GEF - UNDP - UNOPS Project
Integrated Natural Resources Management in the Baikal Basin Transboundary Ecosystem

Groundwater Resources in Shallow Transboundary Aquifers in the Baikal Basin: Current Knowledge, Protection and Management

A Contribution to the Transboundary Diagnostic Analysis of the Lake Baikal Basin

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UNESCO-IHP

This report has been prepared by Dr Jaroslav Vrba, UNESCO-IHP Senior Consultant and Scientific-Technical Coordinator of the Project, in collaboration with the following national experts from Mongolia and the Russian Federation:

- Dr Borchuluun Urtnasan, Freelance Consultant, Ulaanbataar, Mongolia
- Dr Buyankhishig Nemer, Associate Professor, Mongolian University of Science and Technology, Ulaanbataar, Mongolia
- Dr Alexey Maksimovich Plyusnin, Deputy Director for Science of Geological Institute of Siberian Branch of Russian Academy of Science, Chief of Laboratory of Hydrogeology and Geoecology. Ulan-Ude, Russian Federation
- Dr Marina Aleksandrovna Tugarina, Associate Professor, Irkutsk State Technical University, Department of Applied Geology. Irkutsk, Russian Federation.

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- Dr Lunten Janchivdorj, UNESCO Chair on Sustainable Groundwater Management, Institute of Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia
- Dr Larisa D. Radnaeva, Bioresources and Data Management Expert
- Dr Saskia Marijnissen (Senior TDA Consultant and Scientific Advisory Group Leader, The Lake Baikal Project)

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Abbreviations

BCPC	Baikal Cellulose-Paper Combine (Russia)
GEF	Global Environment Facility
IHP	International Hydrological Programme (UNESCO)
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
MARCC	Mongolia: Assessment Report on Climate Change
MoMo	Model Region Mongolia
MUST	Mongolian University of Science and Technology
SCCC	Selenga Cellulose-Cardboard Combine (Russia)
TDA	Transboundary Diagnostic Analysis
WSSA	Water Supply and Sewerage Authority (Mongolia)
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNOPS	United Nations Office for Project Services
UNEP–NISD	UNEP-Network Institutions for Sustainable Development

Introduction

The present report is a contribution to the Project *Integrated Natural Resources Management in the Baikal Basin Transboundary Ecosystem*, implemented by UNDP and funded by the GEF. The report was prepared by UNESCO-IHP, one of the project's Executing Agencies and partners, in cooperation with the UNESCO Chair on Water Resources at Irkutsk State University (Russia), Irkutsk State Technical University, the Geological Institute of the Russian Academy of Sciences – Siberian Branch, the Baikal Institute of Nature Management of the Russian Academy of Science - Siberian Branch, the UNESCO Chair on Sustainable Groundwater Management, Mongolian Academy of Sciences - Institute of Geo-Ecology, the Institute of Meteorology, Hydrology and Environment of Mongolia, the Mineral Resources Authority of Mongolia, Tsukuba University, Japan, and other national and international partners.

The report consolidates the results of activities under Output 1.3 of the Project, which were focused on the assessment of groundwater resources and their interaction with surface water in the transboundary basin of Lake Baikal. As a central element the role of groundwater in sustaining the functioning of the unique ecosystems of Lake Baikal was explored. This included the identification and description of potential threads to these ecosystems in terms of quantitative (groundwater level decline) and qualitative (pollution) aspects. Priority was given to unravelling the hydrological, hydraulic and hydro-chemical interactions between surface and groundwater, with specific regard to shallow aquifers in fluvial/alluvial deposits and their interactions with adjacent rivers and lakes.

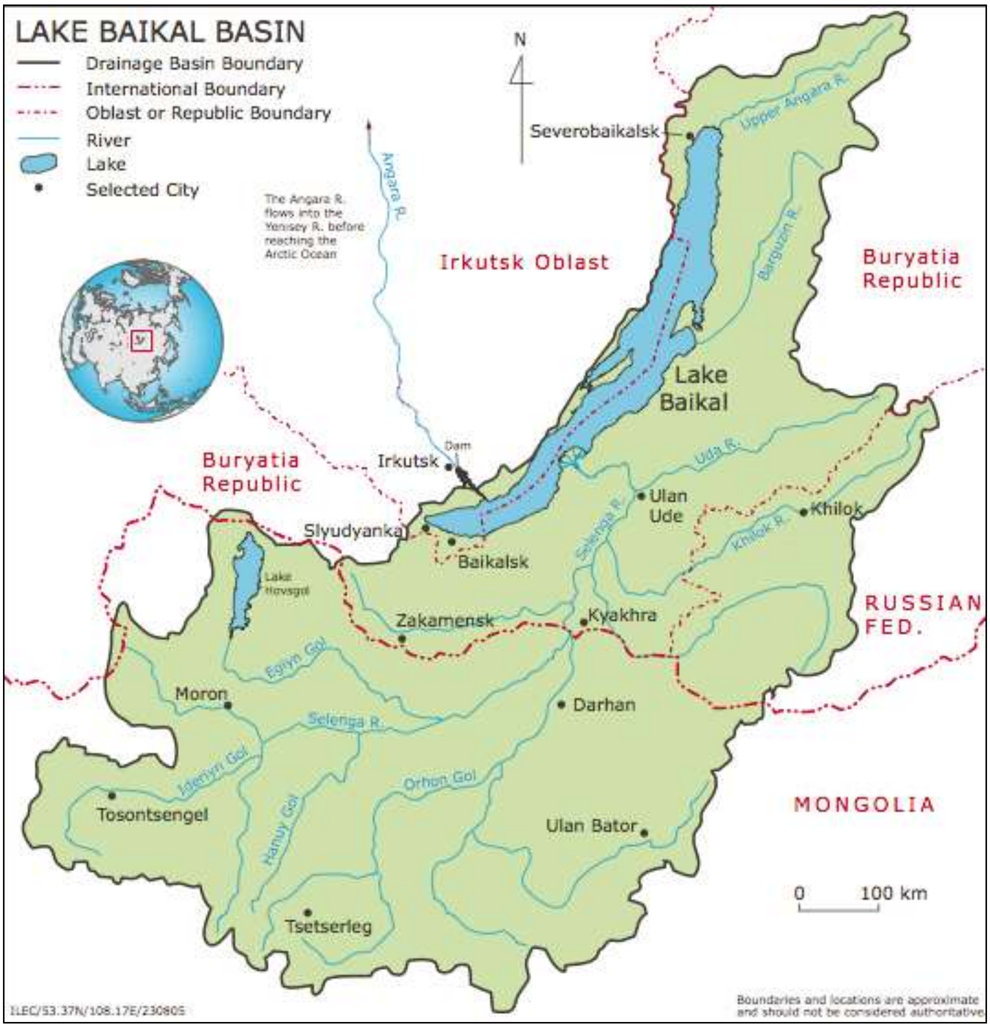
A project team under the scientific lead of UNESCO was established, consisting of partner institutions from Russia and Mongolia and national groundwater experts from both countries. During the project implementation period several face-to-face meetings with the project team were organized by UNESCO. These meetings took place in Ulaanbaatar from 20-22 November 2012 and in Ulan-Ude (20-22 March 2013 and 10 July 2013) provided an opportunity for the project team to discuss in detail the activities and work plan, as well as agree on the structure and content of the deliverables.

A central task of the group was the identification of groundwater-related issues of transboundary concern, such as upstream groundwater resources degradation, potential transboundary transport of pollutants, groundwater pollution, groundwater depletion due to aquifer overexploitation, as well as the risk and uncertainty related to climate change impact on different types of aquifers. Besides the investigation of the biophysical aspects, the assessment also included a review of groundwater management practices, and legal/institutional frameworks for transboundary (ground)water management.

Accordingly, the *Final Report* was structured to reflect the major objectives of the activity:

- Hydrogeological conditions and present status of groundwater resources development
- Shallow alluvial aquifers and their interaction with surface water
- Man-made threats on groundwater resources
- Vulnerability of groundwater dependent ecosystem
- Transboundary aquifers and groundwater data availability in the Baikal Basin
- Climate change influence on groundwater resources
- Groundwater priority issues of transboundary concern.

The present report is the final output describing the findings of the activities carried out by the UNESCO-led groundwater expert team. It aims to be a contribution to the Transboundary Diagnostic Analysis (TDA) of the Baikal Basin, which is being prepared in the framework of the Project.



Overview map showing the Lake Baikal Basin, and political boundary between Russia and Mongolia, main cities, big rivers and their confluence areas, Selenga River Delta and Lakes Baikal and Hovsgol. Lake Baikal lies entirely with the Russian Federation, while is basin extends into Mongolia. (Map produced by the Global Environment Facility)

Executive Summary

In the framework of the UNDP – GEF project "Integrated Natural Resources Management in the Baikal Basin Transboundary Ecosystem" UNESCO-IHP has been entrusted with the execution of activities related to groundwater resources in the Lake Baikal Basin (Output 1.3). The objective of these activities was to assess the main causes of transboundary degradation in the Basin related to groundwater and its interactions with surface water and to include them into the Transboundary Diagnostic Analysis document. The main findings and conclusions are highly relevant for the sustainability of the unique Lake Baikal Basin ecosystems and are presented in the present report "Groundwater Resources in Shallow and Transboundary Aquifers in the Baikal Basin: Current Knowledge, Protection and Management".

The activities carried out by UNESCO-IHP project team focused on (i) the present status of groundwater resources assessment, development and management, (ii) transboundary aquifers and transboundary groundwater runoff and pollution transport, (iii) man-made threats on groundwater resources and dependent ecosystems, (iv) groundwater pollution and protection policy, (v) interaction between surface water and groundwater and integrated management of both resources, (vi) climate change impact on groundwater. The project also reviewed the legal and institutional frameworks for groundwater resources management and provides recommendations towards the harmonization of groundwater management and protection policies in the two countries sharing the Lake Baikal Basin: the Russian Federation and Mongolia.

The above mentioned assessment was constrained by the limited availability and/or accessibility of groundwater-related data in both countries. Recommendations for groundwater monitoring activities and relevant groundwater investigations have therefore been elaborated. The implementation of these recommendations will contribute to expand the knowledge of shallow and transboundary aquifers and will support the sustainable management and protection of groundwater resources in the Baikal Basin, and specifically in transboundary groundwater bodies shared between the Russian Federation and Mongolia. The main objective of this process is to ensure long-term availability and quality of groundwater as a strategic source for human life (for drinking and other sanitary purposes), economic development (e.g. agriculture, industry), and conservation of groundwater dependent ecosystems. The intangible value of groundwater related to the ethical, religious and cultural traditions of the societies living in the Baikal Basin has to be respected too. For some small rural and mountain communities groundwater resources are the key to the poverty alleviation.

Social, economic and environmental role of groundwater in the Baikal Basin

Groundwater is a significant component of the hydrological cycle and aquifers are important hydrological units in watersheds and river basins. In nature, groundwater is a key component of many geological and geochemical processes and has many ecological functions sustaining spring discharges, river base flows, as well as lakes and wetlands. In the Baikal Basin groundwater due to its widespread occurrence, mostly good quality, low vulnerability, reliability to floods and droughts and generally modest development costs play an important role for social and economic development. The majority of the population in the Baikal basin depends on groundwater for drinking and other domestic purposes.

The groundwater system in the Baikal Basin is characterised by deep and shallow aquifers. In Mongolia deep aquifers occur in two geological structures affected by deep tectonic faults and formed in Caledonian orogenic phase (Northern Mongolia unit) and in the late Hercynic orogenic phase (Mongolia-Transbaikal unit). In Russia deep aquifers are developed in the Lena-Kirenga Basin, the Baikal Rift zone and in the Selenga-Dauria Groundwater Basin. Fissure permeability prevails in deep aquifers in metamorphic and igneous rocks however, dual permeability in aquifers in consolidate sedimentary rocks is registered as well. The direction and magnitude of groundwater flows are controlled by the age, size, density orientation and permeability of tectonic faults and fractures; both create vertical passes and cleavages for groundwater movement in the rock environment. In deep aquifers renewable groundwater, fossil groundwater and thermal water with gas hydrates occur.

Shallow aquifers occur in different types of unconsolidated sedimentary deposits. Highly productive shallow aquifers with abundant groundwater resources exist in porous fluvial deposits (sands and gravels) in floodplains and low terraces of Selenga, Tuul, Orkhon and other big rivers in the Baikal Basin. Such shallow aquifers, often hydrologically connected to the rivers and surface streams, are the main sources of drinking water in capital cities of Mongolia (Ulaanbaatar) and the Republic of Buryatia (Ulan-Ude) as well as other big cities on Mongolian and Russian territory of the Baikal Basin. Economic and social importance of shallow aquifers, their accessibility, dependence of many ecosystems on shallow groundwater (e.g. the Selenga River Delta), mutual hydrologic and hydrodynamic relations between rivers and adjacent shallow aquifers, growing human impact on water resources quality and influence of climate change are the main attributes which involved on the decision to consider groundwater in shallow and transboundary aquifers as a priority resource in UNESCO contribution to the UNDP – GEF project.

Based on the collection, verification and evaluation of available reliable groundwater data, hydro-geological maps and other relevant environmental and socio-economic information the following key outputs have been prepared:

- Compilation of existing data and information on shallow transboundary aquifers shared by Russia and Mongolia, and their present state of knowledge
- Identification of groundwater-related priority issues of transboundary concern: Man-made threats on groundwater resources
- Interaction between surface water and groundwater
- Climate change impacts on groundwater
- Groundwater related contribution to the transboundary TDA.

Transboundary aquifers: present status of their knowledge

The following transboundary aquifers occur in the Baikal Basin: shallow aquifers in the floodplain of Selenga River, Kyakhtinka River and Chickoy River. All three aquifers are facing groundwater data scarcity. There is limited knowledge on aquifers thickness, physical properties and groundwater chemistry. Groundwater data are also missing for evaluation of interaction between shallow aquifers and adjacent rivers. So far, the activities under the Russian- Mongolian "Agreement on the protection and use of transboundary waters" have been implemented only in the case of surface water. Transboundary surface water monitoring networks have been established and surface water runoff and quality are regularly measured. However, relevant transboundary groundwater monitoring networks have not been established as yet.

A sound knowledge base is the prerequisite for informed, science-based decision making and management of groundwater resources at the national level, as well as the transboundary context. The establishment of transboundary groundwater monitoring networks based on a harmonized methodology, standardized groundwater measurement techniques and standardized frequency of groundwater sampling is therefore of central importance. Groundwater data are needed for the evaluation of transboundary groundwater runoff, assessment of transboundary groundwater resources, timely identification of groundwater quality deterioration and possible transboundary transport of pollution. The need to establish a common transboundary groundwater database in GIS and data mutual accessibility and fees free exchange between Russia and Mongolia is pointed out.

Groundwater priority issues of transboundary concern: Man-made threats on groundwater resources

Human activities in the Lake Baikal Basin are impacting the state of groundwater resources, both in terms of groundwater quality and quantify. These include:

(i) Wastes disposal and discharge of waste water, in particular that from mining activities, are the main pollution sources of surface and groundwater with potential transboundary implications on the Lake Baikal ecosystems.

(ii) The cumulative effects of these various pollution sources on the Lake Baikal ecosystems may be compounded by increased climatic variability and change affecting river flows and groundwater levels.

(iii) While situations of over-exploitation of the abundant groundwater resources do not presently exist in the Basin, the lack of proper measures to monitor and protect water quality in shallow alluvial aquifers used for drinking water supply and inextricably linked to surface waters, may pose threats to sustainability and human health.

Solid and liquid wastes of different origin are considerable sources of groundwater pollution in the Baikal Basin on the territories of both countries. Particularly mining and processing of gold, copper, molybdenum, tungsten, zinc and coal have been carried out on a large scale for a long time, producing waste often with content of toxic constituents. Sources of pollution with impacts on groundwater quality include uncontrolled leakages of waste water from ore washing and dressing facilities, post-extraction processing of mining material, coal preparation, uncontrolled leakages from tailings, piles, evaporation ponds and other uncontrolled disposal sites. Groundwater and surface water pollution by industrial and municipal waste disposal sites and uncontrolled leakages of untreated waste water have been also registered in several places of Baikal Basin in both countries, Russia and Mongolia.

Groundwater pollution from the above described sources is mostly of local (site – specific) extent. However, due to the interaction between shallow aquifers and rivers and streams, surface water can be polluted by groundwater discharge and pollution can be transported across the Mongolian – Russian boundary. Uncontrolled waste disposal sites located at floodplains and discharges of untreated waste water are the most significant potential pollution sources that threaten the productive and vulnerable shallow aquifers in fluvial deposits.

TDA rating criteria applied for evaluation of the impact of different pollution sources on groundwater quality identified **impact of mining activities on groundwater quality as high groundwater transboundary issue of concern (overall rating 6).** Mining of mineral deposits is pursued by open pit and deep mines with high water demand. Only a small portion of useful mineral components is extracted from the rocks, while 90-95% of rock material is discarded as mine wastes. Tens of millions of tons of ore tailing with 3-4% sulphide mineralization are stored in the River Selenga catchment and due to ongoing oxidation processes likely are a source of groundwater pollution. Mine waste are often stored by using the so called dam method that only protects deposits of tailing from mechanical dispersion in the surrounding area, but it does not solve the migration of soluble hazardous components into the groundwater. Some private mining companies illegally use mercury for gold separation and thereby produce toxic pollution of water resources. On disposal sites, ore mineral constituents are also leached by atmospheric and surface water and moved into aquifers. Site specific groundwater monitoring systems controlling water quality and groundwater depletion around mine facilities are rarely established in both Russian and Mongolian territory of the Baikal Basin.

The following adaptive management strategy has been recommended to control groundwater and surface water quality against pollution originated from mining operations: 1/ investigation and evaluation of mining activities in large mining districts in Mongolian and Russian territories of the Baikal Basin with respect to their potential impact on water resources, 2/ evaluation of mineral compositions of large mine waste disposal sites and chemical composition of waste leakages with the objective to propose effective protective measures and treatment technologies, 3/ construction and operation of site specific groundwater monitoring system around mining districts to control groundwater quality and impact of groundwater abstraction (for mines dewatering and ore processing) on drinking water supplies, irrigation facilities or ecosystems.

National water resources protection policies and regulative frameworks in both countries should stipulate that: 1/ environmentally sound mine operation and management are obligatory for mining concessions granted by governmental authorities, 2/ continuous treatment of waste water in order to avoid the leakage of toxic constituents in waste water discharging from mine facilities into the surface water and/or groundwater, 3/ owners of mine facilities are responsible for investments in and installation of relevant modern mining and waste water treatment technologies, construction of safe disposal sites and operation of site specific groundwater monitoring networks.

The uncontrolled discharge of wastewater from industrial activities and municipal areas is other significant source of groundwater pollution (TDA overall rating 4). Significant investments will be required to construct treatment plants with modern treatment technology. Within the next 10 years waste water management, including waste water reuse will need to be strengthened in order to reduce the impact of industrial and municipal liquid wastes on the quality of groundwater resources and groundwater dependent ecosystems.

Impact of uncontrolled industrial and municipal disposal sites of **solid wastes** on groundwater quality is registered in the Lake Baikal catchment in many industrial areas as well as municipal and rural settlements. Many waste disposal sites are located in permeable fluvial deposits in the floodplain areas where seasonal fluctuation of groundwater level is under the influence of surface water flow in the rivers. Toxic substituents and other pollutants may be washed from uncontrolled waste disposal sites into the shallow aquifers. During seasonal river low flows polluted groundwater may discharge into the surface streams and pollution can potentially be carried over long distances, including across the national boundaries.

New landfills have to be located on the sites where productive aquifers are not developed, groundwater level is deep below ground and unsaturated zone is low permeable and thick. From a technical point of view landfills should be constructed with protective impermeable layers with high absorption capacity, drainage systems and site specific monitoring networks. Such environmentally safe management of solid wastes will require significant investments of municipalities and industrial companies in the near future.

The following activities are recommended to protect groundwater against pollution from industrial wastes: 1/ investigation and evaluation of waste disposal sites of big industrial facilities or industrial services producing toxic wastes located near to the water supply systems or aquifers with significant groundwater resources; 2/ projection and implementation of technical measures for the safe operation of existing disposal sites, or closing of non-adequate disposal sites including removal of toxic wastes; 3/ implementation of techniques for reuse of treated waste water (e.g. for aquifer replenishment, irrigation); 4/ regular control of chemical composition of treated waste water discharge in the surface streams, lakes or groundwater, and 5/ operation of site specific groundwater monitoring networks around waste disposal sites to observe groundwater quality and timely identify potential pollution leakages.

Diffuse groundwater pollution by nitrate and pesticide by agricultural activities is not registered hitherto as a significant environmental problem in the Baikal Basin. Amount of applied fertilizers and chemicals and intensity of farming activities is low in comparison with e.g. European countries and USA. However, crop farming is rapidly developing particularly in Mongolia and the increasing use of fertilizers and chemicals is expected to have considerable impacts on the quality of soil and groundwater in shallow aquifers in the near future.

A coordinated effort between the agricultural and the water sector is therefore needed to define in time the policy for sustainable management of agricultural production and environmentally sound protection of groundwater resources. The following attributes of sustainable agricultural production are recommended to protect groundwater quality in shallow aquifers below cultivated arable land: 1/ maintain traditional crop rotation system, 2/ control fertilizers and pesticides application (type, amount and doses applied and time of their application), 3/ select suitable cultivation techniques (especially tillage), 4/ soil quality conservation (e.g. keeping dynamic stability of the soil organic matter), 5/ control of the nitrogen and carbon balance as essential attribute for control of the amount of nitrogen leached in the saturated aquifer, and 6/ soil and groundwater quality monitoring (vertical profiling of unsaturated zone and aquifer) to control nitrate transport and transformation processes. Monitoring of the irrigation return flow is also needed, because irrigation water contributes to the growing salinity of the soil and leached salts move to the underlying shallow aquifers and degrade the quality of groundwater.

High **groundwater point pollution** by nitrogen-containing compounds (700 mg/l nitrate) has been identified in the areas surrounding the poultry farms in Russian territory of the Baikal Basin. Uncontrolled discharges of waste water from animal farms are significant sources of pollution of vulnerable shallow aquifers. Treatment of waste water from animal farms has to be therefore obligatory for operation of animal farms. The quality of discharging treated waste water has to be regularly monitored.

Transboundary groundwater depletion. Groundwater shortages due to the population growth and groundwater pollution have been registered in some areas of the Mongolian territory of the Baikal Basin. Hydrogeological investigation and evaluation of potential impact of mining activities on the quantity and quality of groundwater resources due to mine dewatering have not been carried out to date. Excessive pumping of mine waters leads to groundwater resources depletion, groundwater quality degradation and may affect groundwater supply systems. Furthermore, the sustainable rate of exploitation of local groundwater resources has already been exceeded in high water demand areas, like the Tuul and Shariin River Basins near to Ulaanbaatar.

In Russian territory of the Baikal Basin groundwater depletion is not registered yet. However, regular observation of groundwater levels and groundwater extraction are not realized till this time.

Increasing demand on groundwater resources for drinking and other purposes requires comprehensive control over groundwater abstraction. Establishment and operation of site specific monitoring networks around water supply systems and other groundwater abstraction sites is recommended. Regular monitoring will provide data for groundwater resources assessment and sustainable development and management.

Interaction between surface water and groundwater

Significant groundwater resources in shallow aquifers occur in fluvial deposits in the Mongolian and Russian territories of the Baikal Basin. These groundwater resources are used to supply drinking water for many cities and rural settlements. Groundwater interaction with adjacent rivers takes place in floodplain areas and in low river terraces. However, water level data are limited for the evaluation of 1/ interaction between both resources, 2/ share of infiltrated surface water into groundwater stored in shallow aquifers, 3/ the amount of groundwater discharges into surface streams, and 4/ transboundary groundwater flow and potential pollution transport in shallow aquifers in Mongolian-Russian transboundary areas.

At the transboundary level and Baikal Basin scale priority in the studies of interaction between both resources should be given to the extensive valleys of the Rivers Selenge, Orkhon, Uda and other big rivers and their confluence areas where thick and permeable fluvial deposits with significant and economically accessible groundwater resources in productive shallow aquifers occur. However, hydrogeological knowledge of such shallow aquifers is restricted and data about their thickness, vulnerability, permeability and hydraulic properties as well as data about regular groundwater level measurements and groundwater chemistry and quality are scarce. Data are particularly needed for the studies of seasonal changes in water level of both surface water and groundwater and their influence on groundwater storage and discharge into rivers in dry seasons and surface water infiltration into adjacent shallow aquifers in wet seasons.

To better understand interactions between groundwater and surface water in Mongolian and Russian transboundary areas and in the Baikal Basin regular observation of surface water levels and runoffs on river monitoring stations has to be completed by observation of groundwater levels in proposed groundwater monitoring wells in shallow transboundary aquifers and confluence areas of big rivers. Such monitoring data facilitate evaluation of transboundary groundwater runoff and the influence of water level fluctuation on the amount and quality of groundwater resources in shallow aquifers adjacent to surface streams. Data will be used for setting up and calibration of conceptual model of the studied areas as a first step in GIS data entry process and grid-based numerical model generation.

Climate change impact on shallow aquifers and dependent ecosystems and on groundwater in permafrost

Deep aquifers with groundwater residence time and renewal period in thousands of years or even millennia in case of fossil groundwater generally have a low vulnerabilty to the contemporary climate variability and change. Shallow aquifers that contain groundwater with shorter residence times (several days up to hundreds of years) are much more vulnerable to the impacts of climate change. Increasing air temperatures and changes in precipitation patterns and intensities affect the conditions for groundwater recharge and consequently influence the groundwater storage in shallow aquifers. Air temperature increased during last decades in Mongolian and Russian territories of the Baikal Basin (e.g. 2.1^{o}C during last 70 years in Mongolia). Precipitations show high regional variability. In Mongolia in the Altai mountain region, Altai Gobi and in the eastern part of the country precipitation increased since 1961. In other regions precipitations decreased by 0.1–2.0 mm/year. In Russian territory the decrease of precipitations (25.5–47 mm during the last 30 year) has been registered in low and middle reaches of the Selenga River. In the River Djida Basin, however, precipitation increase by 11.6 mm over the past 30 years.

A study carried out in the Tuul River Basin highlights the dependence of recharge of shallow aquifers on precipitation. 70% of the annual precipitation occurs during the summer months (April - August) and almost simultaneous groundwater level rise is recorded. Average annual surface water runoff in the period 2000-2010 decreased from 24-39 % in the Rivers Selenga, Chickoy, Khilock and Uda. In winter season the rivers runoff is largely supported by groundwater from shallow aquifers. Based on available data groundwater discharge increased in the Rivers Selenga (on the Mongolian–Russian border), Chickoy and Uda over last decade of about 17,6 %, 10,5 % and 19,2 % respectively. The revealed climatic changes influence the river runoff, groundwater level and groundwater storage in shallow aquifers in many areas of the River Selenga Basin.

In **permafrost areas** specific attention should be given to the influence of climatic conditions on groundwater occurrence and availability. Increasing thickness of thawing layer of permafrost due to growing temperature is registered. Groundwater in the permafrost is a valuable source of drinking water for several small rural settlements and for pasture livestock. With increasing air temperatures groundwater resources in permafrost will become a significant source of drinking water for many rural communities living in mountain and sub-mountain regions. Monitoring of permafrost aquifers in the Baikal Basin to observe climate change influence on groundwater resources is recommended.

Groundwater level decline in shallow aquifers due to climate change will affect groundwater dependent wetlands and ecosystems. Extensive wetlands and their dependence on shallow aquifers occur particularly at the Selenga River Delta. Hydrogeological investigation of shallow aquifers, early warning monitoring and ecological studies are needed to effectively protect wetlands and ecosystems dependent on shallow aquifers in the Baikal Basin.

Priority issues of transboundary concern: Contribution to the Transboundary Diagnostic Analysis (TDA) of the Lake Baikal Basin

Human activities may have irreversible impacts on aquifers and the groundwater resources contained therein. The implementation of recommended actions to address the priority issues of transboundary concern described above as a contribution to TDA will reduce current and future risks of groundwater pollution and depletion. The recommended priority actions will be beneficial for the sustainable development and management of groundwater resources in the Baikal Basin, safeguarding groundwater quality and the integrity of groundwater dependent ecosystems. At the transboundary level the recommended measures will help to anticipate potential conflicts related to the transboundary groundwater resources.

The implementation of the proposed priority actions will 1/ improve the knowledge about groundwater resources quantity and quality and groundwater pollution in the entire Baikal Basin, 2/ clarify hydrogeological conditions in transboundary areas where groundwater runoff discharging Mongolian or Russian territories of the Baikal Basin is not monitored as yet and data are not available to control potential transboundary groundwater pollution transport.

1 | Hydrogeological conditions and present status of groundwater resources development

Overview of hydrogeological conditions on the territory of the Baikal Basin is focused on description of groundwater and aquifers occur in older geological units. Groundwater resources in shallow aquifers are evaluated in the chapter 2 related on the interaction between surface water in large rivers and groundwater in shallow aquifers in adjacent floodplains and river terraces composed by permeable fluvial deposits of Quaternary age.

1.1 Hydrogeological conditions and present status of groundwater resources development on the Mongolian territory of the Baikal Basin

The Mongolian territory of the Baikal Basin is composed by two major geological units: Northern Mongolia unit geologically formed in ancient Caledonian orogenic phase and Mongolia-Transbaikal unit formed in the late Hercynic orogenic phase. Both units are affected by deep tectonic structures Tamir and Bayangol and by some other deep tectonic faults (Jadambaa, 2006).

Northern Mongolia unit

Groundwater in Northern Mongolia geological unit occurs in fluvial deposits of Quaternary age, sedimentary rocks of Mesozoic age and fractured rocks of pre-Mesozoic age (Figure 1.1).

Shallow aquifers in highly permeable fluvial deposits contain significant groundwater resources widely used for water supplies of municipalities and rural settlements.

Deep aquifers in sediments of Cenozoic and Mesozoic age occur in medium elevated area of the Orkhon-Selenge Basin. It consists of conglomerates, sandstones, argillites, siltstones, clays and sands. Groundwater level in the sediments of the Cretaceous age significantly differs (from 4 to 80 m), wells yield vary from 0.15 to 10.4 l/s. Groundwater quality does not meet often the requirements for drinking water standards because of its high hardness and TDS.

Continuous permafrost rocks of 200-500 m or even more thick are widely developed in high massifs of the Khovsgol, Khangai and Hentii mountain ranges. Non-continuous permafrost islands of 15-25 m and 50-100 m average thickness are spread in the small river basins and valleys. Aquifers in permafrost have not been studied as yet in Mongolia. However, groundwater in the permafrost is a valuable source of drinking water for several small rural settlements and for pasture livestock.

N. Jadambaa (2012) calculated renewable and potential exploitable groundwater resources in the frame of the project “Strengthening Integrated Water Management in Mongolia” (2010). Renewable groundwater resources amount to 5.08 billion m^3 (13,931 thousand m^3/day), the total potential exploitable groundwater resources amount to 2.36 billion m^3 (6,473 thousand m^3/day) in the Northern Mongolia groundwater unit.

Mongolia-Transbaikal unit

The Mongolia Transbaikal geological unit consists by variety of deposits and rocks of different age and permeability (Figure 1.1).

In sediments (limestones, sandstones, siltstones and conglomerates) of Permian, Triassic, Jurassic, Cretaceous, Paleocene, Neogene age, and deposits of Quaternary age are developed at different depth, extension, thickness, lithology and permeability (Table 1.1) local aquifers as well as aquifer systems with significant groundwater resources.

Groundwater occurrence in metamorphic and intrusive rocks depends on the tectonic exposure of the rocks. In fractured zones rocks fissure permeability is high and significant groundwater resources have been registered in several boreholes located in these zones.

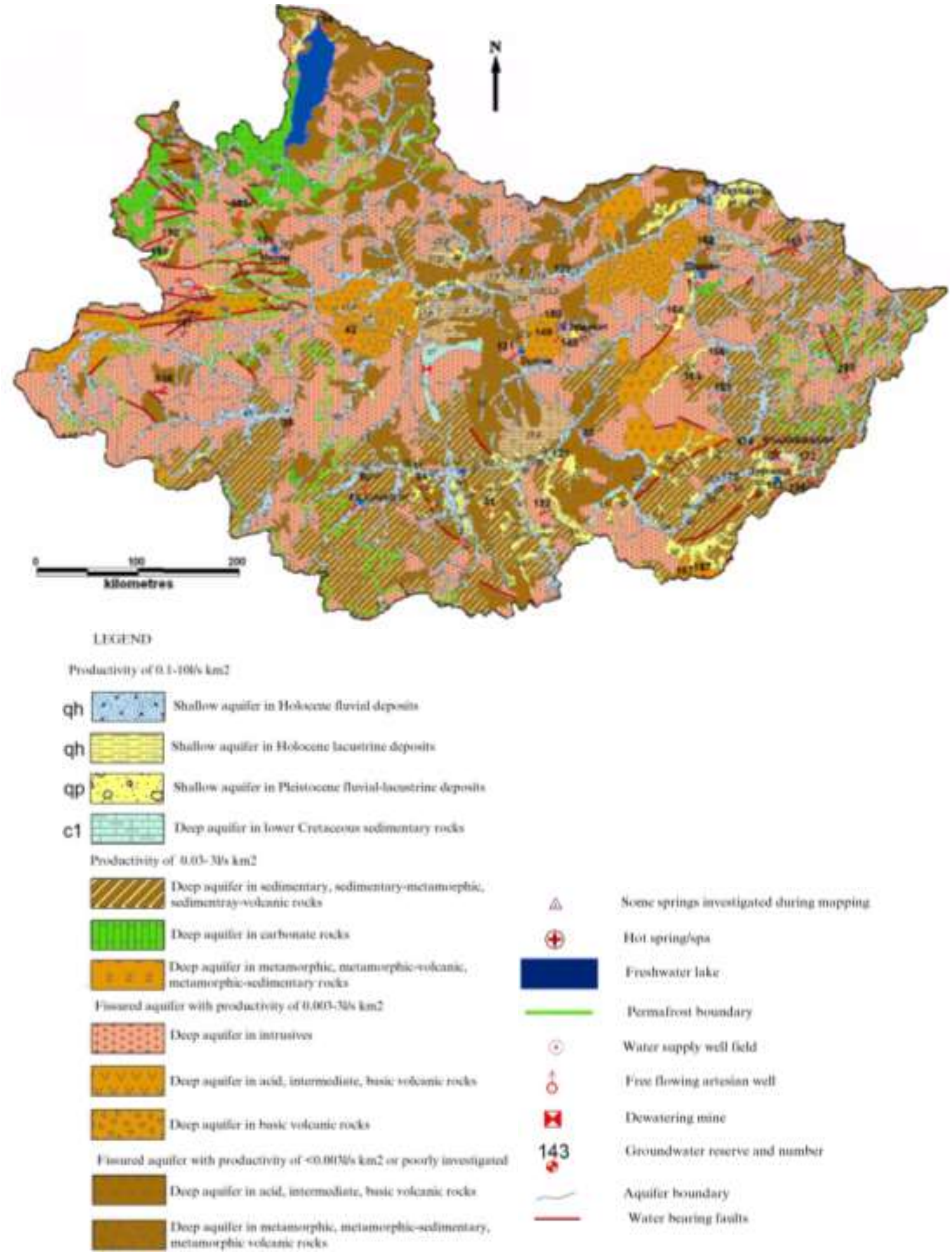


Figure 1.1. Hydrogeological map of Mongolian territory of the Baikal Basin, scale 1:3 000 000 (N. Jadambaa and P. Uuganbayar, 2012)

Water bearing sediments and rocks	*Water bearing rocks and sediments*	*Type of aquifer*	*Well yield, l/s*	*Spring yield, l/s*	*Drawdown, m*	*Specific yield, l/s*	*Chemical type of groundwater*	*TDS, g/l*
Neogene sediments and sedimentary rock	Sand, clay, gravel	confined	0.5-3.8	-	2.0-40.0	0.2-0.09	SO_4-HCO_3-Na, Ca	0.5-1.6
Cretaceous sedimentary rocks	Gravestone, conglomerate, sandstone, coal	confined	0.15-12.4 Up to 24.0	-	1.2-8.0	0.01-2.4	SO_4-HCO_3-Na	0.2-1.4
Triassic-Jurassic volcanic, sedimentary and metamorphic rocks	Basalt, andesite, sandstone, conglomerate, coal	confined unconfined	0.3-0.4	<5.0	1.0-1.5	0.3	HCO_3-Mg, Na, Ca SO_4-HCO_3-Na	0.2-0.3
Paleozoic sedimentary, metamorphic and volcanic rocks	Sandstone, shale, gneiss, conglomerate, andesite	unconfined	0.02-10.0	<14.0	4.5-17.0	0.01-0.7	HCO_3-Ca, Mg HCO_3-SO_4-Ca, Mg	0.1-1.2
pre-Paleozoic sedimentary, metamorphic and carbonate rocks	limestone, dolomite, shale, sandstone, conglomerate	confined unconfined	0.3-10.0	0.1-20.0 Up to 70.0	Up to 15.0	<0.7	SO_4-HCO_3-Na	0.3-1.0
intrusives with different ages	Granite, granodiorite, syenite	unconfined	0.1-4.3	0.6-20.0	2.6-5.1	0.03-0.84	HCO_3-Na, Ca	0.1-0.7 Rare 1.3

Table1.1. **Hydraulic characteristics and chemical composition of groundwater in aquifers in Mongolian territory of the Baikal Basin**

Calculated (2011) potential exploitable groundwater resources amount to 1.29 billion m^3 (3,558 thousand m^3/day) and renewable groundwater resources 2.96 billion m^3 (8,134 thousand m^3/day) in the Mongol Transbaikal groundwater unit.

Hydraulic characteristics and chemical composition of groundwater in aquifers in Mongolian territory of the Baikal Basin are shown in the Table 1.1.

Groundwater resources in Mongolian territory of the Baikal Basin

The total calculated potential exploitable groundwater resources in the Mongolian territory of Baikal Basin amount to 3.53 billion m^3 per year (9.78 million m^3/day), that is about 44% of total renewable groundwater resources (8.05 billion m^3 per year) in Mongolian territory of the basin. The current groundwater exploitation in Mongolian territory of the basin reaches 5.3% of total exploitable groundwater resources. The estimated exploitable groundwater resources of shallow aquifer in the Mongolian territory of the Baikal Basin amount to 2.76 billion m^3/year or 7.58 million m^3/day. Groundwater investigations have not been realized in the wider scale as yet in the river floodplain areas. Exploitable groundwater resources from shallow aquifers approved by Mongolian Water Resources Commission amount to 1.12 million m^3/day in the Mongolian territory of the Baikal Basin.

	Sub basin name	*Area km²*	*Calculated renewable groundwater resources*		*Calculated exploitable groundwater resources*	
			billion m³/year	*l/s /km²*	*billion m³/year*	*l/s /km²*
1	Selenge	30,983	1.104	1.13	0.697	0.7
2	Khovsgol-Eg	41,321	1.276	0.98	0.432	0.33
3	Delgermurun	23,018	0.435	0.60	0.229	0.32
4	Ider	22,757	0.507	0.71	0.129	0.18
5	Chuluut	19,813	0.296	0.47	0.086	0.14
6	Khanui	15,549	0.131	0.27	0.096	0.20
7	Orkhon	52,753	1.448	0.87	0.842	0.50
8	Tuul	49,416	0.960	0.62	0.641	0.41
9	Kharaa	17,463	0.381	0.69	0.182	0.33
10	Eroo	21,986	1.516	2.19	0.239	0.34
	Total	**295,059**	**8.05**		**3.573**	

Table 1.2. **Renewable and exploitable groundwater resources**
(*Source:* Groundwater Resources Assessment, in IWM, National Assessment report, 2012)

Renewable and potential exploitable groundwater resources are estimated in water resources assessment handbook produced by the project "Strengthening Integrated Water Resources Management in Mongolia". The methodology consists of the determination of the specific groundwater runoff (Table 1.2), aquifer potential yield per unit area (l/s / 1 km^2).

1.2 Hydrogeological conditions and present status of groundwater resources development on the Russian territory of the Baikal Basin

In the Russian territory of the Baikal Basin description of groundwater resources includes three administrative areas which partly coincide with geological units. The south-eastern part of the Irkutsk region coincides with the Lena – Kirenga Basin and partly with the Baikal Rift zone on south bank of the Lake Baikal, Republic of Buryatia coincides with main part of the Baikal Rift zone and Buryat territory of Transbaikalia and south-western part of the Transbaikal region coincides with small part of former Chita oblast, now Transbaikalia. Figure 1.2 shows geological structures on Russian territory of the Baikal Basin.

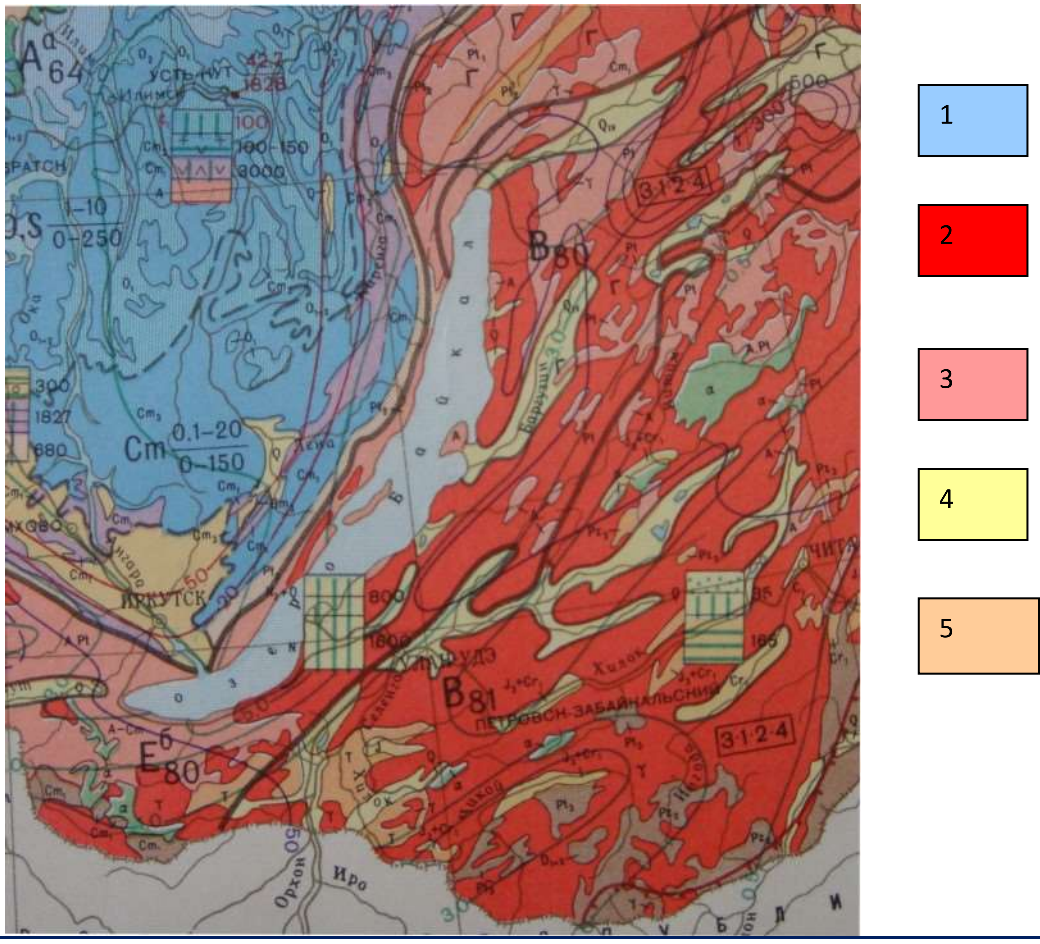


Figure 1.2. Schematic hydrogeological map of the Russian territory of the Baikal Basin (1:7,500,000). 1 – aquifer systems in carbonate, terrigenous deposits of Paleozoic age; 2 – aquifer systems in granites; 3 - aquifer systems in metamorphic rocks; 4 – aquifers in unconsolidated deposits of Cenozoic age; 5 - aquifer systems in consolidated deposits of Jurassic-Cretaceous age (Zaitsev I.K., 1966)

Irkutsk area of the Baikal Basin

The direction and magnitude of groundwater flows are controlled by the size, density, orientation and permeability of tectonic faults and fractures in metamorphic and igneous rocks of the Proterozoic and Archean age and consolidated sedimentary formations of the Paleozoic age. Aquifers in fluvial and lacustrine sediments of the Quaternary and Neogene age occur only locally.

Groundwater resources have been estimated in the year 2011 on about 2,789 thousands m^3/day and exploitable groundwater resources 820 thousands m^3/day. Exploitable groundwater resources have been assessed in 12 Irkutsk areas and amount to 33.74 thousands m^3/day.

Total extraction of groundwater resources reached 9.9 m^3 per day in the year 2011; for drinking water supplies have been used 7.43 thousands m^3/day of groundwater. The main drinking water users are the towns Slyudyanka (2.38 thousands m^3/day) and Baikalsk (4.11 thousands m^3/day). The groundwater quality meets the requirements of the drinking water standard. Available groundwater resources satisfy current and future needs for drinking water supplies. Groundwater extraction from mines of Khamar-Daban reached about 2.46 thousands m^3/day in the year 2011.

Buryat area of the Baikal Basin

Exploitable groundwater resources in the Republic of Buryatia were estimated on 103 million m³/day (State Report, 2012). Estimated exploitable groundwater resources in shallow aquifers inclusive of bank infiltration from the Selenga and other big rivers amount to 4 million m³/day (the surface water runoff in winter season from Mongolia and Trans-Baikal region was not considered in calculations). Groundwater in shallow aquifers meets the requirements of drinking water standards.

The TDS of groundwater in aquifers in central districts of Buryatia (the Borgoi, Low Orongoi, Ivolga intermountain depressions) due to low groundwater recharge reach 1-3 g/l. The estimated resources of slightly brackish groundwater amount to 10 thousands m³/day.

Exploitable groundwater resources have been evaluated in 76 groundwater intake areas however, only in 33 groundwater intake areas resources are exploited. Total exploitable groundwater resources calculated in the year 2012 reached 1.369.560 m³/day.

The distribution of exploitable groundwater resources is extremely irregular:

- 963.600 m³/day in the valley of the River Selenga and its big tributaries (752.400 m³/day are located in the vicinity of Ulan-Ude town);
- 316.600 m³/day in intermountain basins;
- 54.300 m³/day in hydrogeological massifs.

The available groundwater resources reach 1.4 m³ per person/day. However, in some rural settlements in the Ivolga and Selenga districts drinking water deficiency is registered.

Total extraction of groundwater resources reached 266.130 m³/day in the year 2011 and 194.380 m³/day in the year 2010. For drinking water supply purposes have been used 138.380 m³/day of groundwater (134.220 m³/day of groundwater resources were extracted for water supply of Ulan-Ude town), for industry 44.370 m³/day and for agriculture (inclusive of irrigation) 7.200 m³/day. About 27.490 m³/day of groundwater has been pumped from mines. The remaining groundwater resources were used for other purposes.

Transbaikalian area of the Baikal Basin

The exploitable groundwater resources in Transbaikalian area of the Baikal Basin have been estimated to an amount of 1,121,000 m³/day. The exploitable groundwater resources estimated in two areas in the Petrovsk-Zabaikalski and Khilock districts located in the Selenga-Dauria hydrogeological basin amount to 35,400 m³/day. In the Petrovsk-Zabaikalski district groundwater development is realized from water-bearing rocks of the Lower Cretaceous age (17,900 m³/day) and from fractured zone of intrusive formations (9,500 m³/day). In the Khilok district, extraction of groundwater is realized from water-bearing rocks of the Lower Cretaceous age to the amount of 6,240 m³/day, and 1,760 m³/day from water-bearing fluvial deposits in the river valley.

The total amount of usable groundwater resources on the Russian territory of the Lake Baikal Basin has been calculated to an amount of approximately 5,941,000 m³/day in the year 2011. Exploitable groundwater resources amount to 1,438,700 m³/day. The majority of them (1,405,060 m³/day) occur in shallow aquifers, while 33,640 m³/day are stored in in deep aquifers.

The whole area of the Russian territory of the Baikal Basin is supplied by groundwater resources, excluding the Selenga and Ivolga districts of Republic of Buryatia, where a shortage of groundwater for drinking water supply of local populations is registered.

Hydraulic and chemical characteristics of deep aquifers in Russian territory of the basin and amount of groundwater resources currently used for different purposes can be seen in the Tables 1.3 and 1.4.

Water-bearing rocks	*Sand-stones, sands and coals*	*Conglo-merates, sands, loams, sandy loams*	*Fissured sandstones, conglo-merates, coals and coal schists*	*Fissured conglo-merates, sands-tones and gritstones*	*Fissured metamorphic and lithified sedimentary rocks*	*Fault zones in sedimentary, magmatic and metamorphic rocks*
Age of water-bearing rocks	Neogene	Paleogene-Neogene	Lower Cretaceous	Jurassic	Upper Proterozoic - Lower and Middle Cambrian	Mezozoic and Cenozoic tectonic activizations
Type of aquifer	unconfined-confined	confined	confined	confined	confined	
Hydraulic conduc-tivity m/day	0.25	0.01-5.4	0.06-0.3 up to 120.0	less 0.02 up to 2	0.07-1.0	0.01-1.8
Trans-missivity m^2/day	26.0-52.0	0.4-39.0	1.3-11.0	from 0.26-50 to 250	2.5-400 even 2000	from 0.0 to 50-1500
Porosity	0.1-0.49	0.1-0.7	0.06-0.1	0.17-0.3	0.03-0.05	0.01-0.15
Specific yield l/s/m	0.2-0.4 up to 4.0	0.003 up to 0.1-0.3	0.01-0.2 up to 3.0-8.8	0.002-0.4 up to 1.0-2.4	0.03 up to 2.0-3.0 even 26.8	0.13
Chemical type of ground-water	HCO_3 – Ca, Mg, Na; HCO_3, Cl–K; Cl- K, CaCa, Na;	HCO_3 – Ca, Na, K; SO_4,HCO_3-Ca;	HCO_3 – Ca, Na	HCO_3 –Na	HCO_3, HCO_3 -SO_4 – Ca, Na, Mg	HCO_3 , HCO_3-SO_4 – Ca, Rn, Fe, F, NH_4
TDS g/l	0.2-0.4 up to 2.0-3.0	0.5-3.5	0.2-3.5	0.4	0.1-0.2 up to 0.8	0.1-0.2 up to 0.6

Table 1.3. Hydraulic and chemical characteristics of deep aquifers in Russian territory of the Baikal Basin (*Hydrogeology of the USSR,* Vol. XIX 1968, Vol. XXII 1970)

Groundwater use per sector	*thousands m^3/day*
Total groundwater intake	**311.43**
Drinking water supplies	181.21
Industrial water supply	44.37
Mining extraction	29.95
Agricultural water supply	7.20
Other purposes	48.7
Losses (groundwater discharge without use)	60.09

Table 1.4. The amount of groundwater resources currently used in different sectors (*State Report*, 2012)

2 | Shallow alluvial aquifers and their interaction with surface water

Significant groundwater resources in shallow aquifers occur in Mongolian and Russian territories of the Baikal Basin. Their interaction with adjacent rivers is registered in floodplain areas and in low river terraces. Hydraulic gradients between groundwater and surface water control the possibilities of bank infiltration of surface water to adjacent aquifers and vice versa. However, there are scarce or not available water level data for evaluation of 1/ interaction between both resources, 2/ share of infiltrated surface water on groundwater resources in shallow aquifers, 3/ the amount of groundwater discharge into surface streams, particularly in drought seasons, and 4/ transboundary groundwater flow in shallow aquifers in fluvial deposits in Mongolian-Russian transboundary areas.

Interaction between groundwater and surface water described in this chapter is focused on areas with potential occurrence of significant and economically accessible groundwater resources. Such areas with productive shallow aquifers are known in confluence areas of big rivers, in the valleys of the rivers and in Mongolian – Russian transboundary areas where thick and permeable fluvial deposits exist. However, it has been found that hydrogeological knowledge of such shallow aquifers is mostly restricted and data about their thickness, vulnerability, permeability and hydraulic properties as well as data about regular groundwater level measurements and groundwater chemistry and quality are scarce. Shallow aquifers are vulnerable to human and natural impacts. Environmental sound groundwater protection policy, specifically with regard to the possible impact of mining and industrial pollution sources on groundwater quality, has to be therefore established and carefully controlled.

Shallow aquifers developed in confluence areas and valleys of big rivers contain significant groundwater resources. Their hydrogeological investigation, regular quantitative and qualitative monitoring, groundwater resources assessment and sustainable use will significantly support countries social and economic development.

2.1 Interaction between groundwater of shallow aquifers and surface water in Mongolian territory of the Baikal Basin

Shallow aquifers in fluvial deposits composed mostly by porous sands and gravels of Quaternary age in Mongolian territory of the Baikal Basin contain significant, well accessible groundwater resources mostly of good quality. They are widely used for drinking water supplies as well as for industrial and agricultural purposes. Shallow aquifers occupy large areas of the floodplains of the Eg, Tuul, Orkhon, Selenga, Delger, Ider, Khanui, Chuluut, Kharaa and Yeroo Rivers. The major Mongolian cities, Ulaanbaatar, Erdenet, Darkhan, Murun, Sukhbaatar, Tsetserleg and Zuunkharaa use groundwater from shallow aquifers for drinking water supplies. However, groundwater investigations and monitoring specifically oriented on shallow aquifers in transboundary areas and evaluation of groundwater resources in highly productive shallow aquifers in the confluence areas of big rivers have not been realized as yet.

Confluence area of the Rivers Delgermurun, Ider, and Chuluut

Intrusive and volcanic rocks of Pre-Permian age are locally overlaid by fluvial deposits of Quaternary age (Figure 2.1). The fluvial deposits in the confluence area of the Rivers Delgermurun, Ider and Chuluut consist mostly of permeable gravels, sands, and sandy loams. Shallow aquifers thickness in these deposits ranges between 30 and 48 m. The average hydraulic conductivity is 139.9 m/day. The wells yield ranges from 7 to 15 l/s with a drawdown of 3.56-5.63 m. Total dissolved solids (TDS) reach 0.3 g/l and dominant groundwater and surface water chemical type is bicarbonate-calcium and magnesium.

Groundwater level in the well drilled on floodplain of Delgermurun River was 5.0 m below ground. TDS of groundwater in shallow aquifer amount to 0.4 g/l, well yield 4.5 l/s with a drawdown of 16 m. In the Ider River floodplain groundwater level was 9.5 m below ground. According to the "Integrated Water Management Model on the Selenge River Basin, Status Survey and Investigation - Phase I (2008) the flow of the Ider River is composed of 30% by groundwater, 25% snow water, and 45% rain water. The flow of Delgermurun River is supported by 30% of groundwater, 17% snow water, and 53% rain water. Groundwater of shallow aquifers interacts with surface water in the confluence area; however, there are no data available to quantify the interaction between both water bodies.

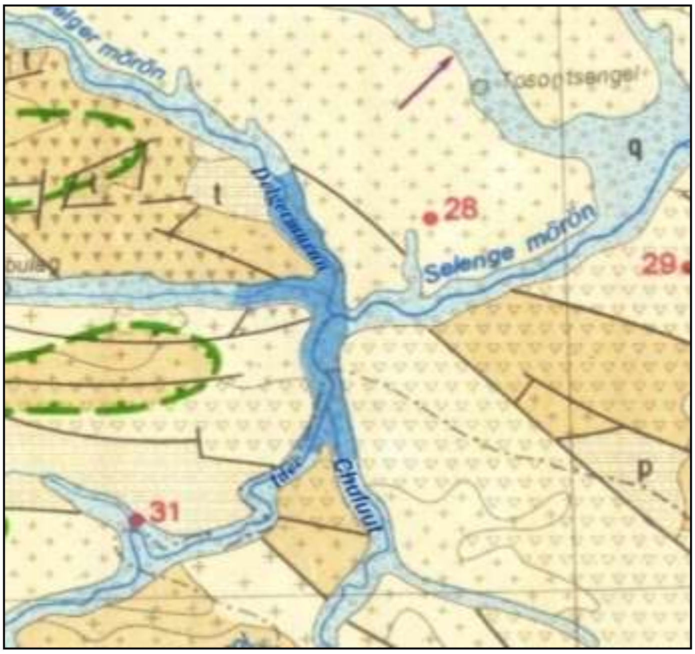


Figure 2.1. Confluence area of the Rivers Delgermurun, Ider and Chuluut (q: fluvial deposits of Quaternary age, t: sedimentary rocks of Triassic age, p: intrusive and volcanic rocks of Permian age), map scale 1 000 000 (Jadambaa, N., Enkhkhishig, 1996)

Confluence area of the River Selenge and River Eg

The Eg River discharges Khovsgol Lake, which is the deepest lake in Mongolia. The confluence area of the Rivers Selenge and Eg is composed by fluvial deposit of Quaternary age underlying by sedimentary rocks of Mesozoic age and volcanic, metamorphic-volcanic and metamorphic sedimentary rocks of pre-Permian age (Figure 2.2).

Yield of test wells drilled in the floodplain of the Selenge River for water supply of the town of Erdenet ranging from 99 to 144 l/s with drawdown from 0.7 to 2.7 m respectively. The thickness of the aquifer varies between 9 – 44 m, 36 m on the average. Groundwater level in the floodplain area is 4.0 m below ground, groundwater TDS 0.3 g/l. According to the "Integrated Water Management Model on the Selenga River Basin, Status Survey and Investigation Phase I (2008) the flow of the Eg

River is composed of 30% by groundwater, 17% snow water, and 53% rain water. Erdenet city exploited 97,800 m³/day of groundwater extracted from 23 wells located in shallow aquifers composed by permeable fluvial deposits. Dominant chemical type of groundwater is bicarbonate-sodium-magnesium.

Groundwater monitoring network is not established yet and relevant data about interaction between groundwater and surface water are not available. However, groundwater levels are closely to the ground and the probability of interaction between surface streams and shallow aquifers is high.

Figure 2.2. Confluence area of the River Selenge and River Eg (q: fluvial deposits of Quaternary age, c1-: sedimentary rocks of Cretaceous (Mesozoic) age, p: metamorphic-volcanic and metamorphic sedimentary rocks of Permian age), map scale 1 000 000 (Jadambaa, N., Enkhkhishig, 1996)

Confluence area of the River Orkhon and River Tuul

The Orkhon River head is on the south slope of the Suvraga Khairkhan Mountains. The source of the Tuul River is the Nergui River that rises at Shoroot Mountains. Intrusive, volcanic, metamorphic, meta-volcanic, meta-sedimentary and sedimentary rocks of Pre-Permian age are widely spread near the confluence area of Orkhon and Tuul Rivers. Fluvial deposits of Holocene age are found along the rivers floodplain. Fluvial and lacustrine deposits and carbonate rocks of Pleistocene age are partially distributed in the confluence area too (Figure 2.3).

The Orkhon River is the largest tributary of the Selenge River and the longest river in Mongolia. The flow of the Orkhon River around Bulgan area consists of 39% by groundwater, 11% snow water, and 50% rain water. Groundwater level in shallow aquifer in floodplain of the Orkhon River is 1.3 m below ground. Groundwater and Orkhon River water both are of bicarbonate-calcium type, groundwater TDS reach 0.5 g/l. Water levels in groundwater and surface water as well as chemical composition of both resources indicate interaction between shallow aquifer and river water. However, regular groundwater level monitoring does not exist till this time.

In fluvial deposits of the Tuul River floodplain dominate gravels, sands and clays of irregular thickness (5-65 m) and composition. In coarse-grained deposits are developed productive aquifers which groundwater level changes considerably during the year. When supply wells are not in operation the groundwater level in the Tuul River floodplain near the Ulaanbaatar city is from 2 to 6 m below ground in the winter season and 0.5 to 5.0 m in the summer season. Groundwater level in shallow aquifer in floodplain of confluence area is 5.0 m below ground, TDS amount to 0.3-0.4 g/l. According to the isotopic and chemical analyses, interaction between shallow aquifer in fluvial deposits in floodplain area and surface water in Tuul River near Ulaanbaatar city exists. Shallow aquifer receives seasonal recharge from Tuul river water (Naranchimeg and et al., 2011).

Figure 2.3. Confluence area of the River Orkhon and River Tuul (qh: fluvial deposits of Holocene age, qp-lacustrine deposits and carbonate rocks of Pleistocene age, t: sedimentary rocks of Triassic age, h: meta-sedimentary rocks of Carboniferous age, p: sedimentary rocks of Permian age), map scale 1 000 000 (Jadambaa, N., Enkhkhishig, 1996)

Confluence area of the River Orkhon and River Kharaa

The Kharaa River head lies in Khentii Mountains. The area near the confluence of the River Orkhon and River Kharaa is composed by sedimentary rocks of Mesozoic age, carbonate rocks of Pre-Permian age and fluvial-lacustrine deposits of Pleistocene age. Fluvial deposits of Holocene age are widespread along the floodplain of both rivers (Figure 2.4). Shallow aquifers in fluvial deposits of the Orkhon River occur in river floodplains and older terraces. Groundwater investigation realized in the vicinity of Kharkhorin city verified in shallow aquifer groundwater level 2 m below ground. By pumping test made on investigation borehole has been proved the yield 6.8 l/s and groundwater level drawdown 1.8 m.

According to the "Hydrogeological Map at the scale on 1:500 000 of the northeast part of Mongolia" (Koldisheva and et al, 1991) shallow aquifers in the fluvial deposits of Holocene age in the Orkhon River valley provide groundwater to the Hotol town from 7 water supply wells. Their specific yield is variable, ranges between from 11.9 to 33.4 l/s/m. At the site called "Barjgar Ulaan" hydrogeological studies confirmed the aquifer thickness of 50 - 60 m, specific yield 0.3 - 6.8 l/s/m, hydraulic conductivity 4.0-26.4 m/day, and transmissivity 123.0-776.4 m^2/day. Previous studies indicated that the Kharaa River water is composed of 43% by groundwater, 15% snow water, and 42% rain water. Water type of both groundwater and surface water is of bicarbonate-calcium type with higher content of magnesium. That indicates interaction between groundwater in shallow aquifer and river water. However, regular groundwater monitoring is not realized as yet.

Figure 2.4. Confluence area of the of River Orkhon and River Kharaa (q: fluvial deposits of Quaternary age, qh: lacustrine deposits of Holocene age, p: sedimentary rocks of Permian age, h: meta-sedimentary rocks of Carboniferous age), map scale 1 000 000 (Jadambaa, N., Enkhkhishig, 1996)

Confluence area of the River Selenge and River Orkhon and River Selenge shallow aquifer closely to Russian-Mongolian border

Highly productive shallow aquifers of the thickness over 100 m are developed in fluvial-lacustrine deposits of Pleistocene age and fluvial deposits of Holocene age in floodplains of the Selenge River closely to the Mongolian – Russian border (Figure 2.5). The pumping test confirmed the yield of the production well located in this area 38.4-48.2 l/s with a drawdown 2.45-3.73 m and hydraulic conductivity 42.5 m/day. Groundwater level was observed 1.3 m below ground and TDS reach 0.5 g/l (Jadambaa, 2012).

Groundwater level in the well No. 3 drilled near Sukhbaatar city has been observed 1.3 m below ground. Pumping test confirmed well yield 4.5 l/s with a drawdown of 1.5 m and groundwater TDS 0.5g/l. Around Sukhbaatar the flow of Selenge River consists of 36% by ground water, 18% snowmelt, and 46% rain water. Groundwater monitoring network has not been established till this time and there is a lack of information about potential interaction between groundwater in shallow aquifers and surface water in confluence areas of both rivers as well as in the area closely to the Mongolian – Russian border.

Hydrogeological parameters of the above described shallow aquifers in fluvial deposits in the Mongolian territory of the Baikal Basin are summarized in the Table 2.1.

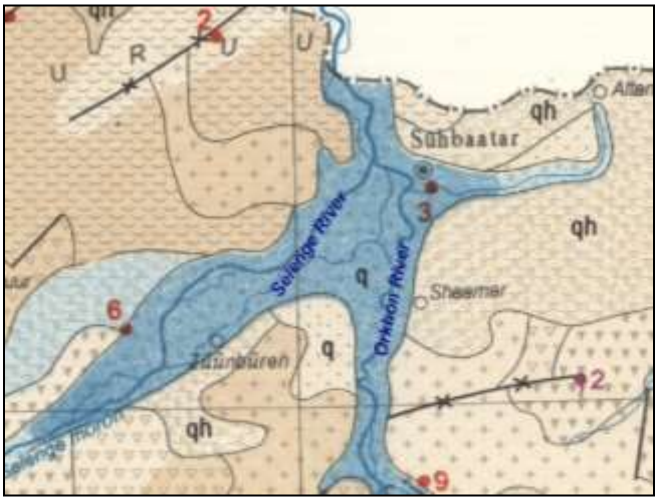


Figure 2.5. Confluence of the River Selenga and River Orkhon (q: fluvial deposits of Quaternary age, qh: fluvial deposits of Holocene age, qp: fluvial-lacustrine deposits of Pleistocene age, **map scale 1 000 000** (Jadambaa, N., Enkhkhishig, 1996)

Sub basin (settlements, cities)	*Well yield, l/s*	*Drawdown, m*	*Aquifer thickness, m*	*Hydraulic conductivity, m/day*	*Transmissivity, m²/day*
Selenge (Erdenet)	40-144	0.7-2.7	9-44	276.2	7319.3
Delgermurun (Murun, Burenkhaan)	7-45	3.5-5.6	30-48	139.9	5456.1
Orkhon (Sukhbaatar)	40-83.3	2.4-3.7	50-100	42.5	3187.5
Tuul (Ulaanbaatar)	23.7-48.8 up to 105	0.24-3.3	35-48	131	4847
Kharaa (Darkhan)	17-117.6	1.0-2.97	55.4	87.7	4654.3

Table 2.1. Hydrogeological parameters of shallow aquifers in fluvial deposits in the Mongolian part of the Baikal Basin

Future hydrogeological studies have to be focused on investigation, monitoring and evaluation of groundwater resources in productive shallow aquifers in fluvial deposits in confluence areas of large rivers like Tamir and Orkhon Rivers, Orkhon and Selenge Rivers, and Tuul and Orkhon Rivers as well as in shallow aquifers in floodplains with occurrence of thick and permeable fluvial deposits.

Some studies realized in the past showed interaction between groundwater in shallow aquifers and rivers water. E.g. near Ulaanbaatar city, during rainy season surface water discharges into shallow aquifers, in dry, cold season groundwater discharges into surface streams. Conditions for interaction between both resources during dry and wet seasons in areas affected by pumping have to be studied by water level monitoring and implementation of relevant models.

2.2 Interaction between shallow aquifers and surface water on Russian territory of the Baikal Basin

Shallow aquifers in fluvial deposits of Quaternary age contain significant, well accessible groundwater resources mostly of good quality. They are exploited for drinking water purposes in several cities and rural areas in the Russian territory of the Baikal Basin. E.g. interaction between groundwater in shallow aquifers and the River Selenga led to establishment of water supply system in the city Ulan-Ude based on bank infiltration of surface water into adjacent aquifers owing to series of wells located along the river bed. However, in many confluence areas with occurrence of productive shallow aquifers groundwater data are not available for the study of potential relation between both resources. Establishment of groundwater monitoring networks and additional hydrogeological investigation both will support knowledge about groundwater resources in shallow aquifers and their potential for social and economic benefits of local populations.

River Selenga shallow aquifer nearby the Russian – Mongolian border

The Selenga River crosses the Burguntuj ridge on the Mongolian – Russian border. The valley is narrow and the river is characterized by rapid flow. Fluvial deposits in the river valley are composed by sands of various granularity up to 10 m thick. There are underlying by fractured and monolithic gneisses. The well drilled in the north-western margin of Naushki railway station on the floodplain area reached the sandy loam 10 m thick followed by the crushed rock material of 20 m thick, and then entered into granite and gneisses. The well yield 3.4 l/s relates to 21 m of groundwater level decline (Hydrogeology USSR, 1970).

Groundwater level observed in three wells indicated seasonal fluctuation depending on precipitations and surface runoff. One well is located in floodplain and other two wells in the higher terrace. Groundwater level depends on well location and has been observed in the depths 2.6, 3.5 and 12.1 m below ground. Groundwater level decline is observed from October, continues to mid-November and slight groundwater level increase is observed in December due to seasonal freezing. Groundwater level does not change from January to April. In May and following wet season groundwater level continuously increase. Seasonal groundwater level fluctuation is associated with water level and related runoff in the River Selenga. However, interactions between River Selenga and adjacent shallow aquifers as well as transboundary groundwater runoff crossing the Mongolian-Russian border and potential transboundary movement of pollution plume are not possible to evaluate or detected because regular groundwater monitoring is not realized and relevant groundwater data are not available.

Confluence of the River Selenga and River Chickoy

The Chickoy River confluence with the River Selenga (Figure 2.6) occurs in the area of the Novoselenginsk village, crossing the ridge Chernaya Griva. The river valley is narrow and bounded by steep slopes on both banks. The thickness of the fluvial deposits composed by the coarse gravels and sands reaches 35 m. The deposits are underlying by the fractured syenite. The well yield 3.3 l/s corresponds to the groundwater level decline 7 m. The Chickoy River drains the groundwater artesian basin of the same name. Deeper aquifers occur in fissured porous conglomerates, sandstones, aleurolites and coals of the Low Cretaceous age. The groundwater level occurs 13-65 m below ground. In the fractured sandstones and conglomerates interlayered by coals are developed highly yielding aquifers. The yields of some wells reach 10-15 l/s, in some cases up to 60 l/s. Shallow aquifers are developed in fluvial deposits in the Chickoy River valley and in its tributaries. Their thickness is from 1.5 to 45 m. The wells yield 5-10 l/s relates to groundwater decline 2-3 m. The groundwater is of HCO_3-Mg-Ca type, and its TDS amount to 0.2 g/l (Table 2.2). For evaluation of interaction between surface and ground water relevant data are not available.

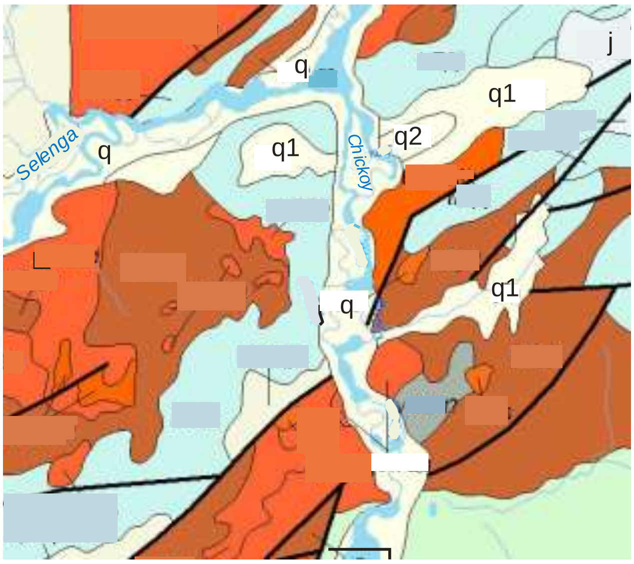


Figure 2.6. Confluence area of the River Selenga and River Chickoy, (q: fluvial deposits of Holocene age, q1: fluvial deposits of upper Quaternary age, q2: fluvial deposits of mid-Quaternary age, J: fluvial-lacustrine deposits of the Low Cretaceous age), scale 1: 500 000 (Yalovik, 2007)

Confluence of the River Selenga and River Djida

The estuary of the River Djida lies within the Borgoiskaya intermountain depression of the Mesozoic age. The maximum thickness of the Quaternary deposits in the Djida valley reaches mostly 60-70 m. The groundwater level occurs from 0.3-0.5 to 3-5 m below ground. The amount of groundwater in Quaternary deposits depends on their granulometrical composition. The highest well yields (3-4 l/s) have been registered in the coarse-grained sands and gravels where hydraulic conductivity achieves 127 m/day. The low wells yield 0.0004-0.0005 l/s (groundwater level decline 2-3 m) has been found in the shallow aquifer in the sandy clays of the fluvial-proluvial genesis, where the average hydraulic conductivity amounts to 1.85 m/day only.

The deposits of the Gusinoozerskaya series (argillites, conglomerates, aleurolites and sandstones) prevail among the sedimentary rocks of Mesozoic age. The main groundwater-bearing rocks are fractured argillites. The groundwater level in these deposits varies from 0-7 m below ground in the central part of the depression and from 30 to 47 m in its flanks. The aquifer productivity is low and depends on the degree of rock fracturing (well yield 0.01-0.1 l/s relates to groundwater level decline from 3 to 10 m). The groundwater occurrence in effusive formations of the Mesozoic age is associated by their exogenous fracturing that can be registered up 100 m below ground. In deeper rock environment rocks fracturing decreases. The specific yield reaches 1-3.5 l/s/m. The shallow aquifer system in the unconsolidated formations (predominantly boulder-pebble deposits, 50–60 m thick) of the Quaternary age is most productive, particularly in the upstream reach of the River Djida near Zakamensk town. The groundwater level has been observed from 5 to 50 m below ground. The well yield amounts to 5-6 l/s.

The River Djida is characterized by sharp changes in water discharge and water levels that can reach almost 5.60 m. Hence, significant variations in groundwater levels in adjacent shallow aquifers are observed too. Groundwater level increase over the land surface during floods is registered in the floodplain areas. However, regular groundwater level monitoring has not been realized as yet.

Confluence of the River Selenga and River Temnick

The estuary of the Temnick River lies within the Gusinoozeorskaya depression of the Mesozoic age. The aquifers in fluvial, fluvial - proluvial and deluvial-proluvial psephitic deposits are 2.5- 8 m thick. The groundwater level occurs at the depth 0.8-2.5 m below ground. The yield of wells reaches 2.8-3.1 l/s, related groundwater level decline is from 9 to 23m. TDS of the groundwater is from 0.1 to 0.3 g/l, and water is of HCO_3-Ca-Mg type (Table 2.2).

Two groundwater flows of different direction occur in the area of the River Temnick estuary. The first one connected with the River Tsagan-Gol is directed to the Lake Gusinoe. The other one in the shallow aquifer in floodplain of the River Bayan-Gol is directed to the River Selenga. Groundwater and surface water discharging toward the Tsagan-Gol tributary are influenced by the hydrological regime of the River Temnick. The return flow from existing irrigation canals into shallow aquifer is registered as well groundwater discharge from shallow aquifers into the River Bayan-Gol. Significant amounts of sulfate ion enter from coal-bearing rocks into aquifer and affect groundwater quality. Hydrological regime of the Lake Gusinoe influences quantitatively and qualitatively adjacent aquifer. However, regular groundwater monitoring does not exist and data about interrelation between groundwater and river and lake waters are not available.

Confluence of the River Selenga and River Khilock

The thickness of fluvial and fluvial-proluvial deposits reaches up to 50m. The yield of the wells located closely to the surface streams amount to 5 l/s, exceptionally 10-15 l/s. The groundwater level occurs from 3 to 5 m below ground. The permeability of the deluvial-proluvial, lacustrine-fluvial and aeolian deposits is generally low. Sands, sandy loams, disintegrated rock material with sandy loam are well permeable sediments. The yield of wells usually does not exceed 2-3 l/s, however, groundwater level decline is significant (several tens of meters). Underlying aquifers in the deposits of the Gusinoozerskaya series (conglomerates, sandstones, argillites) are under confined and unconfined conditions. The permeability of the rock matrix depends on spatial distribution and degree of its fracturing. The yield of the wells drilled in fractured rocks amount to 0.5 l/s. However, yield of wells located outside the fractured zones is significantly lower (0.001-0.0001 l/s). In the effusive formations of the Mesozoic and Neogene age fissured aquifers occur at the depth from 3 to 80 m below ground. The wells yield is from 0.2 to 3 l/s (groundwater level decline 10-20 m). The groundwater TDS do not exceed 0.5 g/l, and water is of HCO_3-Na-Ca type (Table 2.2). Groundwater and surface water data are not available for the study of interactions between rivers and shallow aquifers.

Confluence of the River Selenga and River Uda

The aquifer systems in the confluence area of the Rivers Selenga and Uda (Figure 2.7) are developed in rocks of different origin, age and permeability and their productivity and chemistry are widely variable. Hydrological interaction between groundwater and surface water exists in case of shallow aquifers in floodplains and lower terraces composed by Quaternary deposits.

The thickness of the recent fluvial deposits of the River Uda reaches 20-30 m, in case of the River Selenga locally exceeds 100 m. Groundwater levels in shallow aquifers in fluvial deposits (gravels, pebbly river drifts and grained sands with interlayers of sandy loams) vary from 0.5 to 6 m below ground. The amount of groundwater depends on permeability of fluvial deposits. The yield of wells located in the sandy deposits amounts to 0.5-1 l/s, in the pebble deposits 5-10 l/s. Hydraulic conductivity varies from 1-5 to 30-50 m/day respectively. Groundwater TDS in the aquifers in recent fluvial deposits does not exceed 500 mg/l, and HCO_3-Ca and HCO_3-Ca-Na types of groundwater prevail.

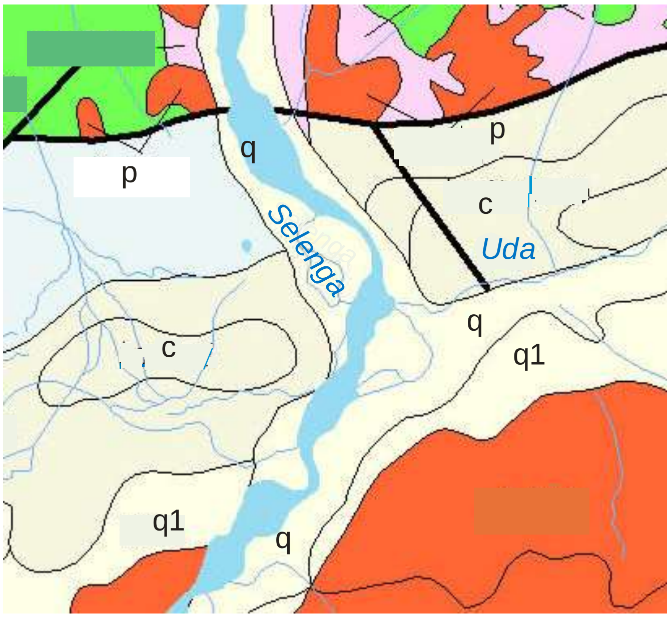


Figure 2.7. **Confluence area of the River Selenga and River Uda, (q: fluvial deposits of Holocene age, q1: luvial deposits of Quaternary age, c: fluvial deposits of the Cretaceous age, p: metamorphic-volcanic and metamorphic sedimentary rocks of Paleozoic age), scale 1: 200 000 (Yalovik, 2007)**

Aquifers in the Upper Quaternary and recent deposits are spread in the northern part of Ulan-Ude town in the valleys of small rivers and also within aprons and deluvial plains. Aquifers occur in sands, sands with crushed rocks, sandy loams and pebbles, and their productivity depends on their granularity and filtration properties. The yield of the wells is highly variable (from 100 l/s to 2-3 l/s) as well as groundwater level decline (up to 10 m). Hydraulic conductivity does not exceed 2-3 m/day.

The aquifer system in the lacustrine-fluvial mostly sandy deposits of Low-Middle Quaternary age is spread within floodplain terraces developed on the left bank of the River Uda. Aquifers thickness varies from 30-40 to 90-120 m. The average water well yield is from 2 to 6 l/s, groundwater level decline reaches up to 20 m. Hydraulic conductivity varies from tenths to a few meters per day.

The thickness of the aquifer system in the deposits of the Neogene-Low Quaternary age underlying the above described aquifers is between 10–65 m. The wells yield is up to 10-12 l/s, related groundwater level decline is from 5 to 15 m. Hydraulic conductivity is from 0.2 to 5 m/day.

The aquifer systems are developed also in underlying sedimentary rocks of the Cretaceous age (the Sotnikovskaya strata, Gusinoozerskaya deposits) and in the fissured zones of intrusive and metamorphic rocks spread in the northern and southern parts of the Ulan – Ude town within the mountain frame.

Hydraulic interaction between groundwater and surface water of the River Selenga is rather close. The width of the river channel near the studied area is 300-320 m, depth up to 5 m, average monthly river water discharge is 77-3,070 m^3/s (minimum in February and maximum in late July caused by summer floods). Annual amplitude of groundwater level fluctuation is from 144 to 249 cm. Replenishment of groundwater resources occurs in the period of high river runoff. The sediments of the river channel are permeable. Erosional river activity and erosion rate on the right bank of the river are high (about 6 m/year). A close relationship between groundwater in shallow aquifers and the River Selenga and higher permeability of the riverside sediments led to the decision to established water supply system based on advantages of bank infiltration of surface water into adjacent aquifers. Series of wells have been drilled along the right bank of the river at the distance of 160 m from the channel. The maximal extent of the zone where river waters influence on groundwater level has been registered in the River Ivolga valley (1.4 km). Additional studies and models have to be applied to determine factors that influence on groundwater level rise in the riverside territory and to better understand and use advantages of seasonal discharge of river water into the adjacent shallow aquifers and related seasonal changes in groundwater storage.

Selenga River Delta

The Delta of the Selenga River lies within the Usty-Selenginskaya depression of the Cenozoic age (Figure 2.8). Variety in permeability of groundwater-bearing deposits, their large thicknesses, and presence of faults involve jointly on hydrogeological conditions of the delta area (Figure 2.9). In the Usty-Selenga artesian basin (Figure 2.10) the following groundwater zones may be distinguished: 1/ zone with active groundwater exchange between aquifers occurs in the deposits of the Quaternary age up to 500 m below ground, 2/ zone of slow water exchange with confined aquifers in the deposits of the Neogene age up to 3,000 m below ground, 3/ groundwater in fractured crystalline rocks in the basement of the basin. Some aquifer systems are each other hydraulically connected due to the groundwater flow on the fractures (fissure permeability).

Figure 2.8. Satellite image of the Delta of the River Selenga

The aquifer system in the low permeable lacustrine and swamp deposits of the Holocene age occurs only in the Delta and Kaltus flexures. The thickness of the groundwater-bearing zone reaches 3-5 m. The depth of groundwater table below ground during the year seasonally changes from.2-0.3 to

1.0-1.6 m. The wells yield in sandy loams reaches 0.08-0.4 l/s (groundwater level decline 2.3-3.5 m) and in turfs 0.2-0.6 l/s (groundwater level decline 1.5-2.0 m). Groundwater occurrence in wells located in the sandy environment increases up to 1-2 l/s. Permeability is from 0.01-0.03 to 0.4-0.8 m/day in loams, 0.4-0.9 to 3.5 m/day in sandy loams and 0.1 to 4.5 m/day in turfs.

The aquifers in fluvial deposits of the Upper Pleistocene and Holocene age (highly permeable boulders, gravels and sands) are extended in the floodplain areas and low terraces of the Selenga and Kabanya Rivers. The thickness of the groundwater-bearing formations reaches 80-120 m. Groundwater level occurs 2-3 m below ground in floodplains and 8-15 m below ground in the low river terraces. Groundwater is under local pressure in the Kaltus flexure where can be found in the depth 8-12 m. Groundwater piezometric level is recorded 1.2-2.5 m below ground. The above described aquifer system is very productive. The yield of wells located in the River Selenga floodplain areas reaches 26-40 l/s, groundwater level decline is very small (Domracheev, Moiseeva, 1964). The wells yield sited in the pebble-sandy deposits in the floodplain terraces reaches mostly 2-3 l/s, rarely 7-9 l/s. The average values of hydraulic conductivity 30-70 m/day in pebbles, 8-20 m/day in sandy-pebble deposits and 5-10 m/day in sands. The groundwater resources in the shallow aquifer system are significant source of drinking water. However, their use is limited by high content of iron (up to 50 mg/l).

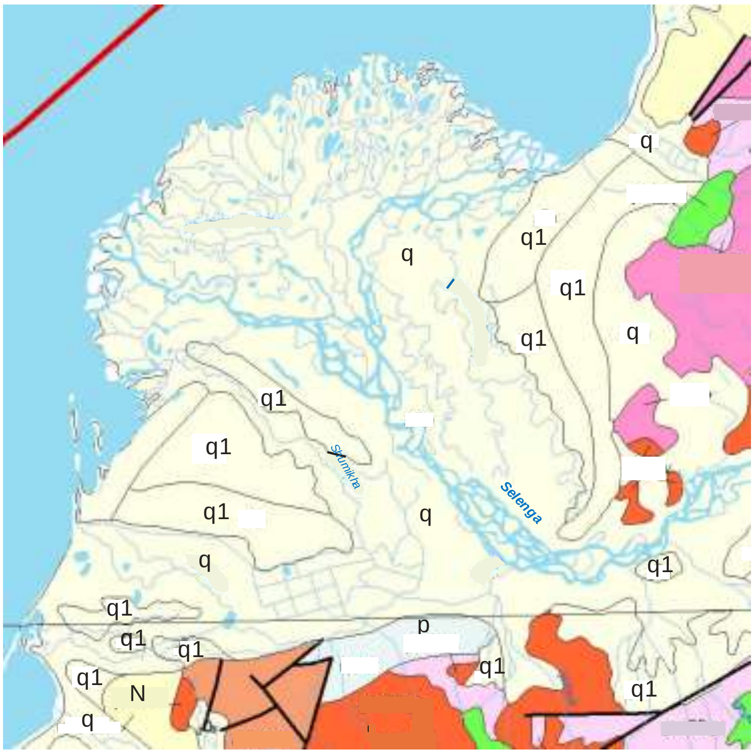


Figure 2.9. Delta of the River Selenga (q: fluvial deposits of Holocene age, q1: fluvial deposits of Quaternary age, N: fluvial deposits of Neogene age, deposits of Jurassic age), scale 1: 500 000 (Yalovik, 2007).

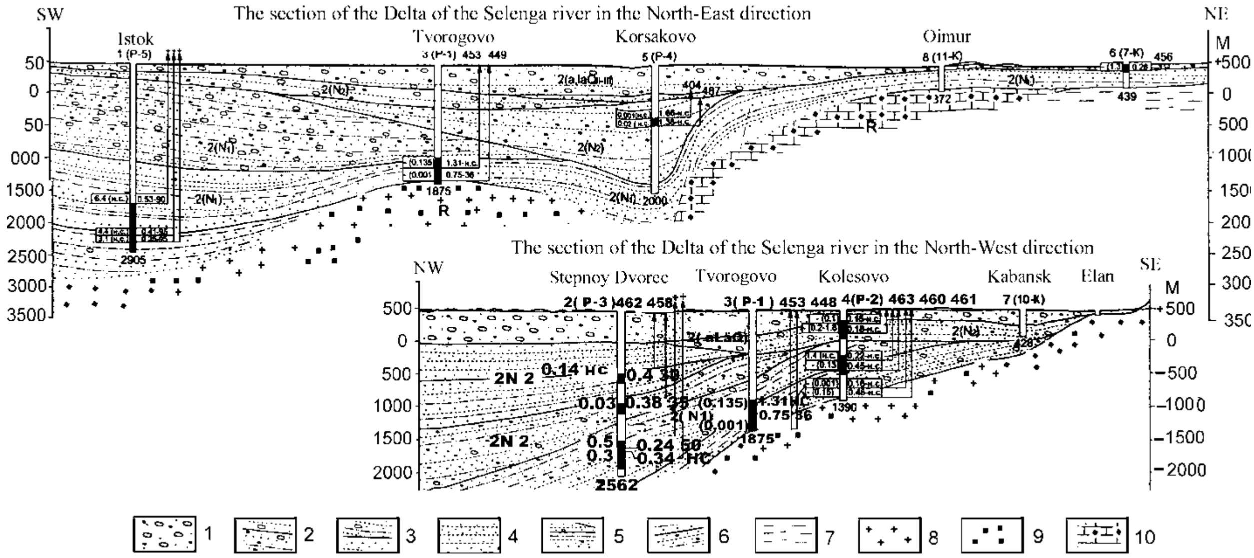


Figure 2.10. Hydrogeological cross-sections of Usty-Selenginsk artesian basin. 1: gravel-pebble-sandy sediments, 2: gravel-pebble deposits with sand and interlayers of clay, 3:- intercalation of sand, clay, shale and siltstone and sandstone, 4: gneiss, 5: granites, 6: granite and gneiss, 7: quartzites.
Well – top: location; figures from the bottom: depth (m); black-out in the well: tested interval
(Tulochonov and Plyusnin, 2008)

The aquifer system in the deluvial and proluvial deposits of the Upper Pleistocene age is associated to the gently sloping margins of the depressions. Deposits are composed by the weakly sorted material of variable lithological composition: crushed rock, gruss, pebbles, gravel, sand, sandy loams and loams. Sorting of the unconsolidated material becomes evident from marginal parts to the centre of the basins. The aquifer system is split up by low permeable layers of clays and loams into several local, each other interconnected aquifers. The groundwater level occurs 1.2-8.5 m below ground. The wells yield is variable: 7.5-10 l/s in the pebble deposits (groundwater level decline 2.8-5 m), 0.001-0.8 l/s in sands and loams (groundwater level decline 1-24 m). Hydraulic conductivity of the pebbles deposits is 21-93 m/day and of sands and loams 0.05-1.0 m/day.

Aquifer system in the deposits of the Neogene-Eopleistocene age occurs below groundwater-bearing deposits of the Quaternary age (zone 1) in more than 3000 m below ground (zone 2). Due to their lithological features they are of different permeability. The deep aquifers are confined, their piezometric levels are 32.5 m and less below ground. Groundwater overflowing pressure in the head of the wells reached 5 to 20 atm. The amount of groundwater resources in the aquifer system differs. Wells yield reaches 1.2 - 6.4 l/s in sandstones and sandy-gravel deposits and 0.1-0.9 l/s in the fine-grained sediments. By log measurement methane has been identified in the composition of groundwater gases. The groundwater chemical composition is characterized by high content of iron (up to 48 mg/l).

In the Selenga River Delta seasonal interaction between the surface water in the Lake Baikal and shallow groundwater has been observed. The Baikal depression drains shallow groundwater flowing from the surrounding areas as well as deep aquifers into the Baikal Lake. In the central part of the delta bogy areas are extensive. In marginal parts of the Usty-Selenga Basin permafrost with thickness up to 30 m occurs. Hydrogeological investigation and groundwater monitoring are needed to improve knowledge about groundwater and surface water relation in the Selenga River Delta and groundwater dependent ecosystems.

River Berguzin above its inflow to the Lake Baikal

The hydrogeological conditions of the Cenozoic Barguzin intermountain depression are largely determined by the wide occurrence of permafrost rocks. Three types of permafrost areas may be distinguished: 1/ areas without permafrost rocks, 2/ areas with near-surface permafrost and 3/ areas with deep permafrost.

The areas without permafrost are found along the north-western part and in the southern final part of the depression. The width of the melt rock band at the foothill trail of the Barguzin ridge side reaches 5-7 km, and broaden up to 8-10 km in the river valley. Thawed zone has been formed owing to the warming impact of the infiltrating surface water and intense underground runoff.

Area with occurrence of near-surface permafrost rocks is known in the floodplains and low river terraces. It occupies the central part of Barguzin depression. The minimum depth of the permafrost strata achieves 6-7 m and expands into the north-eastern direction. In the final part of the depression the thickness of permafrost rocks reaches up to 300 m.

The aquifer system in the lacustrine and lacustrine-swamp deposits of the Upper Quaternary and recent age has been identified in the Barguzin River valley and in its left bank tributaries. The groundwater-bearing sediments are represented by boulders, pebbles, sands of various grain-size and sandy loams and loams. Coarse deposits prevail in the River Barguzin tributaries. Their thickness varies from several meters at the flanks of the basin up to 130-150 m in zones of the latest tectonic activities in the center of the depression. These deposits are frozen in the large area. Seasonally thawed layers are formed above-permafrost in the warmer months of the year. Its thickness is 0.6-0.8 m. The wells yield does not exceed 0.4 l/s. Permafrost 'taliks' (thawed sediments) are distributed only locally. Their thickness is up to 22 m. Sub-permafrost water has been found from 7 to 46 m below ground.

The Barguzin depression is characterized by surface water drainage into groundwater in the foothill trails. Many rivers that flow from the Barguzin and Ikat ridges successively infiltrate in the coarse sediments of aprons. The amount of infiltrated river water reaches 3-6 m^3/s. The zone of influence of groundwater recharge by surface water level attains 15 km. Regular groundwater monitoring is needed to precise calculations related to the surface water and groundwater interface and exploitable groundwater resources.

River Upper Angara above its inflow to the Lake Baikal

The thickness of sedimentary formations of various geneses has been estimated from 700 to 2,500 m in the estuary of the Upper Angara. The fluvial-proluvial sediments of Upper-Pleistocene age are 25-40 m thick. They are composed by boulder and gravel-pebble deposits with sandy and loamy fillers. The alluvial sands of the Mid-Pleistocene age are more than 26 m thick and are overlain by pebbles. The groundwater level occurs 1-4.5 m below ground and thickness of the aquifer reaches 23.5 m. The presence of the loamy filler is reflected in lower occurrence of groundwater resources, e.g. the yield of the wells is from 2.9 to 4.8 l/s and related groundwater level decline is from 1.6 to 6.8 m. Hydraulic conductivity reaches 9.8 m/day (Table 2.2). Range of seasonal groundwater level variations attains up to 3 m. Regular groundwater monitoring is needed to collect and evaluate data related to the interaction between groundwater and surface water.

Groundwater characteristics Confluence of rivers	*Thickness of aquifer, m*	*Specific yield, l/s/m*	*Hydraulic conductivity, m/day*	*Trans-missivity, m²/day*	*Porosity*	*Chemical type of ground-water*	*TDS, g/l*
River Selenga shallow aquifer closely to the Russian-Mongolian border	30	0.16	0.7	20.8		HCO_3,SO_4– Ca,Mg,Na	0.3-0.5
Confluence of River Selenga and River Chickoy	1.5-45	1.7-5		221-650		HCO_3 – Ca,Mg	up to 0.2
Confluence of River Selenga and River Djida	50-60	0.0002-4.0	1.85-127	0.026-650	0.35-0.72	HCO_3 – Ca	up to 0.5
Confluence of River Selenga and River Temnick	2.5-8	0.12-0.3	0.1-3.6	15.6-39		HCO_3 – Ca,Mg	0.1-0.3
Confluence of River Selenga and River Khilock	50	3-5 up to 10-15	7.8-39	390-1950		HCO_3 – Ca,Na	0.2-0.4
Confluence of river Selenga and River Uda	20 - 100	0.3 - 10	1-5 - 30-50			HCO_3 – Ca,Na	0.3-0.5
Selenga River Delta	80-120	2-3 up to 40	5-70			HCO_3 – Ca,Na	0.2-0.4
River Barguzin	130-150					HCO_3 – Ca,Na	0.1-0.2
River Upper Angara	140-200			230		HCO_3 – Ca,Na	0.1

Table 2.2. Hydraulic characteristics and chemical composition of groundwater in shallow aquifers on Russian territory of the Baikal Basin

3 | Man-made threats on groundwater resources

Solid and liquid wastes of different origin are significant sources of groundwater pollution in the Baikal Basin. In Mongolian territory of the basin mining and domestic wastes and in Russian territory industrial and domestic wastes are the main potential pollutants of water resources.

Environmental sound management of mine solid wastes and waste water is particularly important in the Baikal Basin because mining and processing of gold, copper, molybdenum, coal and other mineral resources produce wastes often with high content of toxic constituents. Sources of wide range of impacts on groundwater quality are uncontrolled leakages of waste water from ore washing and dressing facilities, post-extraction processing of mining material, coal preparation, uncontrolled leakages from tailings, piles, evaporation ponds and other disposal sites. Excessive pumping of mine waters may produce impact on groundwater quality too.

The engineering design of landfills, installation of impermeable layers and drainage systems at the base of the landfills and establishment of site specific groundwater monitoring networks around the mining and processing facilities as well as construction of treatment plants to treat liquid waste leakages and mine waste water are the essential protective measures for reducing or even eliminating impact of mining wastes on groundwater system. Use of environmental sound mining and processing technologies, often financially demanding, which restrict production and amount of waste and toxic constituents together with regular control of landfills environmental safety have to be included in regulations of mining concession and mining operation.

Similar approach requires environmentally sound control over industrial wastes. Design of landfills and applied chemical treatment technologies have to be related to the chemical composition of produced wastes. Waste water volume and concentration have to be reduced as much as possible and regularly monitored.

Only few disposal sites of domestic wastes meet the requirements for safe management of produced wastes in the territories of both countries in the Baikal Basin. Environmental sound policy has to be applied particularly in construction and location of new safe landfills described above. Comprehensive hydrogeological investigation has to be realized before decision is made about landfills siting. Impermeable geological environment, groundwater level deep below ground, groundwater flow direction, landscape morphology, distance of the landfill from water supply systems and the nearest population centres are the main criteria for landfill site siting and operation. However, wastes selection and recycling and organic wastes composting are some of activities and technologies used for reduction of produced wastes. Treatment technologies applied for collected municipal and domestic waste water have to include physical, biological and chemical treatments and capacity of the treatment plants has to correspond to the contemporaneous and future requirements on waste water safe management. Treated waste water has to be used in the wider scale for aquifers replenishment and for irrigation and industrial purposes.

Diffuse nitrate and pesticide pollution of groundwater by agricultural activities is not registered in the Baikal Basin as yet, because amount of used fertilizers and chemicals is low in comparison with e.g. European countries and USA. A coordinated effort between agricultural and water sectors is however needed to define in time policy for sustainable management of agricultural production and environmentally sound protection of groundwater resources. Control measures depend above all on the steps taken in the agricultural sector. Maintain traditional crop rotation system, control fertilizers and pesticides application (e.g. type, amount and doses applied, time of application with respect to the crops type),selection of suitable cultivation techniques (especially tillage), soil quality conservation (e.g. maintain of soil organic matter), and groundwater quality monitoring (monitoring of unsaturated zone and vertical profile of the aquifer to control nitrate transport and transformation processes) are the main attributes of environmental friendly agricultural production. Keeping dynamic stability of the soil organic matter is pointed out with respect to the protection of groundwater. The nitrogen and carbon balance is essential for gaining insight to the physical, chemical and biological processes which take place in the soil-unsaturated zone and which control the amount of nitrogen leached in the saturated aquifer.

Irrigation of arable soils has been applied in several areas of the Baikal Basin. Monitoring of the return flow is needed because irrigated water contributes to the growing salinity of the soil and leached salts are transported to the underlying shallow aquifers and degrade the quality of groundwater.

Groundwater protection zones around drinking water supplies and recharge areas lead to the consecutive reduction of human activities. Particularly crop and root farming have to be often limited and controlled in areas where protection zones are established. The objective evaluation of farmers' past production and allocation of costs and benefits between agricultural and water sectors are the key factors in the strategy of sustainable utilization of soil and water resources and in establishment of environmental sound protection policy of both resources.

Groundwater resources depletion has been registered locally in Mongolian territory of the Baikal Basin. Recognition of the impact of intensive abstraction of groundwater resources for irrigation, mine fields dewatering, drinking water supplies and other purposes is almost always based on hydraulic phenomena. However, subtle changes in groundwater chemical composition caused by pumping may be often observed before becoming evident from groundwater level decline. Groundwater monitoring both quantity and quality should be therefore implemented and targeted on the specific groundwater quality problem caused by intensive aquifer exploration.

In highly productive arable lands in the Kharaa River valley and downstream of the Orkhon River and in other areas in the Baikal Basin with intensive agricultural activities as well as in areas with large mining operations and in industrial centers comprehensive cooperation between agricultural, mine, industrial sectors and water sector has to be established in Mongolian and Russian territories of the Baikal Basin with the scope to control and prevent the man-made threats on groundwater resources and groundwater dependent ecosystems on the transboundary and countries levels.

3.1 Management of solid and liquid wastes in Mongolian territory of the Baikal Basin

Uncontrolled leakages of solid and liquid wastes from mining facilities and municipal waste disposal sites are the main sources of groundwater pollution in Mongolian territory of the Baikal Basin. Particularly in large cities e.g. Ulaanbaatar, Erdenet, Darkhan and Sukhbaatar are registered many potential point pollution sources, uncontrolled waste disposal sites and discharges of poorly treated or untreated waste water. Data about the impact of mining activities on groundwater quality are missing because site specific monitoring networks around mining sites are not established. However, at present there are planned and projected several activities focused on improvement of waste management, waste water treatment, construction of safe landfill sites, recycling of solid and liquid wastes and others. E.g. Japanese project on development of Master plan for solid waste management in Ulaanbaatar financing by JICA (Japan International Cooperation Agency) has been realized.

Management of solid and liquid domestic wastes

Cities and rural settlements often located along or nearby the rivers are the main producers of solid and liquid wastes in the Mongolian territory of the Baikal Basin. More than half of Mongolian populations live in the cities and produced wastes are disposed in 490 mostly uncontrolled waste disposal sites/dumps (MARCC, 2009).

In Ulaanbaatar 1,500-1,800 m^3 daily and 650-700 thousand m^3 annually of solid wastes are produced. According to the World Heath Organizations the daily production of solid wastes per person in Ulaanbaatar amount to 0.334 kg (MARCC, 2009). Two disposal sites are available in Ulaanbaatar. The older one is uncontrolled waste disposal site without relevant protective constructions and drainage systems. The new sanitary landfill called Narangiin Enger has been constructed within Japanese Governmental Grant and its operation started in the year 2008. About 75% of produced wastes is collected and transported by municipal companies on both disposal sites, 15% wastes is managed by private companies and 10% wastes are deposited on many illegal uncontrolled waste disposal sites in the urban area of Ulaanbaatar. Illegal wastes dumping has become a serious environmental issue in Ger (traditional tent-like housing) district of Ulaanbaatar where many nomadic people are living. Open garbage disposals are linked to the environmental degradation, including the pollution of soil and groundwater. Similar situation in solid waste management exists also in other Mongolian cities.

In Ulaanbaatar operate 2 chemical, 4 mechanical and 7 biological waste water treatment plants. In total, 62.1% of waste water are treated biologically, 37.6% mechanically and only 0.3% chemically. Almost all (95%) treated waste water is discharged into the Tuul and Bayangol Rivers. Efficiency of the central waste water treatment plant in Ulaanbaatar is only 60-70%.

Totally, 58 municipal waste water treatment plants are located in the Mongolian territory of the Baikal Basin. In some major towns, as well as aimag and soum centers, basic sewerage networks were constructed. Waste water mechanical and biological treatment systems consisting of aeration, sedimentation and chlorination are established in many waste water treatment facilities, while simple pond systems are used in the smaller treatment schemes. About 91 million m^3 of waste water is treated annually in the Mongolian territory of the Baikal Basin. Waste water produced by the cities Darkhan, Zuunkharaa and Ulaanbaatar (160,000 m^3/day) is not adequately treated and is registered as important source of pollution of the Kharaa and Tuul Rivers.

The waste water treatment plant of Darkhan city came into operation in the year 1965 and was reconstructed in 1998. The capacity of the treatment plant amount to 50 000m^3/day however, only 18,000 m^3/day of waste water is treated. Under the project of UNEP partnership quality of surface water in the Selenge River Basin was studied in the year 2008. Chromium content (0.26 µg/l) was detected near the discharge of treated water from Darkhan treatment plant.

In the Mongolian- Russian transboundary area a waste water treatment plant with a capacity to carry out biological treatment of 450 m^3 wastewater per day was established in Altanbulag soum of Selenge aimag in 1970. However, wastewater treatment plant is out of operation and its only function is to collect and discharge untreated wastewater into the river.

For expanding Erdenet city waste water treatment plant construction started in the year 2009 with technical and financial contribution of France. Plant is now in operation and the intention is to treat up 48,000 m^3 wastewater per day (originally 31,400 m^3 per day of wastewater was treated). A modern treatment technology applied increased treatment efficiency up to 98%. In the past waste water was discharged into the Khangal River which pollution was higher than the treated waste water from the treatment plant (Baldangombo, 2012).

There is no evidence about groundwater pollution by municipal wastes, liquid or solid, because groundwater monitoring networks around waste disposal facilities have not been established till this time.

Management of solid and liquid mining wastes

In the Selenge River Basin over 400 gold-mining companies were registered in the year 2006. Among the main pollutants produced by gold mining activities are mercury and cyanide. Almost 200,000 tons of mercury-containing slime (Figure 3.1) is deposited in uncontrolled disposal sites in Selenge River Basin (Lake Baikal Basin TDA, 2013). Elevated levels of mercury have also been detected in the urine of the area's inhabitants. Wastewater and sludge produced by Boroo gold mining activities and stored in reservoirs can be considered as extremely danger potential toxic pollution sources.

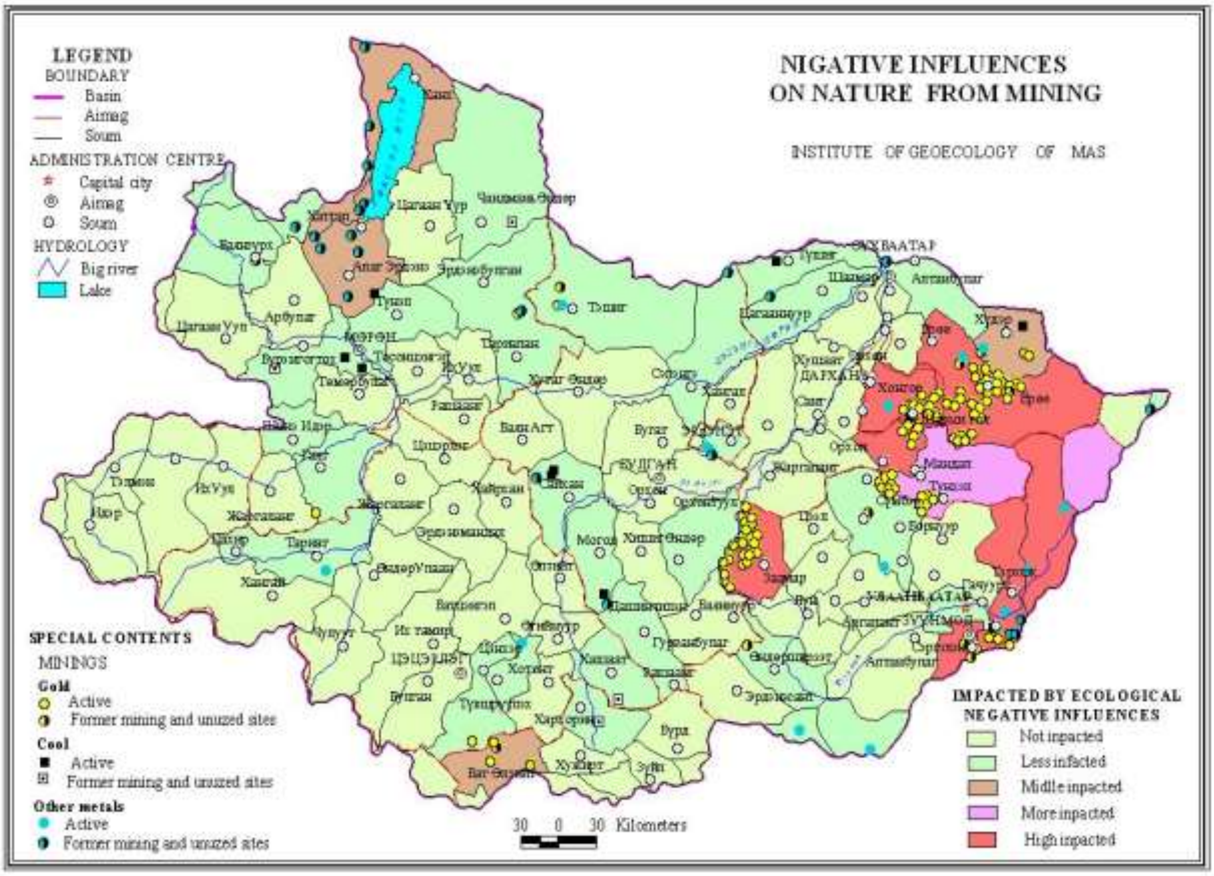


Figure 3.1. Impact of mining activities on environment and water resources in the Selenge River Basin

Copper mining and associated tailing dams are other potential pollution sources of groundwater. Mining companies such as the joint Russian-Mongolian copper and molybdenum ore processing and dressing plants in Erdenet have been identified as the source of pollution of the Orkhon River. The mean content of arsenic in the Khangal River was 2.17 μg/l and it ranges from 0.4 μg/l to 20.2 μg/l in tailing waste water (UNEP- NISD, 2008).

Data about groundwater quality in mining areas are scarce and extent of potential groundwater pollution is not well known. However, pollution of shallow aquifers by heavy metals has to be considered as a serious environmental issue in mining areas. Groundwater quality monitoring and other activities have to be implemented to protect groundwater against pollution, especially in the river basins where use of mercury or cyanide for gold mining activities are registered.

Management of solid and liquid industrial wastes

Wood and cashmere processing factories and tanneries are operating in the floodplains of the Tuul River and produce the wastes with significant amount of heavy metals and toxic substances. Tanneries are concentrated in the bigger urban centers such as Ulaanbaatar, Darkhan, and Erdenet. E.g. 46 tanneries were registered in Ulaanbaatar in the year 2008 (26 functioning permanently and others operating during winter time only). They use chromium-based technology to process skin and wool. All tanneries are obliged to pre-treat their waste water before to be connected to the municipal waste water treatment plant. However, in Ulaanbaatar most of the new settled tanneries do not have waste water pre-treatment plants and there are not connected to the municipal sewerage network (Lkhasuren, 2008). Content of chromium in surface water have been reported in the in the Kharaa River downstream of Darkhan city. Chromium content does not exceed yet the drinking water standards. Potential impact of tanneries on surface water and groundwater quality is not regularly observed and relevant groundwater protection policy to regularly control impact of industrial pollution on water resources is not implemented as yet.

Impact of agricultural activities on groundwater quality

The Selenge River Basin is the main Mongolian area focused on various farming activities. However, the size of farm lands is very small in comparison to the whole river basin. Any special studies focused on the impact of nitrogen fertilizers or pesticides on the soil and groundwater quality in the Selenge River Basin were not conducted. In 2002 have been applied on 1 hectare of arable land 4.9 kg per year of fertilizers and in 2008 amount of applied fertilizers increased on 8.2 kg/ha/year. Mainly industrial fertilizers such as ammonium nitrate, super phosphate and potassium chloride are used (Demeusy, 2012). Various chemicals (herbicide, fungicide, and others) are also applied; however, application of slowly decomposed chemicals is prohibited.

Nutrients concentration in surface water and groundwater are still low in the Selenge River Basin. Increasing concentrations of phosphorus and nitrate are reported downstream of the Orkhon River and in the Kharaa River Basin, but there are still below the drinking water standards.

Crop farming is rapidly developing in Mongolia. Increasing use of fertilizers and chemicals with the scope to increase crop production will involve on soil and groundwater quality in shallow aquifers. Groundwater diffuse pollution by nitrate registered worldwide may occur in Mongolia too. In areas where agricultural activities depend on irrigation, irrigation return flow has to be controlled, because leads to groundwater pollution.

Intensive use of groundwater resources and depletion impact

Groundwater shortages due to the population growth and groundwater pollution are registered in some areas of the Mongolian territory of the Baikal Basin. Hydrogeological investigation and evaluation of potential impact of mining and industrial activities on groundwater resources both quantity and quality has not been realized on the relevant level till this time. Furthermore, the sustainable rate of exploitation of local surface and groundwater resources has already been exceeded in high water demand areas, including the Tuul and Shariin River Basins close to Ulaanbaatar. Establishment and operation of site specific monitoring networks around water supply systems and other groundwater abstraction sites and groundwater data evaluation will support groundwater protection policy and sustainable development and management of groundwater resources.

3.2 Management of solid and liquid wastes in Russian territory of the Baikal Basin

Man-made threats on groundwater are related to the leakages from uncontrolled waste disposal sites and poorly treated or untreated waste water. Domestic and industrial waste disposal sites and waste water from municipalities, industrial centers and mining areas are the main sources of pollution which can affect on different levels and geographic scope groundwater and groundwater dependent ecosystems.

Management of solid and liquid domestic wastes

In the central part of the Baikal Basin (areas on the Lake Baikal shoreline), several companies are licensed to provide various services for municipalities and industrial sectors, such as treatment of municipal and industrial wastewater, and collection and disposal of solid wastes in the Irkutsk region (Slyudyanka and Irkutsk towns, Olkhon Island) and Buryat Republic (Kabansk, Pribaikalie, Barguzin and Severobaikalsk areas and Severobaikalsk town).

In the area of the Slyudyanka administrative region, there are available two authorized municipal disposal sites. One disposal site (4.0 hectares) is sited 300 m away from the Talaya River and 5 km from Lake Baikal. Groundwater monitoring network is not established around the disposal site. The surface water quality control is conducted by sampling analyses of the Talaya River. The other disposal site of solid wastes in Baikalsk town (4.6 hectares) is located 4 km away from the town, 0.4 km from the Babkha River and 2 km from the Lake Baikal. The site-specific groundwater monitoring network has been established to control potential pollution leakages from the disposal site. Chemical analyses include 30 components in order to regularly control groundwater quality. The current low contents of ammonium nitrogen (0.1-0.25 mg/l) and nitrite nitrogen (0.07-0.15 mg/l) as well as other analyzed constituents indicate that groundwater quality is not affected in the area around the waste disposal site.

In the territory of the Buryat Republic, about 50% of total waste generated by household and communal services in Ulan Ude town are deposited on the authorized waste disposal site. Approximately 75% of wastes from the remaining 50% are reused. In Selenginsk settlement, 50% of wastes are reused, and only 3% placed on the authorized disposal site.

Waste water treatment facilities in Buryat Republic have been constructed in 18 cities and 23 rural settlements (that is only 7% of total number settlements). The discharge of insufficiently treated wastewater into rivers amounted to 48.24 million m^3 in the year 2005.

The higher contents of organic substances, zinc, and manganese have been found in the stream near the Selenga River, where the treated sewage water from Ulan-Ude town is discharged. Some part of sewages is treated on filtration fields in Kabansk, Novaya Bryan' and Zaigraevo.

Waste water treatment of Ulan-Ude town is realized by specialized organization 'Vodokanal'. The capacity of municipal waste water treatment plants amount to 185 thousands m^3 per day. The treatment scheme includes combined mechanical and biological facilities. Mechanical treatment of waste water has an average efficiency of about 53%. Biological treatment is performed in aero-tanks with regenerators, secondary sedimentation tanks and bioreactors and its average efficiency is 92%.

Management of solid and liquid mining wastes

Mining of the ore deposits provides numerous environmental problems in Russian catchment basin of the Lake Baikal. Mining impact depends on the extent of mining operations, type of minerals, and proximity of mining operations to the Lake Baikal or surface streams and groundwater supplies.

The most serious environmental impacts are associated with waste processing at the Djida tungsten-molybdenum plant, where more than 40 million tons of wastes are stored. They contain 3-4 % of oxidized sulfide minerals and products of their decompositions are carried into the surface water and groundwater as well as pollute the surrounding area. Cadmium, zinc, copper, and iron have been found in groundwater of the Zakamenskurban area (in the wells and shallow boreholes) where groundwater is used as the source of municipal drinking water supplies. Contents of the above hazardous elements exceed the drinking water standards. The chemical composition of the groundwater changed from the hydro-carbonate type to sulfate one in the zone of the waste impacts. Acid water with high content of some toxic constituents (cadmium, zinc, copper, fluorine) has been identified in effluents from the tailing deposits in the Modonkul' River valley.

Intensive coal exploration is going on in the Tugnuisky, Okino-Klyuchevsky, Daban-Gorkhonsky and Zagustaisky mines. Highly mineralized groundwater of sulfate-hydrocarbonate-sodium type with content of fluorine up to 4.5 mg/l is pumped from deep levels onto the surface. The volume of extracted groundwater amounted to 322,700 m^3 per day in the year 2005.

The gold mining is highly developed in the River Selenga catchment area. The employed technology of washing the gold-containing sands requires significant volume of water and produces considerable amount of wastes. At present the gold-mining companies use the multi-stage system of water purification from suspensions by sedimentation. The experience of using such technology for many years showed that treatment resulted both in reducing the contents of suspended substances and depositing the toxic heavy metals from solution. Such positive effect of treatment is observed in the quality of the Gudzhirka River. Its catchment basin suffers from the overburden effect of the Inkurskoe tungsten-molybdenum ore deposit. Drainage water collected in storage ponds is treated from toxic heavy metals during sedimentation.

Management of solid and liquid industrial wastes

In Pribaikalie, 64 industrial objects are developed in southern Baikal and northern Baikal.The southern Baikal industrial centre, including the Slyudyanka and Irkutsk areas, causes pollution of air, water and soil. In Baikalsk city the main polluters are the Baikal Cellulose-Paper Combine (BCPC) and companies that produce construction materials. In Slyudyanka city pollution is caused by companies that produce construction materials and by electric power industry and transport companies that cause soil pollution with heavy metals. In Kultuk village, a meat-packing plant, transport companies, and oil deposits are potential sources of groundwater pollution. In Listvyanka companies of housing and communal services may cause pollution of groundwater by nitrogen compounds, phosphorus, iron and others. Operations of harbor facility on the shore of Lake Baikal may be associated with pollution by oil products.

The Baikal Cellulose-Paper Combine (BCPC) causes the major impact on environment in the southern part of Lake Baikal. In the area, where BCPC is located, the polluted groundwater of shallow aquifer discharging into the Lake Baikal amounts to 2.5-3.3 g/l of TDS (compared to background value of 0.2 g/l). High contents (above maximum allowable concentrations, MAC) of formaldehyde, phenols, aluminum, and sulfate soap were recorded in the groundwater pollution area in the year 2005. Analyses of groundwater samples taken from monitoring well No.6a located near the shore of Lake Baikal showed that groundwater mineralization reached 0.9 g/l, the content of sulfate amounted up to 364 mg/l. In terms of chemical composition the treated wastewater of BCPC is of the sulfate-sodium type. The Lake Baikal natural water mineralization varies from 86.3 to 102.6 mg/l (depends on location, depth and time of water sampling).

Waste water sampling in the past revealed the presence of non-sulfate sulfur (up to 0.21 mg/l), volatile phenol (0.005 mg/l), suspended particles (1.8 mg/l), and mercury (0.001 mg/l). BCPC constructed facility for treatment of residues produced by its water treatment plant in the year 1988. The quality of the treated wastewater produced by BCBK remains relatively stable. The increasing trend in the content of mineral phosphorus, silicon, ammonium nitrogen and suspended substances and decreasing trend in the content of sodium, COD, nitrate nitrogen, magnesium, organic phosphorus, synthetic surfactants, chlorine, petroleum products, potassium, nitrite nitrogen, and hydro-carbonate have been recorded.

The groundwater area of 32 km^2 has been polluted due to the BCPC activities. Eight groundwater wells were drilled therefore in the year 2000 to protect Lake Baikal from the pollution impact of BCPC. About 2.0–2.2 m^3 of groundwater has been pumped per day from the wells located across the movement of the pollution plume. The area of groundwater pollution significantly reduced after five years of continuous pumping and treatment of polluted groundwater. However, occasional discharges of contaminated groundwater into Lake Baikal cannot be excluded.

The temperature of groundwater reaches 14-21^{0}C due to the discharge of warm water. An unfrozen patch of water in ice (the so-called 'polynia') occurs in the area near the shoreline of Lake Baikal due to discharges of warm water from BCPC. In the year 2005 the 'polynia's length was reduced from a few hundred meters to only 60-70 m.

The Selenga Cellulose-Cardboard Combine (SCCC) located 40 km from the Lake Baikal operates with a closed waste water cycle. Solid wastes produced by SCCC are stored and subjected to stage-by-stage treatment on the authorized site. However, the monitoring studies show that complete treatment of waste water does not occur in sedimentation tanks. Waste water penetrates into groundwater in shallow aquifer and pollutes them with sulfate, organic substances and other toxic components such as zinc and cadmium. The higher concentrations of the components that are specific for pulp production, i.e. lignin, methanol, sulfate, etc. have been identified too.

Groundwater pollution occurs also within the industrial zone of Ulan-Ude. Contents of oil hydrocarbons in groundwater highly exceed the limited values for drinking water in the area of fuel and lubricant storage of 'Ulan-Ude Aviation Plant'. In two monitoring wells 5 m and 6 m deep, located 10 m and 15 m from the fuel and lubricant storage area the content of oil products (kerosene) in groundwater reached 1450 mg/l in the year 2011. In the year 2012 kerosene was detected in the boreholes in a separate phase (layer) on the groundwater level surface. The second area where groundwater is polluted by oil products is 'Buryat-Terminal' managed also by 'Ulan-Ude Aviation Plant'. The content of oil hydrocarbons reached 0.278-1.478 mg/l in the year 2012 in the observation wells located on the right bank of the River Selenga under the pollution source. Lens of oil products as well as groundwater pollution plume movement in the direction to the River Selenga and are drained by the Uda and Selenga Rivers.

Gas emissions impact on groundwater quality

Oxides of carbon, sulfur, nitrogen, and hydrocarbons enter the atmosphere together with industrial emissions. Hundreds of thousands tons of those compounds are annually emitted on the territory of the Republic of Buryatia. In addition, the territory of the Buryat Republic is also affected from other regions located on the leeward side (Irkutsk, Krasnoyarsk regions). Acidic precipitations (pH= 4.06) with high content of sulfur (up to 62.9), chloride (13.8), fluorine (1.23), nitrogen (14.2), ammonium (17.6 mg/l) has been observed in some areas of Buryatia, including the Usty-Selenga depression. In areas affected by polluted precipitations, soils and shallow groundwater contain elevated concentrations of the above components and some heavy metals are leached from the rocks by acidic solutions.

Pollution of atmosphere takes place not only in Russia, but in Mongolia as well (Ulaanbaatar). Further studies are needed to identify areas impacted by acid rains and to evaluate and predict their influence on soil and groundwater quantity.

Impact of agricultural activities on groundwater quality

In the Kabansk drainage-irrigation system of the area of 5 670 hectares makes influence on underground drainage discharges from bogs into Lake Baikal. It carries runoff of 27.6 million m^3 /year of water from bogs. Groundwater is polluted by nitrogen-containing compounds due to the turf decomposition by low temperature in aeration zone. The content of ammonium in groundwater attains 16.5 mg/l, nitrite 3.5 mg/l and nitrate 40 mg/l. The content of manganese, lithium, molybdenum and copper in groundwater, exceeding fishery standards for water, has been found in groundwater from bogs.

Extensive groundwater pollution by nitrogen-containing compounds has been identified in the areas surrounding the cattle farms. E.g. treatment of wastewater takes place only on filtration fields in the Zaigraevskaya poultry farm situated in the River Uda Basin. The movement of large nitrate (700 mg/l) pollution plume has been registered in groundwater in the shallow aquifer. Groundwater diffuse nitrate pollution due to uncontrolled application of fertilizers on arable land has not been monitored.

Intensive use of groundwater resources and depletion impact

Groundwater resource depletions have not been identified in the Russian territory of the Baikal Basin till this time.

3.3 Rating criteria for prioritization of groundwater pollution threats in the Mongolian and Russian territories of the Baikal Basin

Rating criteria for prioritization have been applied with the scope to evaluate the impact of point pollution sources on groundwater, dependent ecosystems and human health. Diffuse groundwater pollution by nitrate or pesticides due to agricultural activities has not been identified in the Baikal Basin as yet. However, the intention to increase crop production by application of growing quantity of nitrogen fertilizers and pesticides, construction of new irrigation schemes, the replacement of traditional crop rotation by continuous cultivation of financially more valuable crops and expansion of arable lands, will increase the risk of soil organic matter degradation and groundwater diffuse pollution in the next 10 years. Potential impact on groundwater quality has to be therefore carefully monitored and controlled in areas where intensive crop farming is currently realized or planned.

Waste disposal sites and discharge of waste water are the main point pollution sources of groundwater. In Mongolia uncontrolled mine and domestic waste disposal sites and discharge of untreated or poorly treated municipal and particularly mine waste water are significant groundwater pollution sources. In Russia both industrial and mining waste disposal sites and waste water are registered as most significant source of groundwater pollution.

Overall rating

Overall rating derived by combining the results of the severity and the scope proved that not sufficiently treated or untreated mine waste water (particularly from gold, copper and molybdenum mines), often with the content of toxic constituents, can moderately or seriously degraded (severity 2 and 3 respectively) quality of groundwater resources and dependent ecosystems in many mining areas in the Baikal Basin (scope 3). Considering enormous gold and other minerals mining activities in Russian and particularly in Mongolian territory of the Baikal Basin and expected expansion of mineral and coal mining operations in both countries in the next 10 years high priority **(overall rating 5 and 6** in case of the content of toxic substituents) was given to the impact of waste water produced by ore and coal mining and ore processing. It must be pointed that discharge of polluted mine waste water into surface streams and aquifers can seriously affect quality of groundwater (in Russia cadmium, zinc, copper, and iron have been found in groundwater in the Zakamensk in municipal drinking water supply wells) and can be also considered as potential water related transboundary conflict, particularly if pollution occurs nearby the Mongolian - Russian border.

Environmentally sound mines operation must be obligatory issue of mining concessions afforded by governmental and aimag authorities. Control and monitoring must guarantee that waste water are continuously treated and toxic constituents are not present in waste water discharging from mine facilities into the surface water and groundwater. Owners of mine facilities have to take responsibility for investments into relevant modern mining and waste water treatment technologies, construction of safe landfills and establishment and operation of groundwater monitoring networks.

Overall rating 4 was given to the discharge of untreated or not sufficiently treated waste water from municipal and rural settlements. Both can affect quality of groundwater in shallow aquifers as well as groundwater dependent ecosystems. Significant investments on construction of treatment plants with modern treatment technology and capacity relevant to the current and future needs, training of human resources responsible for treatment plants operation as well as significant improvements of waste water management will be needed within next 10 years to reduce impact of municipal and rural waste water on the quality of groundwater resources and environment.

Municipal, mine and industrial solid waste disposal sites without relevant protective impermeable liners, drainage scheme, and monitoring networks and particularly illegal uncontrolled waste disposal sites are significant point pollution sources in the Baikal Basin in both countries. They can moderately **(overall rating 2 – 3)** or even seriously **(overall rating 3)** degraded groundwater and dependent ecosystems. There are often located in floodplains or fluvial terraces where groundwater level in shallow aquifers is closely to the ground. Leakages from disposal sites in such areas affect groundwater quality because due to a small thickness of unsaturated zone pollution rapidly reaches the aquifer. During the wet seasons groundwater level increases and wastes on the base of the disposal site can be even saturated. Monitoring networks are only rarely established around waste disposal sites and movement of pollution plume is not controlled. Existing disposal sites have to be evaluated with respect to their potential impact on water resources. Where will be possible, relevant protective measures have to be in addition implemented with the scope to prolong disposal site operation. However, operation of uncontrolled disposal sites have to be closed and toxic waste from disposal sites removed if there are located above productive and vulnerable shallow aquifers exploited for drinking water supplies.

Establishment of landfills constructed with protective impermeable layers, drainage systems and site specific monitoring networks and located on sites where unsaturated zone is thick and impermeable and groundwater level is deep below ground require investments from municipalities and mining and industrial companies in the course of the next ten years.

Generally, solid waste impact on groundwater and related ecosystems in case of domestic waste is limited (**overall rating 2**), in case of mine and industrial waste impact is in category medium (**overall rating 3**) and is high in case of toxic waste (**overall rating 4**).

Severity and scope criteria were also applied to designate overall rating for the impact of industrial gas emissions on groundwater quality (**overall rating 5**).

Tables 3.1 and Table 3.2 show overall rating based on evaluation of rating criteria for prioritization of different pollution sources with respect to their impact on groundwater resources quality.

Issue	*Severity*	*Scope*	*Overall rating*
Domestic solid waste	1: limited	1: limited	2
Mine and industrial solid waste	2: medium 3: high	1: limited 1: limited	3 4
Municipal waste water	2: medium	2: medium	4
Mine and industrial waste water	3: high	2: medium	5
Waste water with toxic constituents	3: high	3: high	6
Industrial gas emissions	2: medium	3: high	5

Table 3.1. **Overall rating of groundwater pollution sources in Russian and Mongolian territories of the Baikal Basin**

	SCOPE				
SEVERITY		4: Very high	3: High	2: Medium	1: Limited
	4: Very high	8	7	6	5
	3: High	7	6	5	4
	2: Medium	6	5	4	3
	1: Limited	5	4	3	2

Table 3.2. **Overall rating of groundwater pollution sources (solid waste in black circles, liquid waste and emissions in red circles) in Russian and Mongolian territories of the Baikal Basin**

4 | Groundwater dependent ecosystems

There are few data available about groundwater dependent ecosystems in both Mongolian and Russian territories of the Baikal Basin. Groundwater level decline or pollution of shallow aquifers both may significantly affect groundwater dependent ecosystems. Relation between shallow aquifers and wetlands and other ecosystems is possible to presume in several areas of the basin, particularly in the delta of the River Selenga and in floodplains of the rivers. Research and monitoring are needed to identify potential groundwater dependent ecosystems and to better understand the processes occur between groundwater and wetlands and other ecosystems in the Baikal Basin.

4.1 Vulnerability of groundwater dependent ecosystems on Mongolian territory of the Baikal Basin

There are two wetlands in Mongolian territory of the Basin registered under Ramsar list; however, their potential dependence on groundwater has not been studied as yet.

Ogii Lake. Ramsar site has been designated under the number 955 in 6 July 1998. Its extent is 2,510 ha, coordinates 48°10'00"N 099°43'00"E, elevation 1280 m. A freshwater lake located in the valley of the Orkhon River comprising extensive alluvial areas of grassland, river channels, pools and marshes surrounded by grassy steppe. The maximum depth of the lake is 16 meters, but about 40% of the lake is less than 3m deep. The lake supports an intensive fishery and livestock grazing. Concentration of livestock around the lake led to the loss of habitats for migratory birds nesting around the lake. Lake is also important breeding and staging area for a wide variety of waterfowl, particularly ducks, geese and swans, highly vulnerable to the water pollution.

Figure 4.1. Ogii Lake

Terhiyn Tsagaan Lake. The Lake has been designated as Ramsar site number 953 on 6 July 1998. Its extent is 6,110 ha, coordinates 48°10'00"N 099°43'00"E, elevation 2060 m. A freshwater and nutrient-poor lake formed owing to past volcanic activity is located in the Suman River valley in the Central Khangai Mountains. Small fishery activities (mainly pike and perches) have been practiced many years, but have been stopped in the year 1991. The marshes in the west part of the lake are an important staging and breading area for migratory waterfowl.

Figure 4.2. Terhiyn Tsagaan Lake

4.2 Vulnerability of groundwater dependent ecosystems on Russian territory of the Baikal Basin

Selenga River Delta in Russian territory of Baikal Basin has been registered in the Ramsar list under the number 682 in 13 September 1994. Its extent is 12,10 ha, coordinates 52°17'N 106°22'E, elevation 456 m-458 m. The site includes the shallow water area of Lake Baikal, streams and oxbow lakes. Vegetation consists of reed beds, regularly flooded sedge-grass meadows, and willow shrub. The site is an example of a unique type of wetland and supports numerous threatened and endemic species of flora and fauna. Human activities include hay harvesting, livestock grazing, commercial and sport fishing, muskrat trapping, water bird hunting, and recreation. River regulation resulted in changes in the hydrologic regime, and rising lake levels (Baikal) are a major threat to delta ecosystems.

Dependence of wetlands on groundwater in the Selenga River Delta has not been studied yet. However, it may be expected that groundwater level decline by pumping or groundwater pollution both will have negative impacts on wetlands and related ecosystems. Relevant hydrogeological and ecological studies are therefore needed to effectively protect wetlands and ecosystems in Selenga River Delta.

Forest-plantations have been applied to prevent erosion in steppe landscapes of many areas with previous agricultural activities on Russian territory of the Baikal Basin. Poplar seeds have been used as the main planting material. The groundwater level decreased significantly in many places due to climate changes, particularly owing to long term (more than 15 years) continuous dry period and changes in nature of atmospheric precipitation (rain showers). Ecosystems of forest-plantations due to the shortage of moisture gradually degraded and woody vegetation disappeared in some areas.

Efflorescence of various salts that contains the toxic elements (cadmium, copper, zinc, fluorine, nickel, chromium) is formed on the soil surface in the areas adjacent to the mining activities where groundwater evaporation occurs in shallow aquifers with groundwater level closely to the ground. Degradation of vegetation and local ecosystems has been registered in such areas.

5 | Transboundary aquifers and groundwater data availability in the Baikal Basin

Transboundary bilateral cooperation between the Government of the Russian Federation and the Government of Mongolia on the Selenga River and Lake Baikal Basin is currently governed by the "Agreement on the Protection and Use of Transboundary Waters" signed in Ulaanbaatar in February 1995 and by the Treaty on the Regime of the Russian-Mongolian State Boundary (Section II "The regime of utilization of the boundary waters…" Arts. 10-14) signed in September 2006 in Moscow. The agreement established a Joint Task Force, chaired at the level of Ministers, to facilitate cooperation towards the protection of Selenga River. The goal was to prepare a land-use plan and schedule for its implementation by both countries till 2010. On April and May 2008 two meetings of the Joint Russian-Mongolian Task Force have been realized.

The following specific joint transboundary issues have been addressed, among others, within the Russian and Mongolian water related agreement: environmentally sound use of water resources, preventing pollution and water resources depletion, joint water quality monitoring, developing common concepts for river basin water management, sharing of water resources and adopting international standards of water quality, preventing or reducing impacts on transboundary waters in national territories, preserving fish habitat and conditions for fish natural migration and protecting ecosystems.

A joint Working Group has been established and during the meeting in the year 2006 joint river basin planning and management were discussed. A list of pollutants that have to be monitored by both countries was compiled in the year 2008. Both countries perform hydro-meteorological monitoring however, related data protocols between both countries are not unified yet. In 2011 under the "Agreement on the Protection and Use of Transboundary Waters" the Protocol for the bilateral collaboration was signed. The Protocol is focused on 1/ regular exchange of information, 2/ cooperation for the implementation of the agreement and harmonization of monitoring methods between both countries and 3/ compiling a list of controlled pollutants and water quality standards. Baikalpriroda, the Russian Federal Environmental Agency on Baikal, has been entrusted to coordinate with Mongolia all transboundary water issues and Selenga River watershed in particular.

Activities under the Russian - Mongolian transboundary agreement are described in more details in the chapter 5.2.2 of the Lake Baikal Basin Transboundary Diagnostic Analysis. However, bilateral initiatives and cooperation between Russia and Mongolia have focused mostly on the Selenga River Basin and not on the entire Baikal Basin. It must be also stated that transboundary water monitoring has been realized only in case in surface water, regular groundwater transboundary monitoring has not been established yet.

Transboundary water monitoring networks both surface water and groundwater are essential for a joint data collection, assessment and sharing between riparian countries and for sustainable management and effective protection policy of transboundary aquifers. The UN Convention on the protection and use of transboundary watercourses and international lakes (Helsinki, 1992) and UNECE Guidelines on Monitoring and Assessment of Transboundary Groundwaters (2000) both endorsed harmonization of rules and standardization of methods for establishment and operation of transboundary water monitoring networks. However, till this time there is no evidence about groundwater quality and quantity flowing in shallow aquifers across Mongolian – Russian boundary.

Absence of groundwater monitoring networks on transboundary and Baikal Basin scale and only few site-specific monitoring networks resulted in groundwater data scarcity that is the main obstacle in assessment and sustainable management of groundwater resources in Russian – Mongolian transboundary aquifers.

To fulfil the Russian and Mongolian "Agreement on the Protection and Use of Transboundary Waters" establishment of **transboundary groundwater monitoring networks** as well as implementation of standardized methodology for groundwater observation and sampling, monitoring frequency and monitoring data management and assessment in common GIS database and mutual groundwater data accessibility and sharing between Russia and Mongolia are pointed out. Transboundary groundwater monitoring is one of the key recommendations made by UNESCO and should be considered as a priority action in the TDA/SAP process.

5.1 Transboundary aquifers on Mongolian–Russian border

On Russian – Mongolian border have been identified three areas where transboundary groundwater runoff in shallow aquifers occurs: floodplain of Selenge River and in contiguous confluence area of the Rivers Selenge and Orkhon, floodplain of River Kyakhtinka and floodplain of the Chickoy River.

Transboundary shallow aquifer in Selenge River floodplain and in contiguous confluence area of the Rivers Selenge and Orkhon

Transboundary surface water monitoring network has been established in Selenga River and surface water outflow and quality from Mongolian to Russian territory are regularly observed. However, relevant groundwater data are not available. Implementation of transboundary integrated surface water and groundwater resources management requires establishment and operation of groundwater monitoring network with the scope to: 1/observe and calculate on Mongolian - Russian border transboundary groundwater runoff and quality and 2/ timely identify and control potential groundwater transboundary pollution transport.

Based on hydrogeological investigation, shallow and deep aquifers have been identified and mapped in transboundary reach of the Selenge River. The thickness of productive shallow transboundary aquifer in fluvial deposits of the Selenge River according to the resistivity survey amounts 100 – 150 m. Shallow aquifers developed along the Selenge River floodplain in permeable (sands, gravels) and low permeable (silt and clay) unconsolidated deposits are of moderate productivity. Deeper aquifers in effusive, magmatic and metamorphic rocks are generally of lower permeability and productivity. Groundwater movement in these aquifers is registered on fractured zones only. Deeper aquifers with long term residence time are not included in the proposed first phase of transboundary groundwater monitoring network.

Establishment and regular observation of proposed eight monitoring wells located in Selenge River transboundary area on Mongolian territory of the Baikal Basin will provide data needed for evaluation of transboundary groundwater flow and groundwater quality in shallow aquifer in Selenga River floodplain. Wells location and their design and depth (in average 100 m) respect hydrogeological condition of the transboundary area (Figure 5.1). Sitting of monitoring wells has to be correlated with surface water monitoring stations. Automatic measurements of groundwater level, temperature, pH, electric conductivity, redox potential, salinity will provide data for early warning of transboundary groundwater pollution or changes in groundwater quality. By specifically oriented groundwater chemical analyses (2–4 per year) can be controlled potential transboundary groundwater pollution related to the mining activities on Mongolian territory of the Baikal Basin.

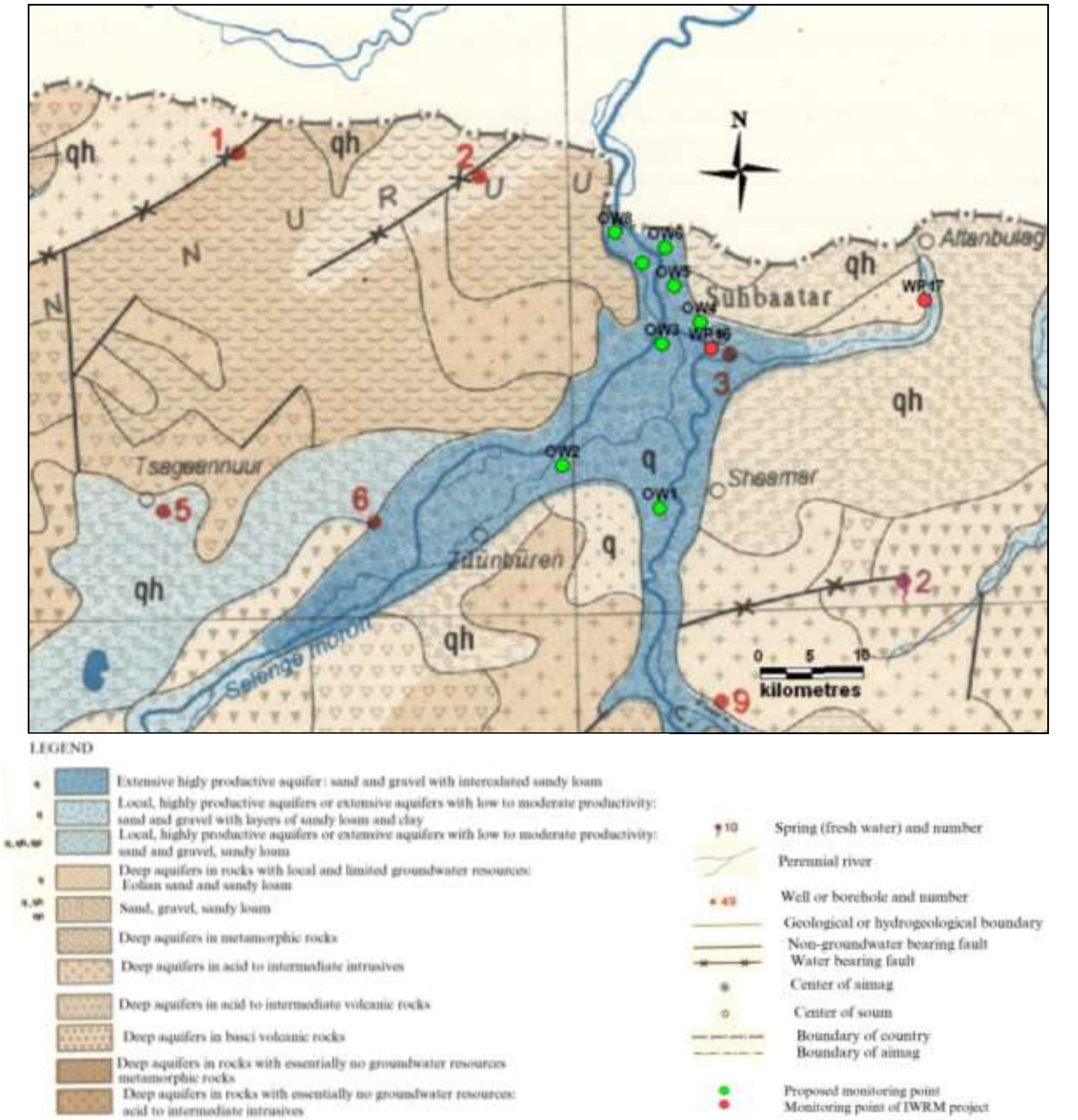


Figure 5.1. Proposed transboundary groundwater monitoring network in shallow aquifer in Selenge River, scale 1: 000 000 (Jadambaa, N., Enkhkhishig, 1996)

Siting of 2–3 monitoring wells in shallow aquifer in fluvial deposits of Selenga River on Russian territory near to the border can be recommended, to make possible mutual control of groundwater data acquired from monitoring wells on both sides of the boundary.

Transboundary shallow aquifer in the floodplain of the River Kyakhtinka

The River Kyakhtinka, one of the most polluted rivers in the Buryat Republic, flows from Russia to Mongolia. On Mongolian territory the River Kyakhtinka joins the River Buryn, the tributary of the River Orkhon. Waste water from Kyakhta town are currently only poorly treated. They are the main source of pollution of Kyakhtinka River. In the year 2006 uncontrolled discharge of untreated waste water occurred and river has been heavily polluted. Construction of new waste water treatment facility is planned in the year 2014.

The shallow aquifer in Kyakhtinka River floodplain is composted by middle-grained sands with crushed rocks of 8 m thick. Deeper weathered schist and gneisses are heavily fractured. Deep tectonic structures (the North-Mongolian fault, the Khilokskiy fault) affect groundwater flow and formation of deeper aquifers. Groundwater flow depends on the degree of permeability of fissures and cracks. However, the aquifer productivity is generally low. Groundwater recharge is also low due to low precipitations (200– 300 mm per year). The wells yield is in order of tenths l/sec and the level of groundwater mineralization is up to 240 mg/l.

Establishment of transboundary groundwater monitoring network is needed to control potential pollution transport from Kyakhta town on Mongolian territory. Polluted river water may seasonally infiltrate into adjacent shallow aquifer and degrade groundwater quality. By four monitoring wells located in shallow aquifer on both banks of Kyakhtinka River on the Russian – Mongolian border can be regularly controlled groundwater quality and potential pollution transport from Russian territory to Mongolia. However, location and design of monitoring wells has to be based on hydrogeological and geophysical investigations.

Transboundary shallow aquifer in the floodplain of the Chickoy River

The Chickoy River reach of about 90 km length forms the boundary between Russia and Mongolia. The boundary area is only little populated and agricultural activities prevail. Hydrogeological investigation of shallow aquifer in the floodplain of the Chickoy River is needed to identify possible hydrological interaction between surface water and groundwater in adjacent shallow aquifer and to decide about the design of transboundary groundwater monitoring network.

5.2 Present status of groundwater monitoring on Mongolian and Russian territories of the Baikal Basin

In **Mongolia** groundwater monitoring networks on the Baikal Basin scale as well as on the country level do not exist as yet and groundwater data scarcity is registered. Social and economic development in Mongolia depends very much on groundwater resources. Establishment and operation of groundwater monitoring network on the Baikal Basin scale is therefore needed to provide data for sustainable development and management of groundwater resources, environmentally sound groundwater protection policy and transboundary groundwater resources management in Mongolia.

First step in development of groundwater monitoring network has been made under the Mongolian - Netherlands project focused on integrated water resources management (IWRM) in Mongolia. 17 monitoring wells have been drilled and screened in Tuul-Orkhon River Basins and 16 wells are regularly observed (Figure 5.2). Two wells are located near to the Mongolian – Russian border (Figure 5.1) and may be included in the groundwater transboundary monitoring network. Monitoring wells realized within IWRM project control significant area of the Mongolian territory of the Baikal Basin and can be included in the Baikal Basin groundwater monitoring network which establishment is strongly proposed. All monitoring wells are well documented and groundwater data are automatically measured from the year 2012.

In **Russia** groundwater monitoring network established on the Baikal Basin scale does not exist. However, groundwater monitoring networks on the Federal and National levels operate several

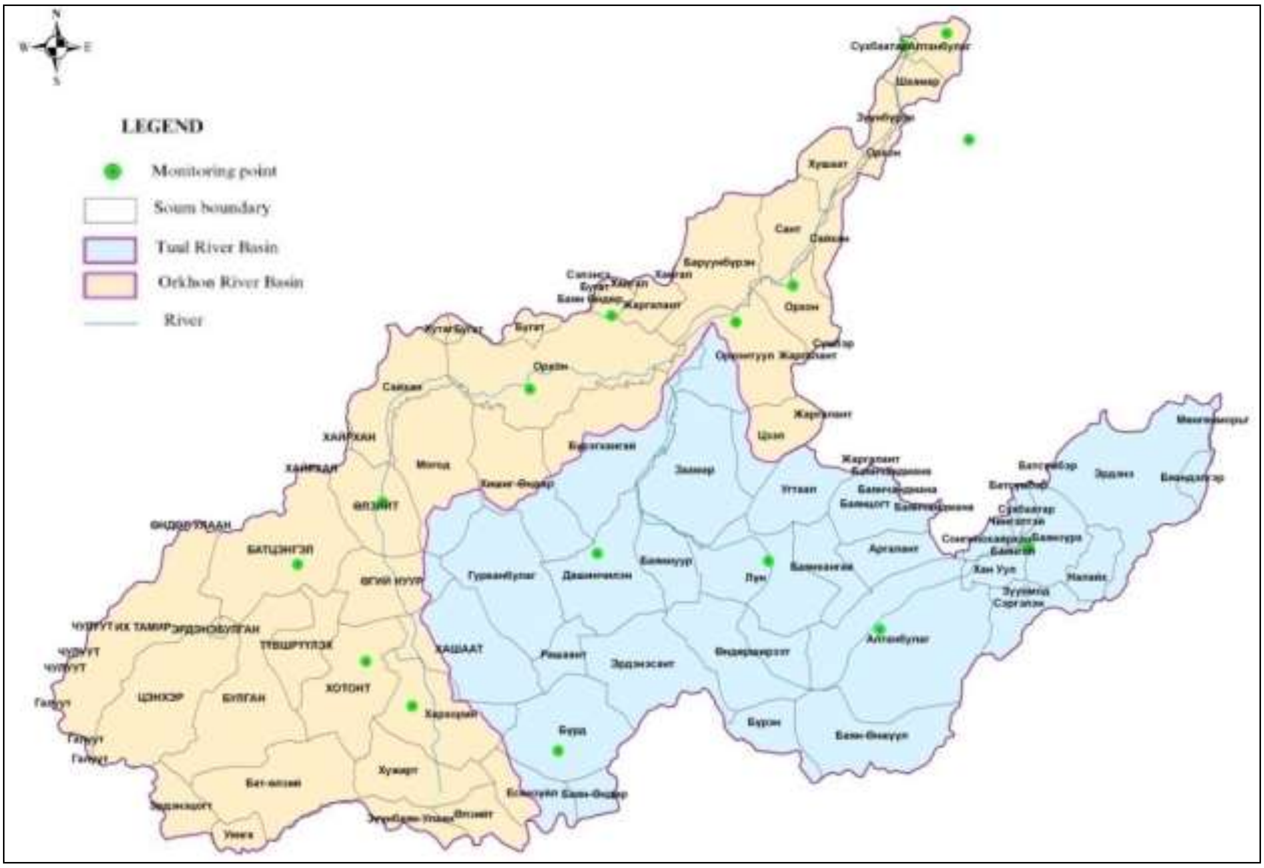
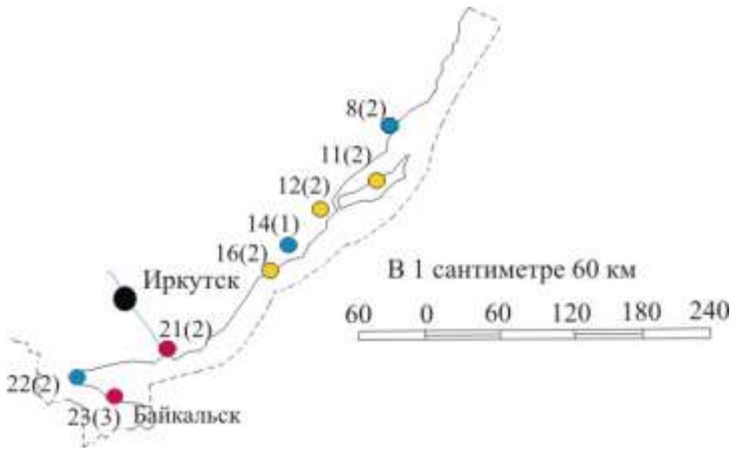


Figure 5.2. Location of groundwater monitoring wells established under IWRM programme

years and some monitoring wells are located in the Baikal Basin. Monitoring data from these wells can be used for evaluation of quantity and quality of groundwater resources in Russian territory of the Baikal Basin.

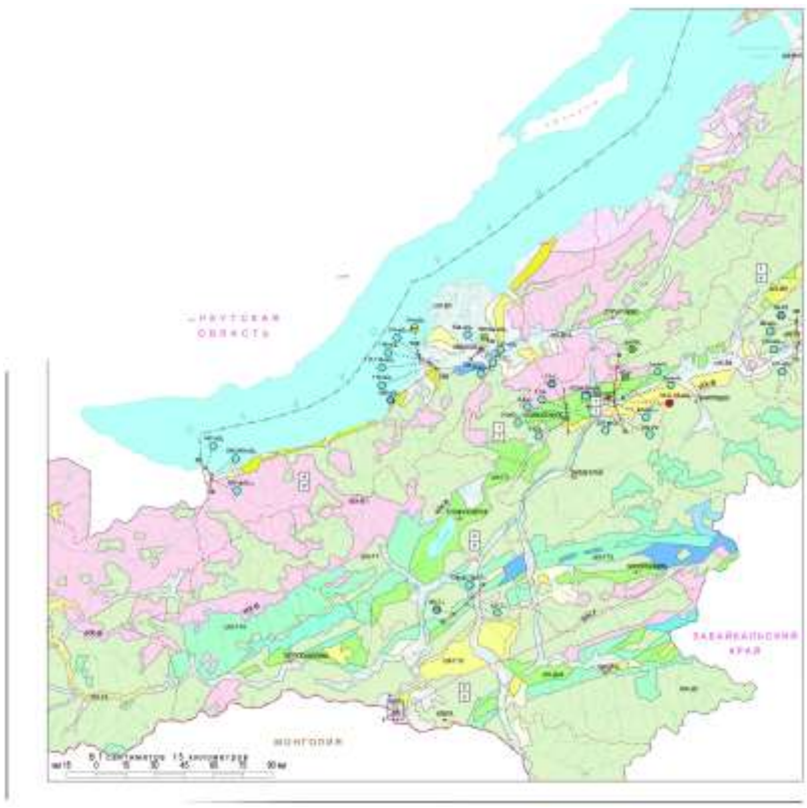
In the **Irkutsk part of the Baikal Basin** monitoring of groundwater both quantitative and qualitative is implemented by Irkutsk Regional Centre of Monitoring of Geological Environment on 16 monitoring wells which are part of the Federal monitoring network (Figure 5.3). Monitoring wells are located in 8 sites (every one with 1 to 3 monitoring wells) where groundwater regime is under different human impact. On 3 monitoring sites (Slyudyanka, Onguryen, Popovo) groundwater system is observed in natural conditions, 3 monitoring sites (Kharantzy, Buguldeika, Shara-Tagot) are located in the area where groundwater regime is only slightly impacted and 2 monitoring sites in areas (Baikalsk, Angarskie Khutora) where groundwater regime is heavily man-made affected.

Federal groundwater monitoring network in the **Buryat Republic** (Figure 5.4) has been significantly reduced during last years. Only 35 monitoring wells are observed at present in comparison with 400 wells observed in the past. Monitoring wells are located in 8 regional profiles in the central, southern and western areas of Pribaikalia. All monitoring wells are sited in the Baikal Basin and groundwater quantity and quality is observed. Groundwater monitoring in Transbaikalia, is realized many years under the Federal monitoring network on 17 monitoring wells. During last years continuous groundwater level decline has been registered.



Monitoring sites with groundwater in natural conditions
sites with slightly impacted regime of groundwater
sites with heavily man-made affected regime of ground water
23(3) number of monitoring sites (number of monitoring wells in the site)

Figure 5.3. Federal groundwater monitoring network in the Irkutsk part of the Baikal Basin (based on data of the Irkutsk Regional Centre of Monitoring of Geological Environment)



Monitoring wells with groundwater in natural conditions
Wells with slightly polluted groundwater
Wells with highly polluted groundwater

Figure 5.4. Federal groundwater monitoring network in the Buryat Republic (on data of the Buryatsky Regional Centre of Monitoring of Geological Environment Center)

Data from monitoring wells of above described Federal monitoring networks located on Russian territory of the Baikal Basin can be included in the Baikal Basin water database. Together with data from new complementary monitoring wells the groundwater monitoring network on the Russian territory of the Baikal Basin can be established.

5.3 Site specific groundwater monitoring

Site-specific groundwater monitoring networks serve for specific purposes. There are located around 1/ point pollution sources (e.g. waste disposal sites, gas stations) to control pollution plume generation and movement, 2/ groundwater abstraction sites to observe groundwater levels decline and spreading of cones of depression, 3/ groundwater dependent ecosystems to timely identify potential groundwater pollution or depletion impact. Great density and special design of monitoring wells relevant to the pollutant properties, multilevel groundwater sampling of both unsaturated and saturated zones and high observation and sampling frequency are typical for site-specific monitoring.

Currently, the site-specific groundwater monitoring networks in both countries, Russia and Mongolia, have been established only around few potential pollution sources and water supply facilities. Control measures over the potential pollution sources and groundwater abstraction sites have to be strengthened by obligatory monitoring of groundwater quantity and quality. Related financial resources will be settled by groundwater users and potential polluters, based on polluters pay principle policy. The reality in the field and the costs of restoration of polluted aquifers suggest that site specific groundwater monitoring may be considered as an important cost-benefit approach for preserving the good state of groundwater as a strategic source of drinking water and valuable component of the environment (Vrba and Adams, 2008).

Site-specific groundwater monitoring networks in Mongolia

Site–specific groundwater monitoring networks have been established around groundwater supply systems of some large cities. 4 monitoring wells located nearby Ulaanbaatar water supply system are controlled by Institute of Geoecology of Academy of Science. Mongolian University of Science and Technology (MUST) installed in three wells automatic devices to monitor groundwater level, temperature and electric conductivity for research purposes. Water Supply and Sewerage Authority (WSSA) responsible for water supply and sewerage in Ulaanbaatar provides regular measurements in two monitoring wells located nearby water supply wells. Groundwater level and temperature, pH, and electric conductivity are observed.

In the Kharaa River Basin 4 monitoring wells have been constructed under the project called “MoMo” (Model region Mongolia) supported by the German Ministry of Education and Research. Groundwater level and temperature are measured in 3 wells located near Darkhan water supply wells and in 1 monitoring well in the Power Station of Darkhan city.

Two large mining companies operate groundwater and surface water monitoring networks to control mine impact on water resources. Erdenet copper mine observes on monitoring wells groundwater quantity and quality. Boroo gold monitoring network is composed by 5 monitoring wells and groundwater level is regularly observed.

Site specific groundwater monitoring networks in Russia

In Irkutsk part of the Baikal Basin site-specific groundwater monitoring networks have been developed and operate around Kultuk municipal waste disposal site, Sludyanka water supply system and Baikalsk Cellulose-Paper Combine. On 40 monitoring wells groundwater level and selected chemical components are regularly observed.

In the Buryat Republic site-specific groundwater monitoring networks compost by 30 monitoring wells have been developed and operate around industrial sites in Ulan – Ude (20 wells) and Gusinoozersk (10 wells). In Transbaikalia groundwater monitoring system composed by 5 monitoring wells is in operation around water supply system of Petrovsk-Zabaikalsky several years. Groundwater level and selected chemical constituents are regularly recorded.

Groundwater monitoring to control groundwater pollution is realized also in the Baikal Cellulose-Paper Combine (BCPC) and the Selenga Cellulose-Cardboard Combine (SCCC).

Monitoring activities realized around groundwater abstraction sites for public water supplies are controlled by Rospotrebnadzor authority.

6 | Climate change impacts on groundwater

Influence of climate change on groundwater resources is not regularly monitored on the Baikal Basin scale. Generally two types of aquifers can be distinguished with respect to the potential impact of the climate change.

Deep aquifers with long groundwater residence times and renewal period in the order of thousands of years or longer in the case of fossil groundwater that has been replenished under different hydrological and climatic conditions in the past. An impact of climate change (registered over the last decades) has not been observed in the case of deep aquifers with renewable and non-renewable groundwater resources.

Shallow aquifers with relatively short groundwater residence time in the order of days up to hundreds of years. Influence of changes of temperature and precipitation on river runoff and adjacent shallow aquifers have been observed in both Mongolian and Russian territories of the Baikal Basin. Decrease of groundwater levels and groundwater storage has been registered in several shallow aquifers. However, in some areas where precipitation increased a reverse trend in groundwater levels has been observed.

Specific attention should be given to the occurrence and availability of groundwater resources in permafrost areas where seasonal thawing of the soil layer is continuously increasing.

The establishment of monitoring networks aimed at regularly measuring groundwater levels and groundwater quality parameters in shallow aquifers in floodplain areas and aquifers in permafrost areas will significantly support the studies focused on influence of climate variability and change on groundwater recharge and shallow and permafrost aquifers.

6.1 Climate change impacts on groundwater in Mongolian territory of the Baikal Basin

Changes in glacier extent and volume, air temperature, precipitations, water level and shifting of freezing and thawing dates of rivers are significant indicators of climate variability and change in Mongolian territory of the Baikal Basin. With respect to the groundwater, shallow aquifers in fluvial deposits in floodplains of the rivers are most vulnerable to the climate change.

According to the records from 48 meteorological stations distributed over the territory of Mongolia, the annual mean temperature of Mongolia increased by 2.1^{o}C during the last 70 years. Precipitations changes differ regionally in Mongolia: since 1961 in the Altai mountain region, Altai Gobi and in the eastern part of the country precipitations increased, and in all other country regions precipitations decreased by 0.1-2.0 mm/year [MARCC, 2009].

Groundwater level measurements in shallow aquifers indicate decreasing trend in correlation with current changes occurring in surface water runoff. E.g. groundwater levels within last 12 years (1997-2009) dropped in the Muren (forest steppe zone) by 0.55 m, in Arvaikheer (steppe zone) by 3.0 m, and in Ulaanbaatar by 2.0-6.0 m (Davaa, 2011). However, groundwater level decline in Ulaanbaatar area is also affected by groundwater pumping.

Recent groundwater monitoring study of the Tuul River floodplain shows dependence of recharge of shallow aquifers on precipitations. 70% of precipitations occur during the summer months (April - August) and related groundwater level rise is recorded (Figure 6.1). Groundwater level declines in the winter and spring seasons, when precipitations are low. Above described relation between amount of precipitations and groundwater level fluctuation have been registered by regular observation on monitoring wells (Naranchimeg., et al, 2011).

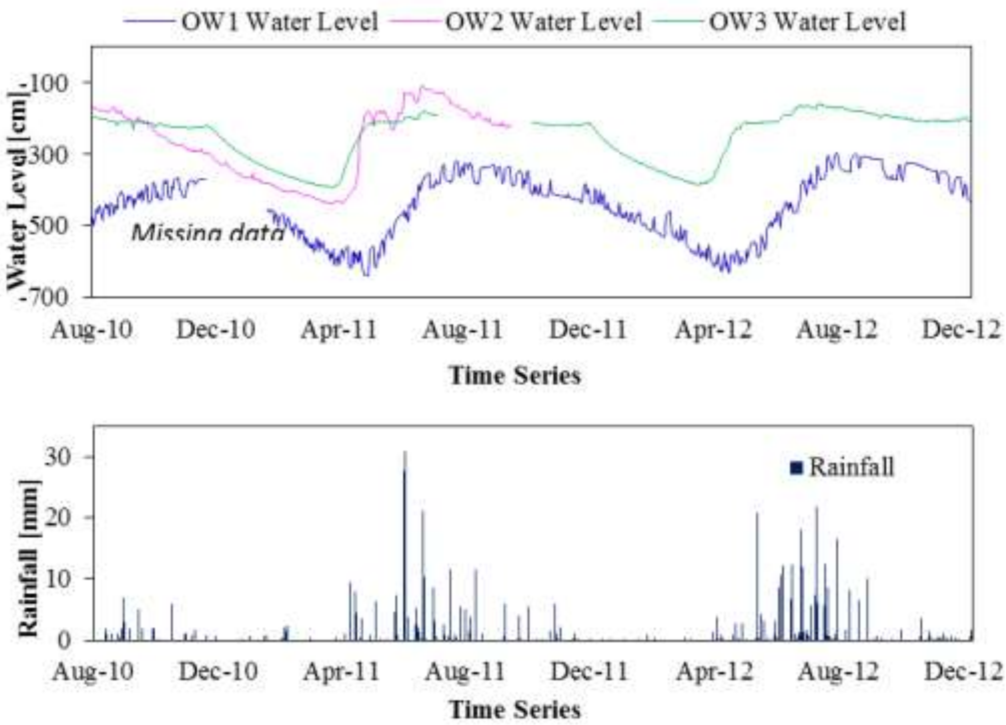


Figure 6.1. Groundwater level fluctuation registered on monitoring wells OW1, OW2 and OW3 and daily rainfall data both valid for Ulaanbaatar central groundwater supply area (21 Aug 2010 to 30 Dec 2012)

Seasonal changes in groundwater flow and chemical composition are observed too. During summer seasons river water discharges in the shallow aquifer, during winter seasons groundwater discharges in the rivers. The groundwater chemistry also slightly seasonally changes; Ca-Mg-HCO_3 and Ca-Na-HCO_3 types of water prevail during summer and Ca-HCO_3 type in winter.

Soil moisture increases due to melting of permafrost has been observed in some areas of the Mongolian territory of the Baikal Basin. Seasonal thawing of the soil layer in the permafrost region has increased by 0.1-0.6 cm in the Khentii and Khangai mountains and by 0.6-1.6 cm in the Khovsgol Mountains over the past 30 years. Permafrost phenomenon such as thermo karst, solifluction, thermo erosion has been registered over the last 50 years. The thermo karst process advances approximately 5-10 centimetres per year and in some places reaches even 20-40 cm per year [MARCC, 2009].

Rivers flow decrease by 30-40% of their long-term average has been registered in last 40 years in the rivers flowing from Khangai and Hentii mountain ranges. Mean runoff data from 1996 to 2010 compare with data from the period 1978-1995 show that the mean runoff of the Selenge River decreased by 39.4% (Khutag Undur station). Similar decreasing trend was observed also in the Ider River basin, mean runoff decreased by 43.8% (Zurkh station).

According to the surface water inventory conducted in 2011, about 641 springs (Bulgan-206, Selenge-56, Khovsgol-170, Arkhangai-202, Darkhan-2, Orkhon-5) dry up in Mongolian territory of the Baikal Basin (Water Authority, 2011).

6.2 Climate change impacts on groundwater in Russian territory of the Baikal Basin

The statistically based reliable increase of average annual temperatures has been registered in Russian territory of the Baikal Basin (Fig. 6.2).

The changes in annual precipitations differ in individual monitoring stations. Precipitations did not change or only with slightly decrease in the forest-steppe and steppe zones of the studied area (Ulan-Ude, Novoselenginsk, Kabansk, Kyakhta, Novaya Kurba). Continuing precipitations increase has been registered in the southern mountain areas (Petropavlovka) of Russian territory of the Baikal Basin. The precipitations increase reached 11.6 mm in last 30 years in Petropavlovka station (River Djida Basin). The decreases of precipitations in Kabansk station amount to 47.7 mm and in Novoselenginsk station 25.5 mm during the last 30 years; both above stations are located in low and middle reaches of the Selenga River. The slight long-term trend in precipitations decrease has been observed at several other monitoring stations located in the basin.

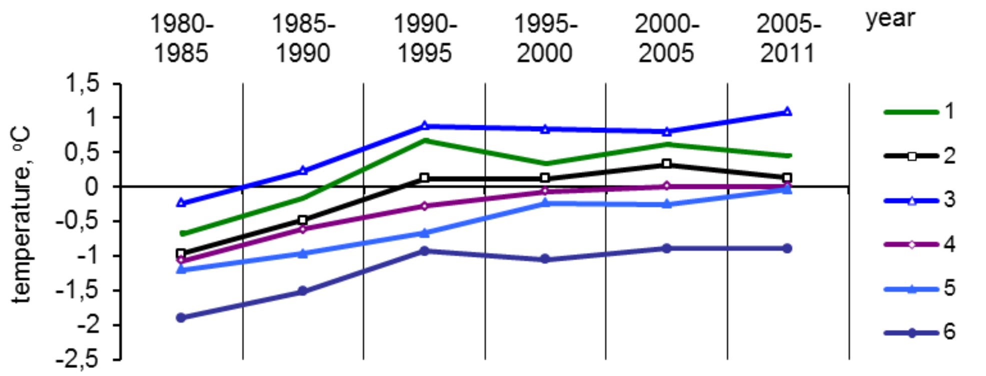


Figure 6.2. Average annual temperatures observed from 1880 to 2011 on monitoring stations in Kabansk (1), Ulan-Ude (2), Kyakhta (3), Novoselenginsk (4), Petropavlovka (5), and Novaya Kurba (6)

The comparison of average annual rivers runoff in the period 2000-2010 with the relevant data from the previous years indicates decrease in the runoff from 24-39 % in the Rivers Selenga, Chickoy, Khilock and Uda. In winter season the rivers runoff is largely supported by groundwater. Based on available data the groundwater discharge increased in the Rivers Selenga (on the Russian – Mongolian border), Chickoy, and Uda over the last decade of about 17.6, 10.5 and 19.2 % respectively. The share of groundwater discharge in the total runoff of the Rivers Khilock, Djida and Temnik corresponds to 6.6, 4.3 and 4.8 % respectively (Khazheeva and Plyusnin, 2012). The revealed climatic changes influenced the rivers runoff and decrease of groundwater level and resources in the shallow aquifers in many areas of the River Selenga Basin.

7 | Groundwater priority issues of transboundary concern in the Baikal Lake Basin - Conclusions and recommendations

Within the framework of the UNESCO–IHP project activities on “Groundwater Resources in Shallow Transboundary Aquifers in the Baikal Basin: Current Knowledge, Protection and Management” the occurrence of groundwater resources in shallow and transboundary aquifers in the Baikal Basin have been analyzed. Human-made threats on groundwater quality (pollution) and quantity (depletion) and groundwater dependent ecosystems have been evaluated. However, groundwater data scarcity limited groundwater resources evaluation. Groundwater investigation and monitoring are recommended with the objective to expand the knowledge of shallow groundwater resources both quantity and quality and to support groundwater resources assessment, sustainable development and management and environmentally sound protection in the Baikal Basin, and specifically in the transboundary territories of Russia and Mongolia.

Based on the collection, verification and evaluation of available reliable groundwater data, hydro-geological maps and other relevant environmental and socio-economic information the following key outputs have been prepared:

- Compilation of existing data and information on shallow transboundary aquifers shared by Russia and Mongolia, and their present state of knowledge
- Identification of groundwater-related priority issues of transboundary concern: Man-made threats on groundwater resources
- Investigation and evaluation of interactions between surface water and groundwater
- Climate change impacts on groundwater in shallow aquifers, groundwater-dependent ecosystems and groundwater in permafrost
- Groundwater related contribution to the transboundary TDA.

7.1 Identification of transboundary aquifers and evaluation of the present status of their knowledge

Three areas on Russian – Mongolian border have been identified (chapter 5) where transboundary groundwater runoff occurs: shallow aquifer in floodplain of Selenge River and in contiguous confluence area of the Rivers Selenge and Orkhon, shallow aquifer in floodplain of the River Kyakhtinka and shallow aquifer in floodplain of the Chickoy River. All three aquifers are facing groundwater data scarcity. There is not sufficient knowledge on aquifers thickness, physical properties and groundwater chemistry. Groundwater data are also missing for evaluation of interaction between shallow aquifers and adjacent rivers. The activities under the Russian-Mongolian “Agreement on the protection and use of transboundary waters” have been realized only in case of surface water. Transboundary monitoring networks have been established and operate several years and transboundary surface water runoff and quality are regularly measured. However, relevant transboundary groundwater monitoring networks do not exist till this time.

To obtain groundwater data for informed transboundary groundwater management decisions establishment and operation of groundwater transboundary monitoring networks is stressed. Groundwater data will support: evaluation of transboundary groundwater runoff, assessment of transboundary groundwater resources, timely identification of groundwater quality deterioration and transboundary groundwater pollution.

The following activities related to transboundary aquifers are recommended:

- Establishment and operation of transboundary groundwater monitoring networks in three transboundary aquifers (chapter 5) on both sides of Mongolian – Russian boundary and implementation of standardized methodology for groundwater observation and sampling and for harmonization of monitoring frequency in both countries.
- Establishment of transboundary groundwater and surface water database in GIS and come to an agreement (legal and technical based) on transboundary monitoring data collection, assessment and management and data mutual accessibility and fees free exchange between both countries.
- Investigation and assessment of transboundary groundwater resources both quantity and quality in transboundary aquifers and evaluation of transboundary groundwater runoff.
- Identification of groundwater potential pollution sources and evaluation of the possibilities of groundwater transboundary pollution movement.

7.2 Man-made threats on groundwater resources and transboundary aquifers

Solid and liquid wastes of different origin are meaningful sources of groundwater pollution in the Baikal Basin on the territories of both countries, Russia and Mongolia. Particularly mining and processing of gold, copper, molybdenum, tungsten, zinc and coal carried out on a large scale for a long time produce waste often with content of toxic constituents. Sources of wide range of impacts on groundwater quality are uncontrolled leakages of waste water from ore washing and dressing facilities, post-extraction processing of mining material, coal preparation, uncontrolled leakages from tailings, piles, evaporation ponds and other uncontrolled disposal sites. Groundwater and surface water pollution by industrial and municipal waste disposal sites and uncontrolled leakages of untreated waste water have been registered in several places of Baikal Basin in both countries too. Excessive pumping of mine waters may lead to groundwater resources depletion, affects groundwater supply systems and groundwater quality.

7.2.1 Transboundary groundwater pollution

Groundwater pollution from the above described sources is mostly of local (site – specific) extent, however, due to the interaction between shallow aquifers and rivers and streams, surface water can be polluted by groundwater and pollution transported across Mongolian – Russian boundary. Particularly uncontrolled waste disposal sites located on floodplains in the rivers valley are significant potential pollution sources of vulnerable and productive shallow aquifers in fluvial deposits.

Impact of mining activities on groundwater

Mining activities have the strongest impact on groundwater resources quality in Baikal Basin. Mining of mineral deposits is pursued by open pit and deep mines with plenty use of water. Some private mining companies illegally use mercury and cyanide for gold separation and produce water toxic pollution. Only a few per cent of useful mineral components are extracted from the rocks, and 90-95% of rock material is handled as the wastes. Tens of millions of tons of ore tailing with

3-4% sulphide mineralization are stored in the River Selenga catchment and due to on-going oxidation processes there are extremely danger sources of groundwater pollution. Storage of wastes is often realized by so called dam method that only protects deposits of tailing from mechanical dispersion in the surrounding area, but it does not solve the migration of toxic components in solutions in groundwater system. Ore mineral constituents are also leached by atmospheric and surface water and moved into aquifer. Site specific groundwater monitoring systems controlling water quality and groundwater depletion around mines and disposal sites of mine wastes are almost missing both in Russian and Mongolian territories of the Baikal Basin.

TDA rating criteria applied for evaluation of the impact of different pollution sources on groundwater quality (chapter 3) identified impact of mining activities on groundwater as high priority issue (overall rating 6) of transboundary concern (Table 7.1).

The following activities are recommended to control groundwater and surface water quality against pollution originated from mining operations:

- Investigation and evaluation of the present status of mining activities in large mining districts in Mongolian and Russian territories of the Baikal Basin with respect to their potential impact on water resources.
- Evaluation of mineral compositions of large mine waste disposal sites and chemical composition of waste leakages with the scope to propose: 1/ effective protective measures for waste disposal sites isolation from surrounding geological environment, 2/ relevant liquid waste treatment technology, and 3/ design of site specific groundwater monitoring networks and standardized monitoring methodology.
- Establishment and operation of site specific groundwater monitoring system around mining districts to control impact of 1/ pollution leakages on groundwater quality and 2/ groundwater abstraction (for mines dewatering and ore processing) on public and private water supplies, irrigation facilities or ecosystems.
- Study of transport and transformation processes of toxic constituents in the unsaturated and saturated groundwater system in mining districts located nearby the Mongolian - Russian boarder and closely to the surface streams in floodplain areas with the scope to effectively protect groundwater resources in shallow aquifers against mining pollution.

With respect to the national water resources protection policy it must be pointed out (chapter 3) that: 1/ environmentally sound mine operations must be obligatory issue of mining concessions afforded by governmental authorities, 2/ control and monitoring must guarantee that waste water are continuously treated and toxic constituents are not present in waste water discharging from mine facilities into the surface water and groundwater, 3/ owners of mine facilities have to take responsibility for investments in and installation of relevant modern mining and waste water treatment technologies, construction of safe disposal sites and operation of site specific groundwater monitoring networks.

Impact of industrial and municipal wastes on groundwater quality

TDA overall rating (chapter 3) identified the uncontrolled discharge of untreated or not sufficiently treated waste water from industrial centers and municipal areas as other groundwater priority issue (overall rating 4, Table 7.1). Both types of **liquid wastes** can affect groundwater in shallow aquifers and degraded its quality. Significant investments on construction of treatment plants with modern treatment technology and capacity relevant to the current and future needs as well as significant improvements of waste water management, inclusive of waste water reuse, have to be implemented within next 10 years to reduce impact of industrial and municipal waste water on the quality of groundwater resources and groundwater dependent ecosystems.

Impact of uncontrolled industrial and municipal disposal sites of **solid wastes** on groundwater quality is registered in the Lake Baikal catchment in many industrial areas and municipal and rural settlements (chapter 3). Produced wastes are mostly stored in the waste disposal sites surrounding the industrial facilities and closely to municipal and rural settlements. Over the time wastes are transformed under influence of the weathering agents and produced fluids and leakages migrate through the unsaturated zone and pollute saturated aquifer.

Many waste disposal sites are sited in the fluvial deposits of the floodplain areas where seasonal fluctuation of groundwater level is under the influence of surface water flow in the rivers. Toxic substituents and other pollutants may be washed from uncontrolled waste disposal sites into the rivers and from rivers discharged in the shallow aquifers. However, reversible situation often occur too. In period of river low flows polluted groundwater may discharge into the surface streams and pollution could be carried on long distances across transboundary areas and may even reached the Lake Baikal.

New landfills have to be located on the sites where productive aquifers are not developed, groundwater level is deep below ground and unsaturated zone is impermeable and thick. From technical standpoint they have to be equip with protective impermeable layers with high attenuation and absorption capacity, drainage systems and site specific monitoring networks. Such environmental safe management of solid wastes requires significant investments of municipalities and industrial companies in the course of the next ten years.

The following activities are recommended to protect groundwater against pollution from industrial and municipal waste:

- Investigation and evaluation of waste disposal sites of big industrial facilities or industrial services producing toxic wastes inclusive of proposal of technical measures for pollution control and protection of groundwater quality.
- Identification and evaluation of uncontrolled industrial or municipal disposal sites located near to the water supply systems or aquifers with significant groundwater resources and projection of technical measures for 1/ safe operation of existing disposal sites or 2/ disposal site closing and 3/ toxic wastes removing.
- Implementation of techniques and methods for effective reuse of treated waste water (e.g. aquifer replenishment, irrigation).
- Regular control of chemical composition of treated waste water discharge in the surface streams, lakes or groundwater.
- Operation of site specific groundwater monitoring networks around waste disposal sites to observe groundwater quality and timely identify potential pollution leakages.

	SCOPE				
		4: Very high	3: High	2: Medium	1: Limited
SEVERITY	4: Very high	8	7	6	5
	3: High	7	6	5	4
	2: Medium	6	5	4	3
	1: Limited	5	4	3	2

Table 7.1. Overall rating of groundwater pollution sources (solid waste in black circles, liquid waste in red circles) in Russian and Mongolian territories of the Baikal Basin

7.2.2 Impact of agricultural activities on groundwater quality

Diffuse groundwater pollution by nitrate and pesticide by agricultural activities is not registered as a significant environmental problem in the Baikal Basin as yet. Amount of applied fertilizers and chemicals and intensity of farming activities is low in comparison with e.g. European countries and USA. However, crop farming is rapidly developing particularly in Mongolia and increasing use of fertilizers and chemicals with the scope to increase crop production will involve on soil and groundwater quality in shallow aquifers.

High **groundwater point pollution** by nitrogen-containing compounds (700 mg/l) has been identified in the areas surrounding the poultry farms in Russian territory of the Baikal Basin. Uncontrolled discharges of waste water from animal farms are significant sources of pollution of shallow vulnerable aquifers. Treatment of waste water from animal farms has to be therefore obligatory for operation of animal farms. Quality of discharging treated waste water has to be regularly controlled as well.

A coordinated effort between agricultural and water sectors is therefore needed to define in time policy for sustainable management of agricultural production and environmentally sound protection of groundwater resources. Control measures depend above all on the steps taken in the agricultural sector.

The following attributes of sustainable agricultural production are recommended to protect groundwater quality in shallow aquifers below cultivated arable land:

- Maintain traditional crop rotation system.
- Control over fertilizers and pesticides application (type, amount and doses applied and time of application with respect to the crops type).
- Selection of suitable cultivation techniques (especially tillage).
- Soil quality conservation (e.g. keeping dynamic stability of the soil organic matter).
- Control of the nitrogen and carbon balance as essential attribute for gaining insight to the physical, chemical and biological processes which take place in the soil-unsaturated zone and control the amount of nitrogen leached in the saturated aquifer.
- Soil and groundwater quality monitoring (monitoring of unsaturated zone and vertical profile of the aquifer) to control nitrate transport and transformation processes)

Irrigation is going on in several areas of the Baikal Basin. Monitoring of the irrigation return flow is needed because irrigated water contributes to the growing salinity of the soil and leached salts move to the underlying shallow aquifers and degrade the quality of groundwater

7.2.3 Groundwater depletion

Groundwater shortages due to the population growth and groundwater pollution have been registered in some areas of the Mongolian territory of the Baikal Basin. However, hydrogeological investigation and evaluation of potential impact of mining activities on the quantity and quality of groundwater resources due to mine dewatering have not been realized till this time. Excessive pumping of mine waters may lead to groundwater resources depletion, degradation of groundwater quality or groundwater dependent ecosystems and may affects groundwater supply systems. Furthermore, the sustainable rate of exploitation of local groundwater resources has already been exceeded in high water demand areas, like the Tuul and Shariin River Basins near to Ulaanbaatar.

In Russian territory of the Baikal Basin groundwater depletion is not registered yet. However, regular observation of groundwater discharge and groundwater levels is not realized as yet.

Increasing demand on groundwater resources for drinking and other purposes owing to ongoing social and economic development requires comprehensive control over groundwater abstraction. Establishment and operation of site specific monitoring networks around water supply systems and other groundwater abstraction sites is recommended. Regular monitoring will provide data for groundwater resources assessment and sustainable development and management.

7.3 Interaction between surface water and groundwater

Significant groundwater resources in shallow aquifers occur in alluvial deposits in Mongolian and Russian territories of the Baikal Basin. Some aquifers are developed and groundwater is used for drinking water supply of cities and rural settlements. Aquifers interaction with adjacent rivers is registered in floodplain areas and in low river terraces. However, there are scarce or not available water level data needed for evaluation of 1/ interaction between both resources, 2/ share of infiltrated surface water on groundwater stored in shallow aquifers, 3/ the amount of groundwater discharge into surface streams, particularly in drought seasons (base flow), and 4/ transboundary groundwater flow and potential pollution transport in shallow aquifers in fluvial deposits in Mongolian-Russian transboundary areas.

At the transboundary level and Baikal Basin scale priority in the studies of interaction between both resources should be given to the extensive valleys of the Rivers Selenge, Orkhon, Uda and other big rivers and their confluence areas where thick and permeable fluvial deposits with significant and economically accessible groundwater resources in productive shallow aquifers occur. However, it has been found that hydrogeological knowledge of such shallow aquifers is mostly very restricted and data about thickness, vulnerability, permeability and hydraulic properties of shallow aquifers as well as data about regular groundwater level measurements and groundwater chemistry and quality are scarce. Data are particularly needed for the studies of seasonal changes in water level of both surface water and groundwater and their influence on groundwater discharge into rivers in dry seasons and surface water discharge in adjacent shallow aquifers in wet seasons. Such situation occurs e.g. in dry seasons in Tuul River below Ulaanbaatar.

To better understand interactions between groundwater and surface water in Mongolian and Russian transboundary areas and in the Baikal Basin at all the following activities are recommended:

- Evaluation of groundwater - surface water seasonal and long term interactions based on regular observation of surface water levels and runoff on river monitoring stations and on existing and new establish groundwater monitoring wells in shallow aquifers in confluence areas of big rivers and in transboundary areas. Such monitoring facilitates the studies of the influence of fluctuation of water levels on the amount and quality of groundwater resources in shallow aquifers adjacent to surface streams. Data will be used for setting up and calibration of conceptual model of the studied area as a first step in GIS data entry process and grid-based numerical model generation.

- Impact of turf degradation on groundwater quality in shallow aquifers discharging into Lake Baikal has been registered. It can be recommended to monitor and study 1/ interaction between shallow aquifers adjacent to Baikal Lake, 2/ the processes occur owing to the turf degradation and 3/ groundwater pollution transport from drained lands into the Lake Baikal

7.4 Climate change impact on shallow aquifers and dependent ecosystems and on groundwater in permafrost

Generally two types of aquifers can be distinguished with respect to the potential impact of the climate change. **Deep aquifers** with groundwater residence time and a renewal period in the order of thousands of years or longer in case of fossil groundwater generally have a low vulnerability to contemporary climate variability and change. **Shallow aquifers** with groundwater residence time in order to days up to hundreds of years are vulnerable to climate change, specifically to changes in air temperature and precipitation. Air temperature increased during last decades in Mongolian and Russian territories of the Baikal Basin (e.g. 2.1°C during last 70 years in Mongolia). Precipitations changes differ regionally. In Mongolia in the Altai mountain region, Altai Gobi and in the eastern part of the country precipitations increased since 1961, and in all other country regions precipitations decreased by 0.1-2.0 mm/year. In Russian territory of the Baikal Basin the decreases of precipitations (25.5–47.7 mm during the last 30 years) has been registered in low and middle reaches of the Selenga River however, precipitations increase reached 11.6 mm in last 30 years in the River Djida Basin. Changes in precipitations jointly with increasing temperature affect conditions for groundwater recharge, changes in groundwater levels and groundwater storage in shallow aquifers. Close hydrological relation between surface water runoff and groundwater level in shallow aquifers in floodplains is registered too.

Groundwater level decline due to natural conditions or by pumping in shallow aquifers and groundwater pollution both have destructive impact on groundwater dependent wetlands and ecosystems. Extensive wetlands and their dependence on shallow aquifers occur in the Baikal Basin at the Selenga River Delta. Comprehensive protection against human impacts is needed in the delta to protect effectively both wetlands and shallow groundwater.

Specific attention should be given to the influence of climatic conditions on groundwater occurrence and availability in permafrost areas widely developed in the Baikal Basin. Continuous increase of the thickness of thawing soil layer of permafrost due to growing temperature is registered. At the present times groundwater in the permafrost is a valuable source of drinking water for several small rural settlements and for pasture livestock. However, with increasing air temperature the groundwater resources in permafrost will be significant source of drinking water for rural communities living in mountain and sub-mountain regions.

The following activities are recommended with respect to the influence of climate change on groundwater resources:

- Study of influence of climate change on wetlands dependent on groundwater in the Selenga River Delta. Hydrogeological investigation of shallow aquifers, early warning monitoring and ecological studies are needed to effectively protect groundwater and dependent wetlands and ecosystems in the Selenga River Delta against the influence of climate change.
- Establish regular groundwater monitoring of shallow and permafrost aquifers at pilot areas in the Baikal Basin and groundwater data correlate with climate and surface water data with the scope to clarify climate change influence on the quality and quantity of groundwater in both shallow and permafrost aquifers.

7.5 Priority issues of transboundary concern: Contribution to the Transboundary Diagnostic Analysis of the Lake Baikal Basin

Human activities may have irreversible impacts on aquifers and the groundwater resources contained therein. The implementation of recommended actions to address the priority issues of transboundary concern described above will reduce current and future risks of groundwater pollution and depletion. The recommended priority actions will be beneficial for the sustainable development and management of groundwater resources in the Baikal Basin, safeguarding groundwater quality and the integrity of groundwater dependent ecosystems. At the transboundary level the recommended measures will help to anticipate potential conflicts related to transboundary groundwater resources pollution and depletion.

The implementation of the proposed priority actions will 1/ improve the knowledge about groundwater resources quantity and quality and groundwater pollution in the entire Baikal Basin, 2/ clarify hydrogeological conditions in transboundary areas where groundwater runoff discharging Mongolian or Russian territories of the Baikal Basin is not monitored as yet and data are not available to control potential transboundary groundwater pollution transport.

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