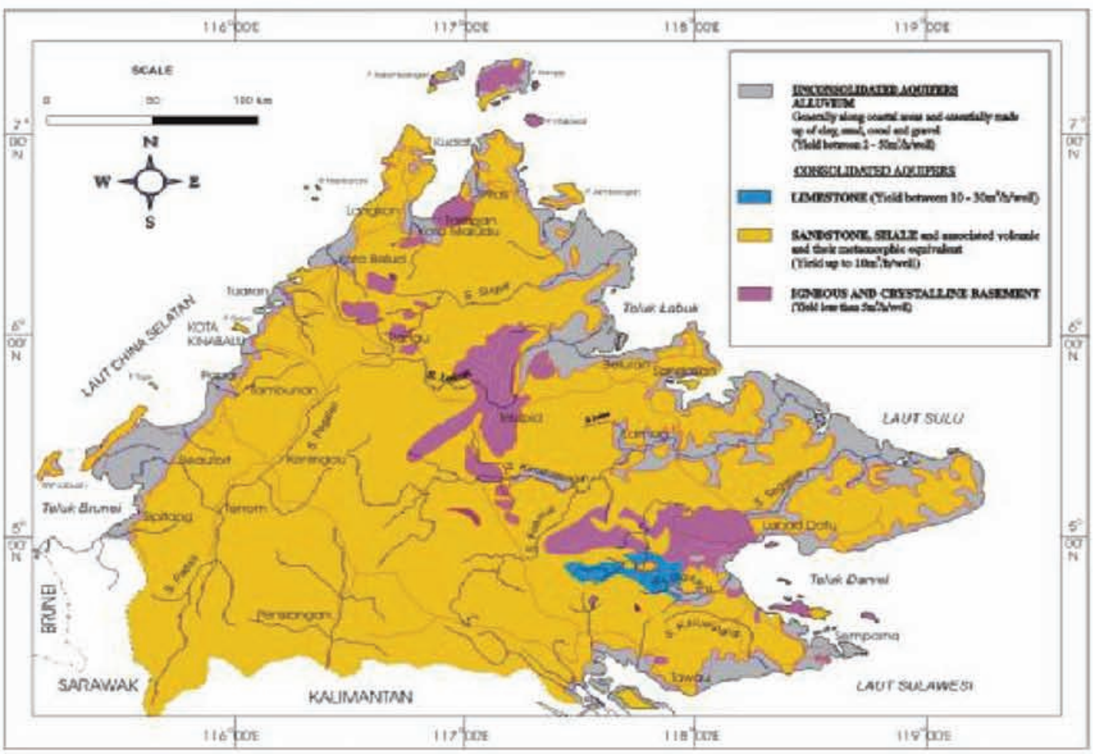

Figure 3: Simplified Hydrogeological Map of Sabah

6.6.2.4 Transboundary Aquifers of Malaysia

Transboundary aquifers add another layer of complexity to the management of groundwater resources in Malaysia as joint management and sharing arrangements may be required in some areas. Transboundary aquifers exist between Malaysia and Thailand, Indonesia and Brunei.

The aquifers between Malaysia and Thailand predominantly occur in the peninsular Malaysian area and both countries are currently extracting water from these aquifers. The north-east boundary has alluvial aquifers and the north-west boundary has limestone aquifers.

Due to fairly limited transboundary hydrogeological studies in Malaysia to date, we can only speculate on the extent of transboundary aquifers in other areas. There is the possibility of the existence of transboundary aquifers between Malaysia, Brunei and Indonesian Borneo (Sabah and Sarawak). The Sabah map, in Figure 3 above, shows that transboundary aquifers may occur between Kalimantan (these aquifers have predominantly sandstones and shale formations) and Sarawak (these aquifers have alluvium and sandstone/shale formations). The Sarawak map, in Figure 2 above, shows that transboundary aquifers can be found between Malaysia and Brunei (these aquifers have limestone formations), and Malaysia and Kalimantan (these aquifers have fractured rock structures with igneous/sandstone/shale formations). Work will be undertaken in the near future on a comprehensive inventory of these aquifers.

6.6.2.5 Policies

Policy 1: Holistic Approach on Water Resources

Groundwater in Malaysia is often not appropriately evaluated. A more holistic approach should be designed to manage the water resources of the country. It should include overcoming the imbalance between the exploitation of surface water and groundwater. The National Economic Action Council (1998) created a National Economic Recovery Plan which identified groundwater as a resource that had a great potential for development. The time has come for geologists, engineers, other scientists, managers, planners and policy makers to develop a strong awareness of the importance of groundwater, the invisible resource, for the country's development.

There are advantages of groundwater over surface water resources:

- Its supplies are not subject to abrupt change as a result of abnormal weather
- It is cheaper to develop: unpolluted, no or less treatment before use and developed stage by stage, and
- It can often be easily tapped near to where it is needed.

However, groundwater is not always the best available source and has some disadvantages:

- It is often too hard to find in difficult geological environment
- It may not occur in sufficient quantities (or have sufficient quality) for the intended use, and
- It may occur too deep to make development economically viable.

Policy 2: Sustainable Utilisation

Due to the prevalence of surface water, groundwater is widely under-appreciated, under-exploited, and possibly also inadequately protected. Groundwater is usually only considered in areas where surface water resources have been exhausted.

There is a need for improved management of the water resources in the country and for emphasis to be placed upon utilising groundwater where it is available. With the development program for urban and rural water supply, groundwater is likely to play an increasingly important role as either a supplementary or alternative water supply.

Policy 3: Legislation on protection and over-abstraction of groundwater

Stringent enforcement should be undertaken to regulate the development and management of the groundwater resource to ensure optimal utilisation and to prevent occurrence of adverse effects due to over-abstraction. The jurisdictions of these laws, which can be broadly classified as Federal or State laws, should cover areas ranging from river/water management, water-use, water pollution abatement to land matters, landuse control and land conservation. However, amendment of these Federal or State laws is extremely important in providing protection for groundwater resources. Probably the Groundwater Management Act is also required to meet the management goals.

Protecting groundwater resources by:

- Controlling groundwater abstraction through legal and administrative steps, followed by licensing requirements, and
- Controlling groundwater pollution through creation of source protection zones and vulnerability mapping.

Policy 4: Jurisdictional streamlining

The policy issues get more complicated as more agencies become involved in the management of groundwater resources. The main government agencies involved in groundwater-related activities are the JMG, PWD, DID, Water Supply Department and Ministry of Health (MOH). JMG has always been the lead agency to undertake the exploration, evaluation and development of groundwater sources in Malaysia. It also acts as a central databank for groundwater data obtained by the government and/or the private sector. Legislative responsibility for the management and protection of groundwater resources, on the other hand, falls to the State Authority. Greater cooperation among these agencies is crucial to ensure the sustainable management of the resource.

6.6.2.6 Sustainable development

A distinct feature of groundwater availability is its high variability, being governed primarily by the geological structure of an area. The development of groundwater requires quantification of groundwater availability, which is achieved through detailed subsurface investigation and on-site testing. Under favourable conditions, groundwater can be developed as it is needed through the addition of wells, and it can often be developed at the point of use. Good design practices and suitable drilling methods, coupled with proper operation and maintenance procedures, can ensure peak performance of groundwater abstraction systems. The development and management of groundwater resources should be based upon best-practice scientific methods in order to avoid disastrous effects. The supply of water to the domestic and industrial sectors by an orderly and rational use of groundwater can contribute towards the sustainable socio-economic development of the nation.

The sustainable development and use of groundwater must take place within the broader context of integrated water resources management. As a pre-condition to effective groundwater management, a full assessment of all water resources should be conducted. This requires the consideration of both groundwater quality and quantity and must take into account the interconnection between groundwater and surface water systems.

6.6.2.7 Action Plans

Basically there are a number of common regulations and actions for sustainable groundwater utilisation. Immediate actions that need to be undertaken are:

- Understanding the resources
- Collection of comprehensive groundwater data
- Setting groundwater quality standards
- Control of extraction
- Groundwater monitoring
- Identification and control of sources of pollution
- Establishment of protection areas, and
- Enforcement of standards and regulations.

6.6.3. DISCUSSIONS

Groundwater vulnerability mapping helps in identifying the vulnerability of groundwater to pollution. Preparation of groundwater vulnerability maps may combine geology maps, land-use maps, groundwater quality data and contamination sources, and may hence help in planning for the protection of the resource. GIS is a common tool used to help manage the resource.

There is a need for better management of water resources in Malaysia and for more emphasis to be placed on utilising groundwater where available. The existing and future groundwater-based supplies, in both urban and rural areas, should be sustainable. There is a growing need to regulate land-use and control groundwater extraction. This requires the development of institutions with the necessary powers and resources for the creation, coordination and implementation of a comprehensive water resources strategy, policies and action plans.

Drought is a recurring climatic condition affecting many areas in the country and surface water resources are the first to be affected. The wise use of groundwater resources can play a significant role in reducing the impact of drought in both urban and rural environments. This could be achieved through the conjunctive use of surface and groundwater resources. The use of groundwater resources will improve the sustainability of the national water supply sector. The management of water resources to cater for current and future needs and for emergencies should be carried out under properly developed policies and strategies. The conjunctive use of surface water and groundwater (Figure 4) could be one of the important management options to utilise both resources more efficiently.

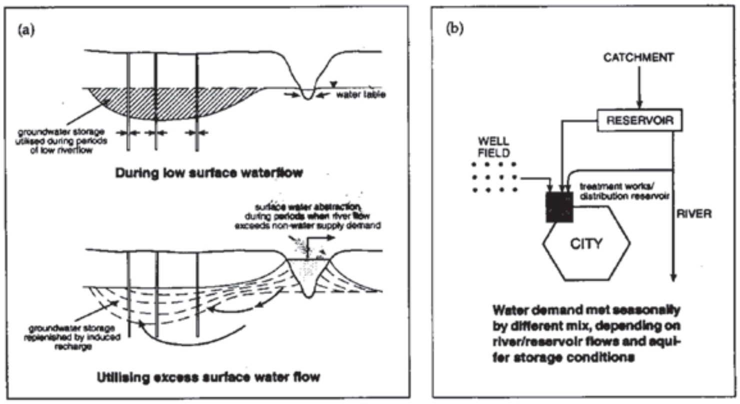

Figure 4: Schematics of conjunctive use in (a) hydraulically connected systems, and (b) hydraulically unconnected systems

Azuhan (2002) discussed the issues of short- and long-term management options which are given in Table 2. The importance of incorporation of the protection of groundwater in landuse planning is very vital in ensuring the sustainability of the resource.

Table 2. Management options (after Azuhan, 2002)

Issue	Short term option	Long term option
Groundwater balance	Monitor abstraction and water levels	Restrict well locations Education and promotion (E & P)
Local drawdown	Education Controls on well location, construction and development	Increase well separation, specify minimum depths and reduce allocations
Cumulative drawdown	Reduce allocation rates and volumes Set environmental trigger levels Monitor abstraction and water levels	Reduce allocation and depth of wells Seasonal allocations Environmental trigger levels E & P
Efficient use	Monitoring, E & P	Monitoring, E & P Restrictions on use Transferable water permits Water charges Efficient abstraction and use specification
Saltwater intrusion and stream flows	Further research Monitor stream flows and coastal wells	Augmentation Increased restrictions Advocacy
Land subsidence	Monitoring, E & P Controls on well location, construction and development	Restrict well locations E & P Specify well construction and completion
Pollution risk	Monitoring Controls on well location and abandonment, and abstraction rate	Monitoring Land use zoning Aquifer protection, remediation and rehabilitation

6.6.4. CONCLUSIONS

Water resources development and management support and promote socio-economic growth. The management of water resources to cater for current and future needs, and for emergencies, should be carried out under properly developed policies and strategies. It is important that long-term strategies and action plans are developed through an integrated and consultative approach involving the relevant authorities at all levels, in partnership with the general public and other stakeholders. Water is everybody's business.

Sustainable water resources management depends on continuous water resources assessment whereby sufficient information is continuously collected as new issues emerged. The complexity of many water-related issues poses a major challenge to policy makers, planners, water professionals and others who are directly or indirectly involved in the planning, development and management of water resources. Water supply management is still required, but increased attention must be given to water demand management practices. Sustainable socio-economic, water and catchment management planning is achieved through partnerships, not simply by enacting legislation, and should be practised within the context of integrated water resources management.

The status of groundwater needs to be raised commensurate with its importance as a strategic resource. The authority should target groundwater development in isolated areas where development levels are low or where local surface water resources have been exhausted (for example on islands and in highly-developed areas). There is also a need to develop a strategic initiative that enhances awareness at political, policy and local levels of the importance of groundwater resources, the significance of emerging problems and practical responses available to address such problems.

It is also important that the various aspects of groundwater promotion are carefully balanced so that groundwater use is not increased to the detriment of the resource. The sustainable development of groundwater resources must take place within the broader context of integrated water resources management. This requires the protection of groundwater quality and quantity and considers the interaction between aquifers and surface water systems. As a precondition to effective ground water management, a full assessment of water resources should be conducted and the sustainability of groundwater development should address the sustainability of the system, not just the groundwater resource, but the running streams, wetlands and all the plants and animals that depend on it.

7. International Law of Transboundary Aquifers: Aims and its Strategies@

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Mr. Chairman, Distinguished Participants

It is indeed an honour for me to be given this opportunity to speak to you on the efforts of the United Nations to establish an international legal regime for the appropriate management of the transboundary aquifers. I understand that most of you are scientific or administrative experts on groundwater. I am a lawyer myself but will try my best to communicate to you in understandable language. I will explain the UN DRAFT ARTICLES OF THE LAW OF TRANSBOUNDARY AQUIFERS with the use of the power point presentation.

1. In order to secure justice and order and to settle any dispute among States by peaceful means, it is essential to establish the "rule of law" in the world society. Such law is the international law, the sources of which are treaties and customary international law. The treaties bind their State parties. The customary international law is defined as "international custom, as evidence of a general practice accepted as law" in Article 38 of the Statute of the International Court of Justice. It binds all the States of the international community. In the absence of a world legislature, the international law has largely developed as customary law. However, it is sometimes difficult to define what the customary rules are and there also often exist differences of interpretation of such rules among States. Furthermore there exist many lacunae in customary law as they are not systemized. In order to remove ambiguity, there have been efforts for the restatement of existing customary rules to be agreed upon by States. This process is referred to as the codification of international law. The Charter of the United Nations, in Article 13, 1(a), provides that it is one of the important functions of the UN General Assembly to promote the codification of international law.

2. The UN International Law Commission (hereafter referred to as ILC) was established in 1947 as a subsidiary organ of the UN General Assembly whose mandate is to prepare the basic documents in the form of draft articles for such codification. The ILC consists of 34 members who have competence of international law and are elected by the UN General Assembly, bearing in mind that in the ILC as a whole representation of the main forms of civilization and of the principal legal systems of the world should be assured. The United Nations has so far adopted many important codification treaties on the basis of the works of the ILC in such fields as Diplomatic and Consular Relations, Law of Treaties, Law of the Sea and Jurisdictional Immunity.

@ From the author's presentation at UNESCO Chair Workshop on International Strategy for Sustainable Groundwater Management: Transboundary Aquifers and Integrated Watershed Management, University of Tsukuba, Tsukuba City, Japan, 6 October, 2009

The draft articles are reproduced in the ANNEX.

3. With respect to the waters, the world community was deeply involved in developing international law on the ocean which covers 70% of the surface of the earth and we now have the comprehensive law in the form of the UN Convention on the Law of the Sea. As for freshwaters, the Rhine and the Danube were subject to international regulations as early as the beginning of the 19th Century for free navigation. However, the first time the United Nations dealt with transboundary freshwater resources was when it instructed the ILC in 1970 to take up the study of the law of the non-navigational uses of international watercourses. Since the mid-20th century, large projects have been undertaken in various parts of the world for construction of dams and other activities on the international rivers for the purposes of drinking, power generation, irrigation and others and they have posed the threat to cause adverse effects upon downstream States. To regulate these activities and to preserve international surface waters, the United Nations adopted in 1997 the Convention on the Law of the Non-Navigational Uses of International Watercourses on the basis of the work of the ILC.

4. While that convention covers theoretically such groundwater as are physically linked to the international surface waters, it meant to regulate essentially the surface waters. In the preparation of that convention, the ILC did discuss the question of whether to include groundwater in the project. Though it recognized the need to deal with the groundwater, it decided that a separate study is required for that purpose. Meanwhile, the United Nations became aware of the rapidly expanding exploitation of groundwater for portal, industrial and irrigation uses in both developed and developing countries and of the resulting critical overexploitation and pollution problems.

5. Accordingly, the United Nations instructed the ILC in 2001 to proceed with the work on "Shared Natural Resources" which were generally understood to include groundwater, oil and natural gas. The ILC embarked on the work in 2002, appointing me as its Special Rapporteur of this new topic. Though there exist many similarities between the groundwater on one hand and oil and natural gas on the other, there are also much dissimilarity between them. Upon my recommendation, the ILC chose to adopt the step by step approach by embarking first on the work on groundwater as the follow up of the 1997 convention on international watercourses. However, the codification work on the law of transboundary aquifers required multi-disciplinary process. As stated before, the ILC is the body composed solely of lawyers of public international law. It does not possess scientific and technical knowledge of groundwater and expertise for proper management of these aquifers. The United Nations Educational, Scientific and Cultural Organization (UNESCO), the coordinating agency of the UN organizations on the world water issue, mobilized a team of groundwater scientists, administrators and water lawyers to assist the ILC. Without their untiring and valuable support, the ILC would not have been able to formulate the draft articles.

6. It might be too obvious for you scientists but I would like to mention some scientific factors on which the lawyers built up the legal regime. The freshwater is the life supporting resource for which no alternative resources exist. The groundwater is of high quality and nourishing. The groundwater exists in most parts of the world and many of them are transboundary. They are fragile and particular care is necessary not to pollute. There exist many kinds of activities in addition to utilization of aquifers which would adversely affect the neighbouring States through transboundary aquifers. The ILC found ample State practices and almost 400 relevant treaties, general, regional and bilateral, on the basis of which customary rules could be identified. The States have also shown keen interests in the ILC's work as aquifers exist in almost all States and the overwhelming majority of States possesst

ransboundary aquifers with their neighbouring States. Those States transmitted their valuable inputs and observations to the ILC.

7. Taking into account the advices of experts and observations from governments, the ILC formulated a final set of 19 draft articles on the law of transboundary aquifers in 2008. It is recalled that the ILC took 24 years to complete the formulation of draft articles on the law of the non-navigational uses of international watercourses. It was rather a rare case for the ILC that the codification work on transboundary aquifers was completed in such a short period of 6 years. It shows that the ILC was fully aware of the current critical situation of groundwater and of the urgent need to establish legal framework for proper management of transboundary aquifers in order to achieve the objectives of equitable and reasonable utilization, protection of environment and international cooperation.

8. The UN General Assembly received the draft articles favourably. It recognized that the draft articles are not only scientifically and technically sound but also they incorporate the positions of the majority of the member States of the United Nations. It adopted the resolution 63/124 entitled “the Law of transboundary aquifers” by consensus on December 11, 2008. The copy of the resolution is also included in the ANNEX for your reference. The resolution took note of the draft articles the text of which is annexed to it. It encouraged the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of the draft articles. It further decided to include in the provisional agenda of its 66th session in 2011 an item entitled “the Law of transboundary aquifers” with a view to examining, inter alia, the question of the form that might be given to the draft articles.

9. The salient points of the draft articles are as follows;

(1) Article 1 Scope

The scope of the application of the draft articles is (a) utilization of transboundary aquifer, (b) other activities that have or are likely to have an impact upon such aquifers and (c) measures for the protection, preservation and management of such aquifers. The concept of the paragraph (b) was not included in the case of 1997 watercourses convention. In the case of aquifers, activities other than utilization above them such as those causing pollution to the aquifers or harmful to normal functioning of aquifers by blocking or destroying geological formation of the aquifers must be regulated. I might mention here that Kyoto has the huge aquifers underneath which supported the city as our old capital for one thousand years. The people there who lived on these aquifers found the lowering of the water table in 1960’s. It was thought that the decline was partly due to the construction of subway networks.

(2) Article 2 Definition

There are various ways of defining aquifers. The definition of aquifer adopted here is for the purpose of applying the draft articles. It is in a sense a legal fiction. Aquifer means both a geological formation which serves as a container and the water contained in the saturated zone of the formation. Recharging and discharging zones and outlets are outside the aquifers. It is necessary to include the geological formation in the definition of aquifer in order to preserve proper functioning of aquifer. It is also necessary to include the geological formation in order to regulate its utilization such as storage, disposal of waste or a new experimental technique for carbon dioxide sequestration.

(3) Article 4 Equitable and Reasonable Utilization

One of the essential principles is equitable and reasonable utilization of aquifers. Factors relevant to such equitable and reasonable utilization are listed in Article 5. The principle of equitable utilization among the States sharing the same resources is identical as is in the case of the 1997 international watercourses convention. However the principle of reasonable utilization, though the same term is used, is quite different here. The principle of sustainable utilization can apply only to renewable resources. International law has developed the precise legal concept of sustainability in relation to marine living resources. You find the principle of the sustainable utilization in almost all the fisheries conventions. This principle is clearly defined as "to take measures, on the best scientific evidence, to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield (MSY)" in Article 119, 1 (a) of the UN Convention on the Law of the Sea (UNCLOS). What it means is to maintain the size of the population of a particular stock of fish that can produce the maximum catches year after year. Science tells us that such a level is somewhat below the maximum population of a particular fish stock which the nature can afford to hold. Now this principle could be applied to other renewable resources. The 1997 international watercourses convention applied this principle and defined it as "optimal and sustainable" utilization in its Article 5, 1. It meant that the watercourse States are obliged to limit the amount of use of water to that of recharge and keep the river flowing permanently. When we learnt the dynamics of aquifers, it became clear that this sustainability principle could not apply to both recharging and non-recharging aquifers. For non-recharging aquifers, there is no room whatsoever to apply this principle as any utilization would lead to depletion of the resources. Even for recharging aquifers, recharge is, in most cases, just a fraction of the large volume of waters accumulated over hundred and thousand years and States could not be deprived of the use of such accumulated resources while the States of non-recharging aquifers were free to use them. Accordingly Article 4 does not refer to sustainability at all and provides only for a recharging aquifer that a recharging aquifer shall not be utilized at a level that would prevent continuance of its effective functioning. Meanwhile, however, the term "sustainability" has become a sort of catch phrase for many environmentalists. Taking into account their positions, the term "sustainable development" is inserted in Article 7, General Obligation to Cooperate.

(4) Article 6 Obligation not to Cause Significant Harm

Another important principle is the obligation not to cause significant harm to other States. This is the cardinal principle of international law. This principle applies not only to adverse effect to other States caused by utilization of transboundary aquifers but also to adverse effect through transboundary aquifers to other States caused by activities other than utilization. Utilization of aquifers and other activities are activities necessary for the society and accordingly could not be prohibited. Other States therefore have obligation to bear certain harm unless such harm does not go beyond the level of significant harm. The concept of "significant" is relative and could not be defined in abstract. However, in view of fragility of aquifers and difficulty of removing pollutants from aquifers once affected, the threshold of "significant" would be much lower than in the case of surface waters.

(5) Article 7 International Cooperation

Yet another important principle is the international cooperation. The key to the proper management of aquifers is the international cooperation among aquifer States. The draft articles provide various measures beginning from regular exchange of data and information, monitoring and establishment of joint management mechanism. As the ILC meets in Geneva, it has been briefed by Franco-Swiss Genevois Aquifer Authority. This French-Swiss cooperation is one of the most successful joint mechanisms. There is also an article which provides consultation procedure for a planned activity which may affect a transboundary aquifer and thereby may have a significant adverse effect upon another State.

(6) Article 16 Technical Cooperation with Developing States

The draft articles also regulate non-aquifer States. In particular, all States are required to promote technical cooperation with developing States in the scientific, educational, technical, legal and other fields for the protection and management of aquifers in Article 16. I do believe that Japan, although a non-transboundary aquifer State, would be able to play a significant role in this field.

10. There have been some critical observations on the draft articles from international lawyers mainly on two points. One is the inclusion of sovereignty clause in Article 3 which might in their view diminish the value of the whole exercise. I do share some of their apprehension. However, we must squarely face the current state of affairs. It was the UN which passed the resolution "Permanent sovereign over natural resources" 1803(XVII) in 1962. Many aquifer States insisted the inclusion of sovereignty article. It is noted that the second sentence of Article 3 states that it [aquifer state] shall exercise its sovereignty in accordance with international law and the present draft articles. I do believe that the current draft Article 3 represents an appropriately balanced text. Another point is the overlap between the 1997 international watercourses convention and the present draft articles. The 1997 watercourses convention theoretically covered the groundwater which are linked to international watercourses. The present draft articles cover all the transboundary aquifers regardless of whether they are linked or not to the international watercourses. The ILC considered that all the aquifers possess distinct characteristics different from those of surface waters. For instance, the Nubian Sandstone Aquifer System is linked to the River Nile south of Khartoum. However the bulk of the Nubian system has only the characteristics of non-recharging aquifer. Accordingly, that aquifer system must be regulated by the present draft articles. The regulations of the present draft articles are generally much broader and stricter than 1997 international watercourses convention. Dual application of the two instruments to a particular aquifer would normally not cause any difficulty. However, if it does, we would have to draft a provision to regulate the relationship between the two instruments when the negotiation takes place to transform the draft articles to a convention.

11. There are two years to go before the UN General Assembly makes the final decision on the status of the draft articles. The best outcome would be to transform the draft articles to a UN convention as the case of the 1997 UN watercourses convention. If it turns out to be difficult, thesecond best would be for the UN General Assembly to adopt the draft articles as the guidelines. There are certain differences in legal effects between the two alternatives. However, that difference would not matter much. As long as the draft articles receive an official endorsement by the UN

General Assembly, the States concerned could make full use of the draft articles in negotiating a bilateral or regional agreement with their neighbouring States in order to properly manage their transboundary aquifers.

12. Our task is twofold. First, the grave situation of many aquifers must be highlight·ed. Second, understanding and appreciation of the draft articles must be promoted. UNESCO-IHP will hold a series of regional and general meetings in this connection. Your valuable support as scientists and experts to this endeavour will be greatly appreciated.

ANNEX
RESOLUTION ADOPTED BY THE GENERAL ASSEMBLY
63/124. The law of transboundary aquifers

The General Assembly,

Having considered chapter IV of the report of the International Law Commission on the work of its sixtieth session, which contains the draft articles on the law of transboundary aquifers,

Noting that the Commission decided to recommend to the General Assembly (a) to take note of the draft articles on the law of transboundary aquifers in a resolution, and to annex the articles to the resolution; (b) to recommend to States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers on the basis of the principles enunciated in the articles; and (c) to also consider, at a later stage, and in view of the importance of the topic, the elaboration of a convention on the basis of the draft articles,Emphasizing the continuing importance of the codification and progressive development of international law, as referred to in Article 13, paragraph 1 (a), of the Charter of the United Nations,Noting that the subject of the law of transboundary aquifers is of major importance in the relations of States,

Taking note of the comments of Governments and the discussion in the Sixth Committee at the sixty-third session of the General Assembly on this topic,

1. Welcomes the conclusion of the work of the International Law Commission on the law of transboundary aquifers and its adoption of the draft articles and a detailed commentary on the subject;
2. Expresses its appreciation to the Commission for its continuing contribution to the codification and progressive development of international law;
3. Also expresses its appreciation to the International Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization and to other relevant organizations for the valuable scientific and technical assistance rendered to the International Law Commission;
4. Takes note of the draft articles on the law of transboundary aquifers, presented by the Commission, the text of which is annexed to the present resolution, and commends them to the attention of Governments without prejudice to the question of their future adoption or other appropriate action;
5. Encourages the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these draft articles;
6. Decides to include in the provisional agenda of its sixty-sixth session an item entitled “The law of transboundary aquifers” with a view to examining, inter alia, the question of the form that might be given to the draft articles.

67th Plenary Meeting, 11 December 2008

ANNEX

The law of transboundary aquifers

Conscious of the importance for humankind of life-supporting groundwater resources in all regions of the world,Bearing in mind Article 13, paragraph 1 (a), of the Charter of the United Nations, which provides that the General Assembly shall initiate studies and make recommendations for the purpose of encouraging the progressive development of international law and its codification,Recalling General Assembly resolution 1803 (XVII) of 14 December 1962 on permanent sovereignty over natural resources,Reaffirming the principles and recommendations adopted by the United Nations Conference on Environment and Development of 1992 in the Rio Declaration on Environment and Development and Agenda 21,Taking into account increasing demands for freshwater and the need to protect groundwater resources,Mindful of the particular problems posed by the vulnerability of aquifers to pollution,Convinced of the need to ensure the development, utilization, conservation, management and protection of groundwater resources in the context of the promotion of the optimal and sustainable development of water resources for present and future generations,Affirming the importance of international cooperation and good-neighbourliness in this field,Emphasizing the need to take into account the special situation of developing countries,Recognizing the necessity to promote international cooperation.

Part one
Introduction
Article 1
Scope

The present articles apply to:

(a) Utilization of transboundary aquifers or aquifer systems;

(b) Other activities that have or are likely to have an impact upon such aquifers or aquifer systems; and

(c) Measures for the protection, preservation and management of such aquifers or aquifer systems.

Article 2
Use of terms

For the purposes of the present articles:

(a) "aquifer" means a permeable water bearing geological formation underlain by a less permeable layer and the water contained in the saturated zone of the formation;

(b) "aquifer system" means a series of two or more aquifers that are hydraulically connected;

(c) "transboundary aquifer" or "transboundary aquifer system" means, respectively, an aquifer or aquifer system, parts of which are situated in different States;

(d) "aquifer State" means a State in whose territory any part of a transboundary aquifer or aquifer system is situated;

(e) "utilization of transboundary aquifers or aquifer systems" includes extraction of water, heat and minerals, and storage and disposal of any substance;

(f) “recharging aquifer” means an aquifer that receives a non-negligible amount of contemporary water recharge;
(g) “recharge zone” means the zone which contributes water to an aquifer, consisting of the catchment area of rainfall water and the area where such water flows to an aquifer by run-off on the ground and infiltration through soil;
(h) “discharge zone” means the zone where water originating from an aquifer flows to its outlets, such as a watercourse, a lake, an oasis, a wetland or an ocean.

Part two
General principles
Article 3
Sovereignty of aquifer States

Each aquifer State has sovereignty over the portion of a transboundary aquifer or aquifer system located within its territory. It shall exercise its sovereignty in accordance with international law and the present articles.

Article 4
Equitable and reasonable utilization

Aquifer States shall utilize transboundary aquifers or aquifer systems according to the principle of equitable and reasonable utilization, as follows:
(a) They shall utilize transboundary aquifers or aquifer systems in a manner that is consistent with the equitable and reasonable accrual of benefits therefrom to the aquifer States concerned;
(b) They shall aim at maximizing the long-term benefits derived from the use of water contained therein;
(c) They shall establish individually or jointly a comprehensive utilization plan, taking into account present and future needs of, and alternative water sources for, the aquifer States; and
(d) They shall not utilize a recharging transboundary aquifer or aquifer system at a level that would prevent continuance of its effective functioning.

Article 5
Factors relevant to equitable and reasonable utilization

1. Utilization of a transboundary aquifer or aquifer system in an equitable and reasonable manner within the meaning of article 4 requires taking into account all relevant factors, including:
(a) The population dependent on the aquifer or aquifer system in each aquifer State;
(b) The social, economic and other needs, present and future, of the aquifer States concerned;
(c) The natural characteristics of the aquifer or aquifer system;
(d) The contribution to the formation and recharge of the aquifer or aquifer system;
(e) The existing and potential utilization of the aquifer or aquifer system;
(f) The actual and potential effects of the utilization of the aquifer or aquifer system in one aquifer State on other aquifer States concerned;
(g) The availability of alternatives to a particular existing and planned utilization of the aquifer or aquifer system;
(h) The development, protection and conservation of the aquifer or aquifer system and the costs of

measures to be taken to that effect;
(i) The role of the aquifer or aquifer system in the related ecosystem.
2. The weight to be given to each factor is to be determined by its importance with regard to a specific transboundary aquifer or aquifer system in comparison with that of other relevant factors. In determining what is equitable and reasonable utilization, all relevant factors are to be considered together and a conclusion reached on the basis of all the factors. However, in weighing different kinds of utilization of a transboundary aquifer or aquifer system, special regard shall be given to vital human needs.

Article 6
Obligation not to cause significant harm

1. Aquifer States shall, in utilizing transboundary aquifers or aquifer systems in their territories, take all appropriate measures to prevent the causing of significant harm to other aquifer States or other States in whose territory a discharge zone is located.
2. Aquifer States shall, in undertaking activities other than utilization of a transboundary aquifer or aquifer system that have, or are likely to have, an impact upon that transboundary aquifer or aquifer system, take all appropriate measures to prevent the causing of significant harm through that aquifer or aquifer system to other aquifer States or other States in whose territory a discharge zone is located.
3. Where significant harm nevertheless is caused to another aquifer State or a State in whose territory a discharge zone is located, the aquifer State whose activities cause such harm shall take, in consultation with the affected State, all appropriate response measures to eliminate or mitigate such harm, having due regard for the provisions of articles 4 and 5.

Article 7
General obligation to cooperate

1. Aquifer States shall cooperate on the basis of sovereign equality, territorial integrity, sustainable development, mutual benefit and good faith in order to attain equitable and reasonable utilization and appropriate protection of their transboundary aquifers or aquifer systems.
2. For the purpose of paragraph 1, aquifer States should establish joint mechanisms of cooperation.

Article 8
Regular exchange of data and information

1. Pursuant to article 7, aquifer States shall, on a regular basis, exchange readily available data and information on the condition of their transboundary aquifers or aquifer systems, in particular of a geological, hydrogeological, hydrological, meteorological and ecological nature and related to the hydrochemistry of the aquifers or aquifer systems, as well as related forecasts.
2. Where knowledge about the nature and extent of a transboundary aquifer or aquifer system is inadequate, aquifer States concerned shall employ their best efforts to collect and generate more complete data and information relating to such aquifer or aquifer system, taking into account current practices and standards. They shall take such action individually or jointly and, where appropriate, together with or through international organizations.
3. If an aquifer State is requested by another aquifer State to provide data and information relating to

an aquifer or aquifer system that are not readily available, it shall employ its best efforts to comply with the request. The requested State may condition its compliance upon payment by the requesting State of the reasonable costs of collecting and, where appropriate, processing such data or information.

4. Aquifer States shall, where appropriate, employ their best efforts to collect and process data and information in a manner that facilitates their utilization by the other aquifer States to which such data and information are communicated.

Article 9
Bilateral and regional agreements and arrangements

For the purpose of managing a particular transboundary aquifer or aquifer system, aquifer States are encouraged to enter into bilateral or regional agreements or arrangements among themselves. Such agreements or arrangements may be entered into with respect to an entire aquifer or aquifer system or any part thereof or a particular project, programme or utilization except insofar as an agreement or arrangement adversely affects, to a significant extent, the utilization by one or more other aquifer States of the water in that aquifer or aquifer system, without their express consent.

Part three Protection, preservation and management

Article 10
Protection and preservation of ecosystems

Aquifer States shall take all appropriate measures to protect and preserve ecosystems within, or dependent upon, their transboundary aquifers or aquifer systems, including measures to ensure that the quality and quantity of water retained in an aquifer or aquifer system, as well as that released through its discharge zones, are sufficient to protect and preserve such ecosystems.

Article 11
Recharge and discharge zones

1. Aquifer States shall identify the recharge and discharge zones of transboundary aquifers or aquifer systems that exist within their territory. They shall take appropriate measures to prevent and minimize detrimental impacts on the recharge and discharge processes.
2. All States in whose territory a recharge or discharge zone is located, in whole or in part, and which are not aquifer States with regard to that aquifer or aquifer system, shall cooperate with the aquifer States to protect the aquifer or aquifer system and related ecosystems.

Article 12
Prevention, reduction and control of pollution

Aquifer States shall, individually and, where appropriate, jointly, prevent, reduce and control pollution of their transboundary aquifers or aquifer systems, including through the recharge process, that may cause significant harm to other aquifer States. Aquifer States shall take a precautionary approach in view of uncertainty about the nature and extent of a transboundary aquifer or aquifer system and of its vulnerability to pollution.

Article 13
Monitoring

1. Aquifer States shall monitor their transboundary aquifers or aquifer systems. They shall, wherever possible, carry out these monitoring activities jointly with other aquifer States concerned and, where appropriate, in collaboration with competent international organizations. Where monitoring activities cannot be carried out jointly, the aquifer States shall exchange the monitored data among themselves.

2. Aquifer States shall use agreed or harmonized standards and methodology for monitoring their transboundary aquifers or aquifer systems. They should identify key parameters that they will monitor based on an agreed conceptual model of the aquifers or aquifer systems. These parameters should include parameters on the condition of the aquifer or aquifer system as listed in article 8, paragraph 1, and also on the utilization of the aquifers or aquifer systems.

Article 14
Management

Aquifer States shall establish and implement plans for the proper management of their transboundary aquifers or aquifer systems. They shall, at the request of any of them, enter into consultations concerning the management of a transboundary aquifer or aquifer system. A joint management mechanism shall be established, wherever appropriate.

Article 15
Planned activities

1. When a State has reasonable grounds for believing that a particular planned activity in its territory may affect a transboundary aquifer or aquifer system and thereby may have a significant adverse effect upon another State, it shall, as far as practicable, assess the possible effects of such activity.

2. Before a State implements or permits the implementation of planned activities which may affect a transboundary aquifer or aquifer system and thereby may have a significant adverse effect upon another State, it shall provide that State with timely notification thereof. Such notification shall be accompanied by available technical data and information, including any environmental impact assessment, in order to enable the notified State to evaluate the possible effects of the planned activities.

3. If the notifying and the notified States disagree on the possible effect of the planned activities, they shall enter into consultations and, if necessary, negotiations with a view to arriving at an equitable resolution of the situation. They may utilize an independent fact-finding body to make an impartial assessment of the effect of the planned activities.

Part four
Miscellaneous provisions

Article 16
Technical cooperation with developing States

States shall, directly or through competent international organizations, promote scientific, educational, technical, legal and other cooperation with developing States for the protection and management of transboundary aquifers or aquifer systems, including, inter alia:
(a) Strengthening their capacity-building in scientific, technical and legal fields;
(b) Facilitating their participation in relevant international programmes;
(c) Supplying them with necessary equipment and facilities;
(d) Enhancing their capacity to manufacture such equipment;
(e) Providing advice on and developing facilities for research, monitoring, educational and other programmes;
(f) Providing advice on and developing facilities for minimizing the detrimental effects of major activities affecting their transboundary aquifer or aquifer system;
(g) Providing advice in the preparation of environmental impact assessments;
(h) Supporting the exchange of technical knowledge and experience among developing States with a view to strengthening cooperation among them in managing the transboundary aquifer or aquifer system.

Article 17
Emergency situations

1. For the purpose of the present article, “emergency” means a situation, resulting suddenly from natural causes or from human conduct, that affects a transboundary aquifer or aquifer system and poses an imminent threat of causing serious harm to aquifer States or other States.
2. The State within whose territory the emergency originates shall:
(a) Without delay and by the most expeditious means available, notify other potentially affected States and competent international organizations of the emergency;
(b) In cooperation with potentially affected States and, where appropriate, competent international organizations, immediately take all practicable measures necessitated by the circumstances to prevent, mitigate and eliminate any harmful effect of the emergency.
3. Where an emergency poses a threat to vital human needs, aquifer States, notwithstanding articles 4 and 6, may take measures that are strictly necessary to meet such needs.
4. States shall provide scientific, technical, logistical and other cooperation to other States experiencing an emergency. Cooperation may include coordination of international emergency actions and communications, making available emergency response personnel, emergency response equipment and supplies, scientific and technical expertise and humanitarian assistance.

Article 18
Protection in time of armed conflict

Transboundary aquifers or aquifer systems and related installations, facilities and other works shall enjoy the protection accorded by the principles and rules of international law applicable in international and non-international armed conflict and shall not be used in violation of those principles and rules.

Article 19
Data and information vital to national defence or security

Nothing in the present articles obliges a State to provide data or information vital to its national defence or security. Nevertheless, that State shall cooperate in good faith with other States with a view to providing as much information as possible under the circumstances.

Bibliography:

Aditi Mukherji and Tushaar Shah, 2005, Groundwater Socio-ecology and Governance: A review of institutions and policies in selected countries, Hydrogeology Journal (2005) 13:328-345

Alaerts, G.J. and Khouri N., 2004, Arsenic contamination of groundwater: Mitigation strategies and policies. Hydrogeology Journal 12, 103-114.

Central Ground Water Board (2001), Hydrogeology of Indus Basin, Government of India
Foster, S. and Loucks, D.P. (eds.) 2006, Non-renewable groundwater resources: A guidebook on socially-sustainable management for water-policy makers. IHP-VI, Series on Groundwater No. 10, UNESCO, Paris

Gabriel E. Eckstein (2007), Commentary on the UN International Law Commission Draft Articles on the Law of Transboundary Aquifers

Gilbert J, Mathieu J, Fournier F, (eds.) 1997, Groundwater/Surface Water Ecotones: Biological and Hydrological Interactions and Management Options, Cambridge, Cambridge University Press, UNESCO, International Hydrology Series.

Han Zaisheng, R. Jayakumar, Liu Ke, Wang Hao and Chai Rui 2008 Review on Transboundary aquifers in People's Republic of China with case study of Heilongjiang-Amur River Basin, Environ Geol (2008) 54:1411–1422, DOI 10.1007/s00254-007-0922-4

Han Zaisheng, Wang Hao, 2006, Research on Transboundary Aquifers, Earth Science Frontiers 2006, Vol. 13(1) 32- 39

Igor S. Zektser, Lorne G. Everett, 2004, Groundwater Resources of the World and their Use, UNESCO IHP-VI, Series on Groundwater No.6

Institute of Hydrogeology and Engineering Geology, Chinese Academy of Geological Sciences, 1996, Hydrogeological Map of Asia 1:8 M, Geological Publishing House, Beijing, China
ISARM Programme website <http://www.isarm.net>

Mekong River Commission 2005, Overview of the Hydrology of the Mekong Basin, Mekong River Commission, Vientiane, November 2005 p 73.

Mekong River Encyclopaedia Britannica, Encyclopaedia Britannica Ultimate Reference Suite Chicago: Encyclopaedia Britannica, 2010.

Puri S. (ed.) 2001, Internationally Shared (Transboundary) Aquifer Resources Management Their significance and sustainable management, A framework document, IHP-VI, IHP Series on Groundwater No 1 UNESCO, Paris.

Puri S. and Aureli, A. 2008, Transboundary Aquifers: A Global Programme to Assess, Evaluate and Develop Policy. Groundwater, vol. 43, pp. 661-668.

Puri S., Aureli, A. and Stephan, R.M. 2007, Shared Groundwater Resources: Global Significance for Social and Environmental Sustainability. In: Overexploitation and Contamination of Shared Groundwater Resources: Management, (Bio) Technological and Political Approaches to Avoid Conflicts, C.J.G. Darnault et al., (eds.). Springer, The Netherlands.

Puri S. 2007, Transboundary Aquifers and their Management in the Context of Globalisation, Third International Symposium on Transboundary Waters Management, Ciudad Real, Spain, May 30 - June 2, 2006.

Sergey A. Kozlov, 2006, Quality of groundwater of the Middle-Amur artesian basin (The Far East of Russia), 34th IAH Congress paper

Struckmeier WF, Gilbrich WH, Gun JVD, Maurer T, Puri S, Richts A, Winter P, Zaepke M (2006), WHYMAP and word map of transboundary aquifer systems at scale of 1:50 000 000 (special edn). Graphischer Betrieb Betrieb Gieseking GmbH and Co. KG, Bielefeld, p 3

UN, Groundwater in Continental Asia (Central, Eastern, Southern, South-eastern Asia), Natural Resources, Water Series, New York: 1986

United Nations, 2006, Water: A Shared Responsibility, the United Nations World Water Development Report 2, 2006.3, http://www.unesco.org/publishing

UN, Water Resources Development in Asia and the Pacific Some Issues and Concerns//Water Resources Series, New York: 1987, No.62

UNESCO, 2003, World water Development Report: Water for People, Water for life, UNESCO and Berghahn Book, Barcelona

UNESCO Office Beijing, 2006, Transboundary Aquifers in Asia with Special Emphasis to China, P. 39

UNESCO Office Beijing, 2009, Transboundary Aquifers of Greater Mekong River Basin, Unpublished Project report P 25.

USAID, 2004. What is Integrated Water Resources Management ? http://www.usaid.gov/our_work/environment/water/what_is_iwrm.html.

WHYMAP, 2006, Groundwater Resources of the World, Transboundary Aquifer Systems, 1: 50 000 000, Special Edition for the 4th World Water Forum, Mexico City, March 2006, Hannover/Paris, BGR/UNESCO

WHYMAP, 2008, Additional Global Map: Groundwater Resources of the World - Transboundary Aquifer Systems, version 2008, Hannover/Paris, BGR/UNESCO

Yang Wen, Zhang Fenglong, Yang Xiangkui, et al. 2003, Evaluation for Groundwater potential in three rivers plain, Geological publishing company, 2003:349-356

Zhang Zonghu, Li Lierong, Groundwater Resources of China, China Atlas publishing company, 2004

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