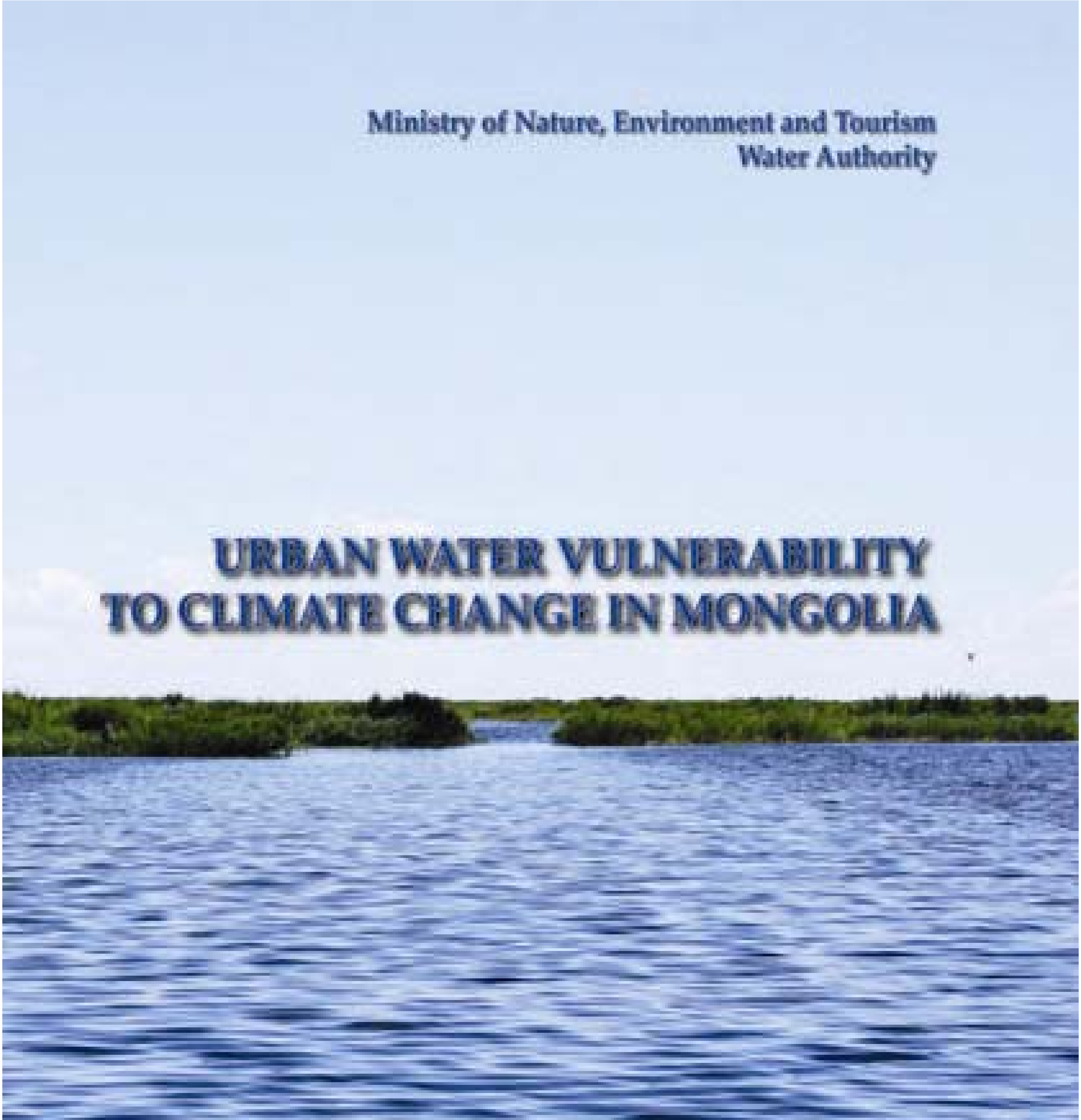

Ministry of Nature, Environment and Tourism
Water Authority

URBAN WATER VULNERABILITY TO CLIMATE CHANGE IN MONGOLIA

Ulaanbaatar
2010

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Ministry of Nature, Environment and Tourism
Water Authority, Mongolia

URBAN WATER VULNERABILITY TO CLIMATE CHANGE IN MONGOLIA

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Ulaanbaatar, 2011

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FOREWORD BY UNEP

The United Nations Environment Programme (UNEP) is mandated to regularly keep the state of the environment under review and bring emerging issues of significance to the attention of decision-makers for action. One mechanism to achieve this is through the Global Environment Outlook (GEO) process with global, regional, sub-regional, national and city-level assessments. The GEO process is participatory and consultative, with capacity building at its core. The result is scientifically authoritative information for environmental management and policy development tailored to a wide target audience.

Mongolia, with a population of 2.5 million of which more than 50% live in the capital city Ulaanbaatar, is already confronted with the effects of climate change. Natural disasters such as drought, heavy snowfall, floods, snow and wind storms, and extreme cold and hot temperatures are becoming increasingly frequent. Annual mean temperatures have increased by 2.1°C since the 1940s. Over 80% of Mongolia's water consumption of approximately 5,000 million m^3 is consumed by industry and agriculture. About 80% of drinking water comes from aquifers and, for domestic water use, 70% of residents either acquire their own water from water trucks or from public kiosks. Water consumption of the population living in the traditional "ger" districts of large cities, town centres and big settlements is equal to 8 to 10 litres per person per day, 4-5 times lower than the accepted sanitary norms. Research results are emerging of the likely pattern of future climate: it is forecast to include higher temperatures all year round, with more snow in winter and less rain in summer. It will also bring more variable weather conditions with longer and more frequent droughts.

The Urban Water Vulnerability to Climate Change in Mongolia Report confirms that with strong evidence of impacts of climate change to water resources, providers for drinking water, as well as agencies dealing with storm water, flood water and wastewater will experience the consequences of effects like reduced snow cover and increased frequencies of floods and droughts. As existing infrastructure is already in need of significant investments to maintain current levels of service, climate change is exacerbating the need for additional resources. Over and above the impact on the urban services, other sectors like health, agriculture and energy are also affected.

The assessment findings provide practical policy options for follow-up actions by the Water Authority, under the Government of Mongolia, especially on adaptation which is to Develop an Integrated Urban Water Management plan for the Tuul river basin, implemented to harmonize the interests of stakeholder groups and environmental constraints and provide a sustainable future for water resources in the Basin.

I strongly hope that the preparation this Report has enhanced the technical capacity of the Water Authority, under the Government of Mongolia and at the same time, the findings of the Report contribute to the mandate of the government and the Ministry in responding to urban water resource and supply management as an urgent issue. I believe that the Report will also provide valuable information and options to assist the country to sustain the quality of life of its residents.

Young-Woo Park

Dr Young-Woo Park

Regional Director and Representative

United Nations Environment Programme

Regional Office for Asia and the Pacific

FOREWORD BY MNET

It is well-known that water is an essential resource for life on earth. What is unfortunately far less common is the knowledge of how to manage this resource properly to ensure its availability for future generations. The mission of the Ministry of Nature Environment and Tourism is to direct the collective efforts and initiatives of the state, citizens, businesses and organizations in fulfilling the right to live in a healthy and safe environment, linking social and economic development with ecological balance, protecting the natural environment in the interests of present and future generations, and making appropriate use of natural resources including water resources and creating proper opportunities for their restoration.

Recently climate change in Mongolia is of growing concern, and its impacts on the economy are potentially significant. Major consequences are likely to be manifested through the water system.Climate change studies conducted in Mongolia so far mostly focused on the impacts on and vulnerability of natural resources but did not focus on the impacts of climate change on urban water and its implications for urban water utilities in Mongolia. This initiative is a response to fill the mentioned gap. The Ministry realises the importance of understanding how the urban water infrastructure will be affected and how these impacts may be mitigated by changes in design and operation. The report points out that climate change will affect all aspects - from the natural water resources to the effectiveness of the water supply capability. Ultimately this will change urban water management practices. This study aims to present the impacts of climate change upon urban water particularly upon the performance of the urban water supply, wastewater and storm water infrastructure, through compiling existing studies on climate change and water resources. When describing impact of climate change on water resources, the term water supply is often used synonymously with urbanization. Thus the urban water supply is no longer the concern of the municipality only. Solving water-related issues under changing climate requires technical and scientific expertise, and greater understanding and integration of environmental, social and political factors and inter-organizational coordination at different level.

The Urban Water Vulnerability to Climate Change in Mongolia Report is the output of effective and successful collaboration effort between the United Nations Environment Programme and the Mongolia Water Authority and provides an assessment of the impact of climate change on and vulnerability of water resources in Mongolia, with the emphasis on urban areas. The report confirms the challenging links between climate change and water availability with solid scientific evidence for the selected rivers and lakes. The report also draws on challenges for country as a whole as well as in urban area in terms of further reducing the climate change burden in water supply, human health and aquatic ecosystems. Conclusions are drawn relating to: i) understanding current and future of vulnerability of water resources to climate change; ii) better integrating water and other policies for sustainable development; and iii) water-related adaptation to climate change in context of urban water management. On behalf of the Ministry, I would like to thank the UNEP Regional Office for Asia and the Pacific for both financial and technical support in preparing this report and special thanks is extended to the team in Mongolia for their commitment. I strongly believe that the report will contribute a great deal to support the urban water management in Mongolia.

Jargalsaikhan Ch.

Vice Minister

Ministry of Nature, Environment and Tourism

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ABBREVIATIONS

AOB	Arctic Ocean Basin
BOD	Biochemical oxygen demand
CSIRO Mk2	Climate change scenario developed in the Division of Atmospheric Research Private, Australia
ECHAM3	Climate change scenario developed in the Institute of Hydrology and Meteorology, Germany
GCM	General Circulation Models
GoAL-WASH	Governance, Advocacy and Leadership for Water sanitation and Hygiene
GoM	Government of Mongolia
HadCM3	Climate change scenario developed in the Hadley Centre
HBV	Integrated Hydrological Modelling System
IDB	Internal Drainage Basin
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated water resources management
MAFLI	Ministry of Food and Light Industry
MAP-21	The Mongolian Action Programme for the 21st Century
MARCC	Mongolia Assessment Report on Climate Change
MCUD	Ministry of Construction and Urban Development (Mongolia)
MDG	Millennium Development Goal
MNET	Ministry of Nature, Environment and Tourism (Mongolia)
NGO	Non Government Organisation
NWC	National Water Committee (Mongolia)
OSNAAG	Housing & Communal Service Authority
POB	Pacific Ocean Basin
PUSOs	Public urban services organizations
SRES	Special Report on Emissions Scenarios
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USUG	Ulaanbaatar's Water and Sewage Company
WA	Water Authority (Mongolia)
WB	World Bank
WHO	World Health Organisation
WSS	Water Supply and Sanitation

URBAN WATER VULNERABILITY TO CLIMATE CHANGE IN MONGOLIA


Orkhon river value

@ T.Bekhbat

EXECUTIVE SUMMARY

Mongolia, with a population of 2.5 million, is located in Northeast Asia between 41°35′ and 52°09′ North, and 87°44′ and 119°56′ East, covering an area of 1,564,000 km^2. Climate change is already a fact in Mongolia: Natural disasters such as drought, heavy snowfall, flood, snow and wind storms, and extreme cold and hot temperatures are becoming more and more frequent. Annual mean temperatures have increased by 2.1°C since the 1940s.

The Mongolian climate will continue to change dramatically over this century. Study results are emerging on the likely pattern of this future climate. It is forecasted to include higher temperatures all year round, with more snow in winter and less rain in summer. It will also bring more variable weather conditions with longer and more frequent droughts.

Mongolia's water consumption is approximately 5,000 million m^3. Over 80% is consumed by industry and agriculture. About 80% of drinking water comes from aquifers and 70% of residents either acquire their own water or get it from public kiosks. Water consumption of the population living in the ger districts of large cities, town centres and big settlements is equal to 8 to 10 litres per person per day, 4-5 times lower than the accepted sanitary norms.

Government surveys show that in 2006 just over half of Mongolian households indicated they had access to clean water. Water consumption in Ulaanbaatar exceeds the average of that in developed countries. In addition, repairs and maintenance of the municipal water supply lines are irregular. Water resources are very susceptible to the pressures of over-use from human activities. While there are measures in place for many sectors to adapt to climate change, there is a need for the Mongolian Government to look at the impacts of climate change on urban water use and management so it can investigate proper measures for urban water managers to deal with issues of water supply and utilization in the context of climate change. Sewage systems design, storm water infiltration systems and subsurface drainage systems are all impacted by changes in the water regime that are caused by extreme weather events and increasing temperatures. Climate change studies conducted in Mongolia so far mostly focused on impacts and vulnerability of natural resources but did not focus on the impacts of climate change on urban water and its implications for urban water utilities in Mongolia. It is important to know how the urban water infrastructure will be affected and how these impacts may be mitigated by changes in design and operation. Climate change will affect all aspects - from the natural water resources to the competitiveness of the water supply capability. Ultimately this will change urban water management practices.

This study aims to present the impacts of climate change upon urban water particularly upon the performance of the urban water supply, wastewater and storm water infrastructure, through compiling existing studies on climate change and water resources.

This vulnerability assessment of urban water resources will help identifying urban communities who will be most affected by climate change and, as a long term plan, will draw strategic views on how water utilities can be planned properly to cope with the likely changes. The Mongolia Water Authority is implementing a project to develop an Integrated Water Resources Management plan at the National as well as at the Orkhon Tuul river basin level. The government can use the findings of this vulnerability assessment to develop Integrated Urban Water Management planning for future use.

CLIMATE CHANGE AND ITS PROJECTIONS

Observations from sixty sites distributed across the country show that the Mongolian climate has already changed significantly. In the last 60 years, Mongolia experienced the following:

- Annual mean temperatures have risen by 2.14°C during the last 70 year. The warming has been most pronounced in winter, with a mean temperature increase of 3.6°C, while spring, autumn, and summer mean temperatures have risen by 1.8°C, 1.3°C, and 0.5°C respectively.
- Annual precipitation changes are quite variable, decreasing at one site and increasing at another site nearby. Seasonally, autumn and winter precipitation has increased by 4-9%, while spring and summer precipitation has decreased by 7.5-10%. Spatially, since 1961 in Altai mountain region, Altai Gobi and in the eastern part of the country, precipitation has increased, and in all other regions has decreased by 0.1-2.0 mm/year.
- The number of hot days increased by 8-13 days and the number of cold days decreased by 7-11 days.

Three coupled General Circulation Models (GCMs), HadCM3, ECHAM3 and CSIRO Mk2 were run with The Special Report on Emissions Scenarios (SRES) of the Inter-governmental Panel on Climate Change (IPCC) for this study. For all the models, the responses to the middle forcing scenarios A2 and B2 were analysed. Future climate change is presented for three 30-year time slices, centred on the 2020s, 2050s, and 2080s, each relative to the climatological baseline period 1961-90. The models suggest that:

- The rate of future winter warming in Mongolia will vary from 0.9°C to 8.7°C, while the summer temperature will increase and vary from 1.3°C to 8.6°C.

- Winter precipitation will increase by between 12.6-119.4% when the summer rainfall varies from 2.5% decrease to 11.3% increase.

Contrasting a small increase of summer rainfall, there is a much higher increase of evapotranspiration by 13-90.9%, depending on the region.


Uvurkhangai aimag Hujirt @ P.Batimaa

IMPACTS OF FUTURE CLIMATE CHANGE

Increased winter air temperatures and more intense summer rainfalls affect not only the timing of stream flows but also the seasonal runoff. There is a longer dry period with lower flows in the low flow seasons and a shorter period with higher flows in the peak season. Mongolia's annual water resources are likely to decrease while the annual distribution will remain similar to current distribution patterns. This has implications for water shortages which will worsen in low water periods.

There are also clear changes in the dates of autumn and spring ice phenology occurrences, ice cover duration and ice thickness on rivers and lakes. Changes in ice phenology dates correspond to an increase in air temperatures in autumn and spring, when the river ice processes take place.

The impact of precipitation changes is substantially greater than the impact of temperature fluctuations: if the annual precipitation drops by 10% while the temperature remains constant, the average river flow reduces from 7.5-20.3%. If, besides the precipitation drop, temperature increases are taken into account, an additional flow reduction is expected. For each degree temperature increase, annual flow decreases at least 2%.

The effect of climate change on groundwater recharge in Mongolia is still poorly understood. Many factors affect this phenomenon: changes in precipitation, evaporation and temperature regimes; soil properties and their changes; changes in forest management and agricultural practices; and urbanization. Climate change is expected to reduce aquifer recharge and water levels, especially in shallow aquifers. Higher temperatures and droughts will result in increased evapotranspiration. Heavier precipitation events will also impact aquifers, because of more water runoff before it can percolate into the aquifers. Thus, even when overall precipitation increases, aquifer levels may decrease, due to having less but more intense precipitation events.

Climate change and related water stress are having, and will continue to have, consequences for Mongolia's ecosystems and economy. The cropland, pasture, wetlands and forests are under a variety of pressures, much of it anthropogenic, which are aggravated by stress from climate change. The impacts of water scarcity are likely to include the degradation of natural environments, ecosystems, soil quality and structure, and the advance of desertification.


Govi-Altai aimag Zavkhan river @ Ts.Tsetsegee


Khovd aimag Bulgan river @ Ts.Tsetsegee

URBAN VULNERABILITY TO CLIMATE CHANGE

About half of the world's population lives in an urban area. Mongolia is no exception to this even though Mongolia is one of the most sparsely populated countries in the world with a population of 2.7 million over a territory of 1.56 million km^2. Mongolia ranks 233th with 1.6 person/km^2. By the end of 2008, about 1.66 million people (roughly 60% of the total population) were living in urban areas in Mongolia. Mongolia's fastest growing urban area is Ulaanbaatar and the city faces environmental challenges such as air pollution, water pollution and land degradation that affect human health and safety.

Daily water consumption of Ulaanbaatar is about 150-170 thousand m^3. This is pumped from four well fields along the Tuul River, with 100 km of raw water pipes connecting wells and pumping stations and 350 km of distribution lines supplying the city core. Water consumption in Ulaanbaatar exceeds the average of that in developed countries. In addition, the repairs and maintenance of the municipal water supply lines are irregular.

The study shows that the Tuul River water resources have decreased considerably. Current water resources are less than one third of what it was in the mid-1990s. It is projected to decrease at least 2% 2020 by the ECHAM4 model and up to 25% by 2080 by the CSIRO-Mk2b model. Water consumption is predicted to reach 290,000 m^3 in 2010, 358,000 m^3 in 2020, and 458,000 m^3 by 2030. The existing wells, even at full capacity, are designed to supply only around 250,000 m^3 a day.

The effects of climate change on water supplies will depend on the operating characteristics of the reservoir system and the institutional and legal rules constraining the operators.

Housing, commerce and transport compete for the shrinking open space in Ulaanbaatar. Most seriously the settlement area is expanding to the dried river channel. Most of the flood protection work was done after the 1966 flood event that was the highest flood recorded since 1940s. The current flood protection system is hardly functioning because of poor maintenance. It is difficult to claim any storm water drainage capacity in Ulaanbaatar because currently the system can bear neither intense rains nor spring melting flow. Thus, climate change will affect the water service mainly through infrastructure damage. The likely increase in extreme events such as flash floods, but also the changes in permafrost may cause damages to flood protection, drainage works and transport infrastructure and affect road and rail safety. In particular, flooding of roads with inadequate drainage and physical damage to the roads will have more impact due to the melting of permafrost.

The changing runoff patterns and increasing water temperatures may result in water quality effects that either render water unusable for any propose or impose additional treatment costs. Changes in the availability, timing and reliability of rainfall and the water resources that flow from it will affect all water using sectors. These impacts in turn will affect the broader dynamics of the national economy as well as environmental and social needs.

ADAPTATION

The assessment clearly shows that traditional water resources management and development approaches and technologies cannot assure sustainability of water resources under future climate change. Accordingly, new approaches are needed to reconcile conflicting interests on the use and the conservation of water resources to mitigate impacts of or adapt to climate change.

The annual water resources of the Tuul river are likely to decrease but the annual distribution will remain similar to current distribution patterns. This means the water shortages will continue and even worsen in low water periods. Considering the existing scarcity of natural water supplies and their anticipated decrease, adaptation measures are formulated and summarized below.

The principle adaptation recommendation of this report is to develop an Integrated Urban Water Management plan for the Tuul river basin, implemented to harmonize the interests of stakeholder groups and environmental constraints and providing a sustainable future for water resources in the Basin.

More specific adaptation measures related to water resources and supply in Ulaanbaatar can be divided into two categories:

- adaptation of the supply
- adaptation of the demand

These are actions in two directions; the first is linked to the reduced available water resources and the second is linked to the increased water demands. The adaptations related to water supply refer to modification of the existing physical infrastructure and alternative management of the existing water supply systems. The adaptations related to demand focus on water conservation and improved efficiency, technological change and water pricing. Both categories will benefit from improved knowledge on climate change.

@ P.Batimaa

Khovd aimag   Khoton lake   @ Ts.Tsetsegee

INTRODUCTION

RATIONALE

Life on Earth originated from water. Water is essential for human life. We drink it, we produce food and other products with it and we use water for many socio-cultural activities. Our health and wellbeing depend on it. No water, no life. Bad water, bad life. Good water, good life. It's a resource that must be sustained for future generations.

WATER IN MONGOLIA

Water availability in Mongolia is determined by many different things. It is stored in soils, aquifers, snow, lakes, wetlands, and reservoirs. Water also cycles through the system, including precipitation, runoff and evaporative fluxes to and from the land surface. Change in global climate will affect the regional and local climate, climate variability and alter many aspects of this hydrologic cycle. This in turn will affect not only water resources of the region, but as a result of that also water supply. Among the consequences of a changing hydrologic cycle is its interaction with the terrestrial carbon cycle. Most climate scientists agree that global warming will result in an intensification and/or acceleration of the global hydrologic cycle (Figure 1).

Mongolia is one of sixty countries with limited water resources. On a per square km area basis, the availability of Mongolia's water resources is much lower than the world average. There is 11,182 m^3/yr of water for every inhabitant in the country.

Mongolia's total water consumption is approximately 540 million m^3/year (WA, 2007). Over 80% is consumed by the industrial and agricultural sectors and 20% by domestic use. About 80% of drinking water comes from aquifers (MNE, 2007a). Government surveys record that in 2006 almost half of Mongolian households indicated that they did not have access to clean water (MNE, 2007a).

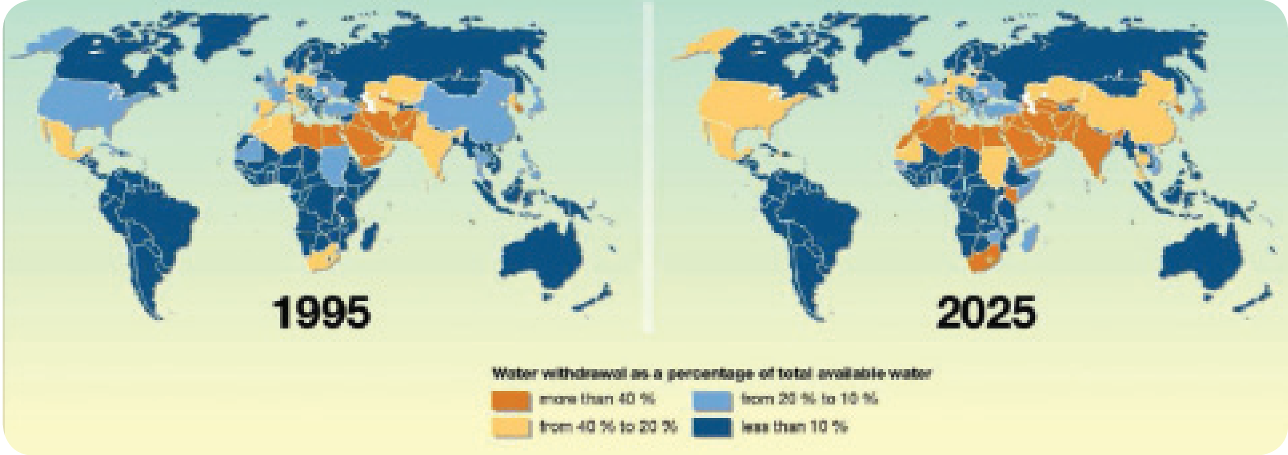


Figure 1. Climate change and Water stress (Source: UNEP Vital Water Graphics, 2008)

CLIMATE CHANGE

Climate change in Mongolia is a source of growing concern, because its impacts on national agriculture, industry, and economy are potentially significant. A variety of natural disasters such as drought, floods, heavy snowfall, snowstorms, windstorms, extreme cold and hot temperatures occur annually. Annual mean temperatures have been increasing since the 1960s. Recent highly variable precipitation and consecutive periods of drought only serve to underline the serious need to prepare for an uncertain future as climate change progresses.

Climate change studies conducted in Mongolia have so far focused mostly on its impact on, and the vulnerability of, natural resources. They include assessments on water resources, snow cover, and permafrost at a national level. They conclude that climate warming would have a significant effect, including an earlier start of spring snowmelt, an increase in high runoff as a fraction of total runoff, and an increase in flood frequency (Batimaa et al., 2005).

The studies did not focus on the impacts of climate change on urban water and its implications for urban water utilities in Mongolia. As the majority of the population live in cities, it is important to know how the urban water infrastructure will be affected by climate change and how these impacts may be mitigated by design or operational changes.

By far the most important city in Mongolia is the capital, Ulaanbataar. This is where water resources are most susceptible to the pressures of over-use from human activities. It is more and more evident that sewage systems, storm water infiltration systems and subsurface drainage systems are all impacted by changes in extreme weather events like sudden spring snow melting and summer flash floods. The Mongolian Government must look at the impacts of climate change on urban water use and management and investigate proper measures for urban water management to deal with issues of water supply and optimal utilization.

This vulnerability assessment of urban water resources firstly aims to identify urban communities **who will be most affected by climate change,** and secondly proposes a long-term plan so that **water utilities** can properly cope with the likely changes.

The Report also seeks to assist decision makers in government and the public and private sectors in formulating and implementing appropriate responses to the challenges and threats posed by global climate change on water resources in Mongolia.

The Mongolia Water Authority is implementing a project to develop an Integrated Water Resources Management Plan at the national, as well as at the Orkhon-Tuul river basin level. Ulaanbataar is located in the Orkhon-Tuul basin. Therefore the findings from this vulnerability assessment are significant for the development of an Integrated Urban Water Management Plan and are of utmost importance for the government when drafting any adaptation strategies in water sector.


Bayan-Ulgii aimag @ Ts.Tsetsegee


Altai tavan bogd mountain @ Ts.Tsetsegee

FOCUS

This report is an assessment of the effects of climate change on the water resources in Mongolia with particular attention to urban water. The lead sponsor of this assessment is United Nations Environment Programme (UNEP). The project was led and coordinated by the Water Authority of the Mongolian Ministry of Nature, Environment and Tourism with support from UNEP and Peking University, China. The assessment was conducted by the team of the “Arvian Khelkhee” NGO.

This report compiles information from existing studies on the impacts of climate change on Mongolian water resources. It then interprets these results in the context of how this will impact the urban water sector, particularly the performance of the urban water supply and the infrastructure for wastewater and storm water processing. The intent is to provide: 1) an essential understanding of climate change, its impacts, and adaptation options for Mongolia; 2) water-related issues under a changing climate; and 3) consideration of the issues of developing suitable water sector responses to climate change.


Ulaan waterfall @ P. Batimaa

The report is divided into two parts. The first part (Chapter 1 to 5) focuses on the water resources in Mongolia and their changes due to climate change. This part presents the current condition of water resources, the management of the water sector and the impacts of climate change on water resources of the country. The second part of the report (Chapter 6 to 9) focuses on the Tuul river basin as a case study on urban water.

URBAN WATER CENTRES

In Mongolia there are two types of urban centres. Firstly, the capital towns of the aimags (provinces) with a small to medium-sized population of usually less than 20,000 people. Mongolia is divided into 22 aimags which are the top-level administrative divisions (Figure 2). These centres are far apart, spread over the


Bayankhongor city @ Ts.Tsetsegee

country. There is not much centralized water supply in aimag centres. Almost all aimag centres are located on the bank of one of the major rivers. Therefore, rivers are the major water source for aimag centres. For example the Khovd river (biggest river originating from the Mongol Altai Mountains) flows through Ulgii (centre of Bayan-Ulgii aimag). The Bayant river that flows into the Knovd river flows through Khovd (centre of Khovd aimag) and the Kherlen river flows through two aimags (Khentii and Choibalsan) centres. Thus, the first part of the report will help local water planners to understand the climate change impacts on the natural water resources they are depending on.

The other urban centre type is the capital city of Mongolia, Ulaanbataar. Ulaanbataar is situated in the Tuul river basin. The total population in the Tuul river basin is 1,107,292 (NSO, 2008). Therefore, understanding the challenges to the Tuul River will help tackle Mongolia's future urban water resource issues.

METHODS AND APPROACHES USED IN THE VARIOUS STUDIES

By using and integrating different methodologies to meet the project activities, the report can better deal with each method's weaknesses. Thus analytical-statistical methods, modelling, GIS technologies and expert judgment provide a comprehensive framework.

Analytical-statistical methods: This part of the assessment is based on existing documents, including relevant scientific literature, measurements and findings published by Mongolian scientists. An exhaustive review of unpublished technical reports was also conducted.

The analyses of time series of climatological parameters such as temperature, precipitation and humidity; and hydrological parameters such as discharge, water temperature and ice phenomenon of the Tuul river basin has been performed using empirical relationships and mathematical statistical methods. Standard procedures for determining the statistical parameters and linear regression have been used to analyse trends in the observed meteorological and hydrological parameters.

Modelling: In previous climate change studies, the Basin Conceptual Model (which uses monthly mean data) was used to assess impacts of climate change on water resources (Batimaa, 1996, 2000, 2003, 2005). For this study the Integrated Hydrological Modeling System (HBV) model was used to assess impacts on the Tuul river. The HBV model is a computerized catchment model that converts precipitation, potential evaporation, and snowmelt into stream-flow by simulating the natural hydrological processes. This model was especially selected for this study to improve the accuracy of previous studies as it uses daily mean values of precipitation, temperature, relative humidity, and runoff. Potential evapotranspiration was estimated using the equation of Ivanov (1954) or when temperature exceeded 5°C, the equation of Blaney and Criddle (1950).

Three coupled General Circulation Models (GCMs: HadCM3, ECHAM3 and CSIRO Mk2) were run with the middle forcing scenarios A2 and B2 from the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC). Future climate change was presented for three 30-year time slices, centred on the 2020s, 2050s, and 2080s, each relative to the climatological baseline period 1961-90.

Uniform changes in temperature ($\triangle$T) and precipitation (%P) were used to test the sensitivity of water resources to climate change. With the set of hypothetical scenarios and using the HBV water balance model, results were generated that give insight into the sensitivity of the basin flows to climate variations.

The "Vulnerability Index" applied in the study is based on UNEP Vulnerability Assessment of Freshwater Resources to Environmental Change (UNEP, 2009).

GIS technologies: GIS overlay methods were used to create hydrogeological maps, coupled with topographical maps, which identify both unconfined and confined groundwater resources within the Tuul river basin.

Expert judgment: Adaptations measures were proposed by expert teams.

Figure 2. Administrative map of Mongolia (Source: Dorjgotov et al., 2009)

@ P.Batimaa

PART ONE

CLIMATE CHANGE AND ITS IMPACTS ON WATER RESOURCES


Khovd aimag Har Us lake @ Ts.Tsetsegee

CHAPTER 1

WATER RESOURCES

1.1 WATER RESOURCES

1.1.1 Surface water resources

The total surface water resource for Mongolia is estimated at 599 km^3/yr (Davaa and Myagmarjav, 1999). Because of the climate and the different landscapes, such as high mountains, forest-steppe, steppe and the Gobi Desert, surface water resources are unequally distributed over the country.

In the central region, water availability is abundant, much in the form of large, fast flowing streams. However, in the desert regions of the southern, western, and eastern provinces, water resources are much scarcer. Also, they are of poor quality with increasing salinity and diminishing water levels in streams and lakes.

Rivers: The rivers in Mongolia originate from the three large mountain ranges: Khangai-Huvsgul, Khentii and Mongol Altai. The rivers are divided into three main basins, depending on their drainage system: the Arctic Ocean Basin (AOB), the Pacific Ocean Basin (POB), and the Internal Drainage Basin (IDB) (Figure 3).

The Arctic Ocean Basin is the largest basin in terms of Mongolia's water resources. About 50% of the surface water resources originate from this basin. Its drainage area covers about 20% of the country's territory. The AOB comprises all rivers flowing from the south-eastern slope of the Khuvsgul mountain, from the northern slope of the Khangain mountain, and from the western slope of the Khentiin mountain system. The Pacific Ocean Basin (POB) is the smallest with respect to the drainage area and the water resources originating from it. Rivers in this basin contribute 11% of the surface water resources in Mongolia. Although the rivers originate from high mountains, a large part of the catchment area of this basin is in the "Mongolian Great Steppe". The Internal Drainage Basin has the largest drainage area: it accounts for 68% of the total territory of the country. The rivers flowing from the Mongol Altai mountains; the southern slope of the Khangain mountains; and the rivers flowing from other small mountain ranges, such as Bulnai and Kharhiraa, contribute to this basin (Myagmarjav and Davaa, 1999).

Lakes: Mongolia has about 3060 lakes with a surface area of more than 0.1 km^2, of which only four lakes have surface areas larger than 1000 km^2; 16 have larger areas than 100 km^2; and 27 lakes areas are larger than 50 km^2. The total water resources of all lakes are 500 km^3, with 314 km^3 being accounted for by the Khuvsgul Lake alone. About 34% of the lakes are located in the mountains and the remaining in the steppe and Gobi.

Glaciers: In Mongolia, there are 262 glaciers, occupying a total area of 65.9 km^2 (Dashdeleg *et al.*, 1983). Glaciers form at elevation above 2750 m with mean air temperatures of –8°C and annual precipitation about 380 mm (Baast, 1999). In Mongolia, glaciers are distributed in an area between 46°25′-50°50′ N, 87°40′-100°50′ E, at an altitude of 2750-4374 m. Spatial distribution is sporadic and decreases from north-west to south-east. The surface area of the biggest glacier valley, Potanin's glacier in Altai Tavan Bogd, is 53.5 km^2. The average depth of Mongolian glaciers has been estimated as 55.8 m.

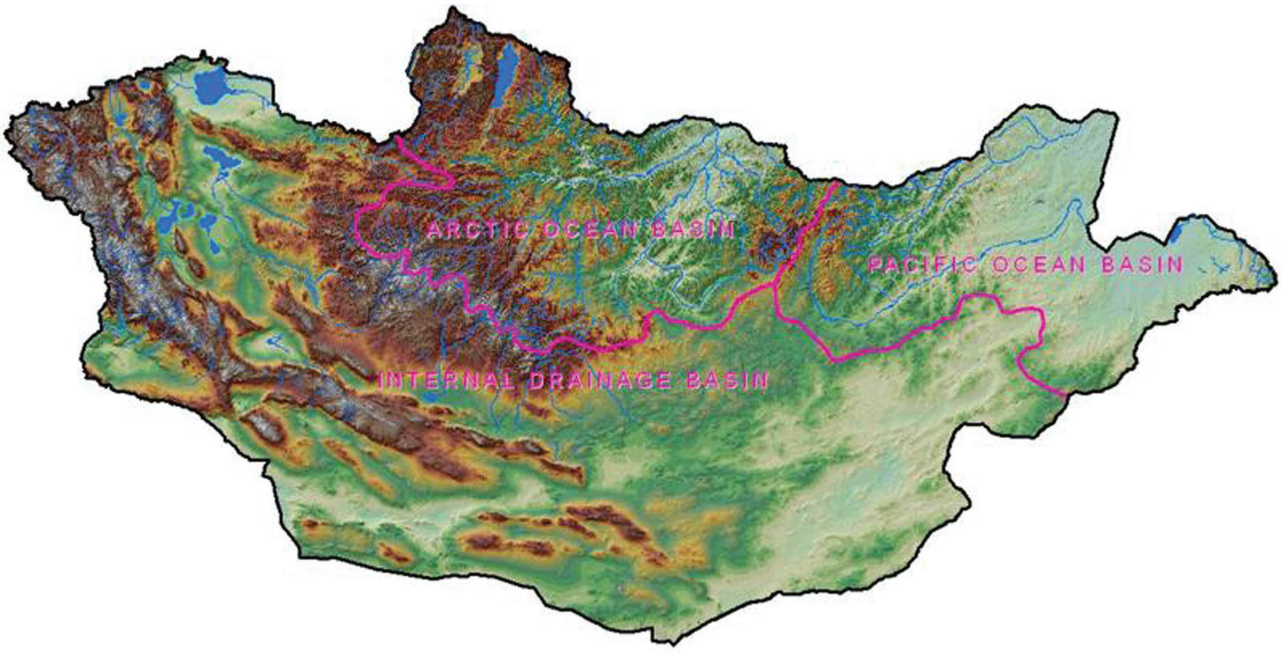


Figure 3. River basins in Mongolia (Source: Dashdeler, 1985)

1.1.2 Groundwater resources

According to the most recent study, groundwater recharge is estimated at 10.8 km^3/yr. However, the spatial distribution of geological groundwater reservoirs (aquifers) varies throughout the basins (Jadambaa, 2002).

The highest groundwater recharge ratios reach 40-60 mm/yr and can be found in alluvial deposits (i.e. aquifers with good permeability). Such aquifers are distributed in the river valley and the lake depression near the lakeshores. The areas with good groundwater resources occur mostly in the floodplains of smaller rivers and on the terraces of big rivers and lakes, where alluvial and proluvial sediments (medium permeability) of varying thicknesses are common. Only small groundwater volumes are present in the high and middle mountain massifs formed of granites and sandstones. Here, water is found only in fissures and weathering cracks, particularly in tectonic fault zones.

According to the results of a study investigating the contribution of groundwater discharge to surface water flow (applying a hydrograph separation method) it can be concluded that the contribution increases along the river courses. For example, groundwater is estimated at 30-35% of the flow of middle river reaches and increases to 35-40% for the most downstream parts of the rivers (Myagmarjav and Davaa, 1999).

1.2 WATER QUALITY

1.2.1 Water chemistry

The chemical composition of rivers include the major ions - such as the cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, and the anions HCO$_3^-$, SO$_4^{2-}$, and Cl$^-$. These are highly variable in surface waters due to local geological, climatic, and geographical conditions. In general, the rivers in Mongolia are similar in that Ca^{2+} and HCO$_3^-$ are the dominant ions. The chemical composition of the rivers and their changes are related to variations in altitude and climatic conditions (Batimaa, 2000a).

The concentrations and quantities of different chemical parameters are of vital importance to assess the quality of water and its suitability for various purposes. Most of the rivers in Mongolia are fresh and clean (Kelderman and Batimaa, 2006).

The practice in Mongolia is to use river water of any quality for drinking purposes, not only in rural areas but also in places where river water is available nearby. Therefore, the reliability of clean river water is important. The national standard for drinking water gives the lower and upper limits of certain ions (NSA, 1998) in Table 1.

In most of the rivers, maximum concentrations do not exceed the upper limits, but the average concentrations of Ca^{2+} in summer time are much less than the lower limit in the river water flowing from the Mongol-Altai mountains and in the upper streams of all rivers. In most of the periods of the year the average concentrations of Mg^{2+} are also still less than the lower limit in most of the rivers.

Khovd aimag Khoton lake @ Ts.Tsetsegee

Ulgii city water treatment @ P.Batimaa

Ulgii city water treatment @ Wim van der Linden

1.2.2. Nutrients in the rivers

In addition to the major ions, the river water quality is also monitored for parameters such as ammonium, nitrate, nitrite, phosphate, dissolved oxygen (DO), permanganate value, biochemical oxygen demand (BOD) and some trace metals. Batimaa (2002) reported that ammonium concentrations in the rivers of Mongolia are among the highest in terms of nitrogen. Ammonium concentrations range from a minimum of 0.1 to more than 1 mg/l, but levels higher than 0.5 mg/l are very rare. The levels of the nitrate vary between 0.184-1.670 mg NO_3-N/l and the overall mean is 0.479 mg NO_3-N/l for the country. The average concentration of phosphorus (PO_4-P) for Mongolia is 0.025 mg/l, which is less than the medium concentration of global rivers' phosphate or about the average for unpolluted rivers (UNEP/GEMP, 1991, 1995).

1.2.3. Trace metals in the rivers

Most of the rivers still contain fresh mountain water. However, many rivers, or parts of the rivers, are polluted due to rapid urbanization and by industrial and mining activities. In recent years, exploration for natural resources has increased rapidly. Many river basins are under intensive use due to mining for gold, silver, coal, precious stones, gravel, and other natural resources. A total of 784 enterprises are engaged in mining, of which 204 small-scale gold mining companies are operating on 6,065,298 hectares of land. Some of the gold miners are reported to use mercury in the gold extraction. The surface water inventory revealed that gold mining activity affects the quality of 28 rivers in 8 provinces of Mongolia. In particular, the upper stream of the Orkhon river, downstream reaches of the Tuul river, and the Eroo river in the Selenge river basin. Also the Orkhon, Tuul, Kharaa and Khangal river basins are experiencing increased pollution by urbanization and industrial activities within the basin (MNE, 2007).

1.2.3 Groundwater quality

Groundwater chemical composition is generally characterized by higher contents of total dissolved solids compared to surface water (Batimaa, 2002; Basandorj and Davaa, 2005). The average concentration of total dissolved solids varies from 100-800 mg/l with a maximum of more than 1000 mg/l in the mountainous regions, 950 mg/l in the steppe, and 1120 mg/l in the Gobi desert. There are no studies on nutrients and other chemical pollutants in groundwater.

Table 1. The upper and lower limits of some ions for drinking water

Ions (mg/l)	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-
Upper	100	30	350	500
Lower	25	10	-	-

1.3 WATER USE

The surface and groundwater resources play vital roles in the country's economy, especially in agriculture, livestock production, industry and domestic water supply.

As mentioned above groundwater is the main source for water use: about 80% of drinking water comes from aquifers. Over 80% is used by the industrial and agriculture sectors, with the remaining used for domestic and other purposes. Although the actual water use (540 million m^3/yr) seems small compared to the water resources available, water resources are unequally distributed over the country. In the southern part of Mongolia (Gobi Desert) the water availability is 10 times less than the world average and several ten times less than northern part of the country.

Domestic water use: Water use by this sector is 18.1% of the total water use in Mongolia. 70% of the residents either acquire their own well or get water from public kiosks. 30.7% of the total population is connected to the water supply by a network of pipelines; 24.7% obtains their water from water trucks; 35.6% from water distribution kiosks; and about 9.0% use spring water. The proportion of the urban population that is connected to both the distribution network and sewer system is 40% (MNE, 2007). Government surveys record that in 2006 just over half of Mongolian households indicated that they had access to clean water.

Ulaanbaatar and most aimag centres have centralized systems that involve pumping groundwater through a piped network. However, the current condition of these water supply networks is outdated because they were constructed in the 1980s and have not been well maintained.

Agricultural water use: The agricultural water use is for two purposes: livestock water use and irrigation.

Livestock water use: The water use by this sector is 24.0% of the total water use in Mongolia. Currently more than 40 million animals are kept in Mongolia (NSO, 2007). Traditionally, herdsmen have lived near open water sources because that is the only available source of water for the animals.

In the northern part, or the Altai, Khangai and Khentein mountain regions, surface water is used for animal watering. Water supply is a critical problem in the southern part, especially in the Gobi region, where ground water is the only source. In places where surface water resources are not available, people live around wells.

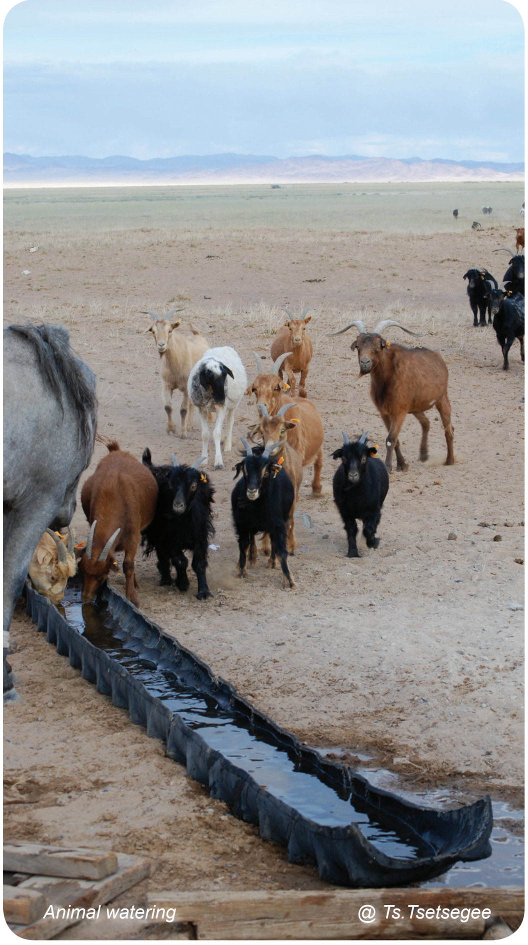
In the period 1960-1990 water supply in pasture was largely improved. 64.5% was provided with water and over 29,000 wells were installed. Unfortunately, as stated in National Water Programme (1999), in the last decade almost half of the water supply points were damaged and are now out of operation due to economic constraints. Therefore, pasture water supply is now a very serious problem for both livestock and people in the steppe and Gobi desert.

One third of the inhabitants in rural areas stated that animal watering is their most difficult task. To water and feed their animals, herdsmen are forced to regularly move to areas where enough water and food is available. In the Gobi, herder families move six to seven times a year and travel up to 90 km. This leads to an increased pressure on the land through land use change and higher cattle densities. Thus, overgrazing, trampling erosion, sand movement, and desertification are intensified. Therefore, water shortage should be viewed as one of Mongolia's major socio-economic and environmental problems.

Water use for cropland: Water use by this sector is 17.4% of the total water use in Mongolia. Arable land occupies 1.3 million hectare, 0.8% of Mongolia's territory (NSO, 2007). Most of the cropland area is in the Selenge, Orhon, Kharaa, Kherlen, Onon, Khalh and Buyant river basins where irrigation can be applied. Water for agriculture is free of charge.

Industrial water use: Water use by this sector is 39.3% of the total water use in Mongolia. In the early 1990s, annual industrial water use was 0.115 km^3 and slightly increase to 0.137 km^3 in 2008 (WA, 2007). Sufficient information is missing about the mining processes (how much water is needed) and quality and quantity of available water resources (how much is available). This makes it difficult to set a national norm for water use for mining industries. At the moment, the biggest water users are gold mining industries and larger mining companies like Erdenet, Tomortei-Ovoo, Olon-Ovoot, and Boroo. According to the Water law (2004), the mining industries are also responsible for establishing water supply systems for new cities and towns that accommodate large-scale mining operations (WA, 2007).

Guulin- irrigation channel *@ Wim van der Linden*



Animal watering *@ Ts.Tsetsegee*

PART ONE

CLIMATE CHANGE AND ITS IMPACTS ON WATER RESOURCES

Bayan-Ulgii aimag Hoton lake @ Ts.Tsetsegee

CHAPTER 2

WATER MANAGEMENT

2.1 WATER POLICY AND LEGISLATION FRAMEWORK

Institutionally, Mongolia has laid a substantial foundation for encouraging environmental protection policies. Mongolia has enacted a comprehensive policy and legal framework for water resources. It has policies, legislation and strategies in place to manage its water and to satisfy its international obligations. However, the focus of water management in Mongolia is to protect and restore water resources. Less emphasis is given to the development of water resources for socio-economic development; matching water demand with water supply; allocating water among different users; or designing strategies for action planning or long-term investment schemes. Although laws and regulations have been developed, implementation and enforcement are often lacking.

The National Water Programme, which was adopted first in 1999 and renewed on 20 May 2010, is a major policy initiative. The Program reflects issues related to water management activities including water resources, water quality, water use and protection from deterioration and pollution of water resources. The Program defines priority objectives that will be implemented in two-stages (up to 2010-2015 and 2016-2021).

The objectives are: 1) to protect water resources; 2) to increase information and management efficiency by expanding the monitoring network; and 3) to improve water supply and quality by increasing water storage.

Other national programmes also cover water resources issues. These include the National Environmental Action Plan (1996), the State Environmental Policy (1997), the National Plan of Action to Combat Desertification (1996), the Biodiversity Conservation Action Plan (2002), the National Plan of Action for Protected Areas (1998), the Mongolian Action Programme for the 21st Century (1999), the National Forestry Programme (1998), the National Plan for Public Ecological Education (1997) and the National Action Programme On Climate Change (2000).

In 2000, the Mongolian government committed itself to achieving the Millennium Development Goal (MDG) targets. Mongolia will be able to partly achieve its target of halving poverty, but will not be able to achieve its targets to improve access to water supply, and improve access to sanitation by slum dwellers. A recent report of MCUD (2006) shows that only 39.2% of the total population has access to drinking water sources, which is 20% lower than the global average. When disaggregated according to type of improved drinking water sources, 20% have access to the centralized water supply network. The report also indicates that 26.6% of the total population has access to improved sanitation facilities. Thus meeting the target of increasing the coverage of improved water sources to 70% by 2015 appears difficult. Similarly, the target for doubling the number of slum dwellers with access to sanitation by 2015 does not appear to be achievable. However, in order to meet the MDG targets the GoM just joined the UNDP GoAL-WASH programme.

The national policy of the Government of Mongolia embraces integration of natural resources management planning and puts improvement of environmental management in the mainstream of development strategies and programmes. The Mongolian Action Programme for the 21st Century (MAP-21) values a holistic approach to socio-economic and ecological issues as the fundamental feature of sustainable development. Creation of a favourable environment for sound management of water resources is one of MAP-21's seven primary objectives.

From the long list of National Actions the following have been extracted as having relevance for water supply and sanitation:

- Improve the quality of potable water for all Mongolians, including continuation of the installation of water softening equipment in soums and settled areas where water is hard and rich in minerals;
- Install drinking water purification filters and equipment for 102 soums of 17 aimags, and supply residents of all settlements with drinking water meeting standard requirements;
- Promote initiatives involving private entities in delivery of services such as water, heat, power supply, wastewater and removal of trash in the peripheral areas of the cities;
- Expand, repair and renovate facilities for public utilities of the ger districts, cities and other settlements;
- Initiate the connection of ger district families to the WSS networks; and
- Provide for the ever-increasing needs of cities and populated settlements, introducing progressive and cost-saving technologies that use renewable energy resources for heating, water supply, sewage and power transmission networks.

At present, expansion of water supply coverage is only matching the population growth rate. Of more immediate concern is the increasing influx of people into Ulaanbaatar and other urban centres that strain water supply, sanitation, and other public services.

Since 1994, Mongolia has adopted about 40 laws regulating the protection of the environment and the proper use and restoration of natural resources based on its Constitutional concept of ensuring the right to a healthy environment. Concerns and problems with respect to water resources are reflected directly in these laws.

The Law on Water (1995, amended in 2004) authorizes local government to regulate and manage water resources. It has pointed out the need for stronger water management in the country. The Law on Water covers pricing policies, which are intended to ensure cost recovery and the equitable allocation of water resources. At present, however, only about 65% of water costs are recovered through pricing, partly because of the present economic conditions (WB, 2006).

In recognition of its global responsibilities, Mongolia has acceded to the Convention on the Protection of Wetlands of International Importance (Ramsar). Other water resources related international conventions Mongolia has acceded to are: the Convention on Biological Diversity (1993), the UN Framework Convention on Climate Change (1994), and the UN Convention on Combating Desertification (1995).


Orkhon river @ P.Batimaa

2.2 INSTITUTIONAL FRAMEWORK

Prior to 1987, the Ministry of Water was responsible for the water sector. Presently, responsibilities for policies and implementation related to water resources and supply are split among several ministries and implementing agencies. Of most importance are the Ministry for Nature, Environment and Tourism (MNET), the Ministry of Agriculture, Food and Light Industry (MAFLI) and the Ministry of Construction and Urban Development (MCUD).


Gobi-Altai aimag @ Wim van der Linden

MNET is the lead Government agency for environmental management in Mongolia with responsibilities spanning biodiversity, protected areas, forests, the environmental impact assessment process and water. The mission of MNET is to direct the collective efforts and initiatives of the state, citizens, businesses and organizations in fulfilling the right to live in a healthy and safe environment. The Ministry seeks to link social and economic development with ecological balance; protect the natural environment in the interests of present and future generations; make appropriate use of natural resources; and create proper opportunities for their restoration. Reduction of air, water and soil contamination in urban areas and increasing the appropriate use and conservation of water resources are among six mid-term goals of the Ministry (Tortell *et al*., 2008).


Khovd aimag Khar lake @ Ts.Tsetsegee

In 2005, the National Water Committee (NWC) was established with the purpose of coordinating the water sectors and monitoring the National Water Programme's implementation. The NWC is chaired by MNET and reports to Prime Minister.

The Water Authority, also established in 2005 within MNET, has full authority for water management. However, the mandate for monitoring compliance with implementation of the environmental laws is vested with the State Professional Inspection Agency.

The mission of MAFLI is to support rural and regional development that provides substantial economic growth and to create a sound environment for sustainable development of the food and agricultural sector. Priorities of the MAFLI include extending irrigation activities and improving water point management and ownership in rural areas.


Khovd aimag Khovd river @ Ts.Tsetsegee

MCUD is responsible for advising the government on the policy framework for public services, urban development, housing, water supply and sanitation. The policies related to hydropower are prepared at the Ministry of Fuel and Energy and public health issues are within the scope of the Ministry of Health.

The research and monitoring of water resources is divided among various institutions. The Institute of Meteorology and Hydrology is responsible for the systematic observation and monitoring of surface water resources and quality, as well as limited study of ground water and glaciers. The Institute of Geo-Ecology mostly deals with ground water resources and quality but does not conduct systematic observation or monitoring. The Institute of Geography deals partly with lakes but not their systematic observation or monitoring. Furthermore, results are owned by each of the institutions. A major problem is the absence of coordination at the policy level as well as at the programme level.

At present, the national government invests less than 0.25% of Mongolia's GDP in the water sector (NSO, 2008). This indicates the low priority of the water sector plans and programs compared to other development sectors. Due to the institutional setting, organizational structure, inconsistent legislation, and few and inexperienced human resources related to water management, the plans and programs do not meet the present requirements. To solve these problems, the water sector needs to strengthen its capacity and should prepare national and river basin water management plans.

Both the urban and the water sectors face challenges from the cross-sectoral nature of the problem and the proliferation of responsible agencies. It is not uncommon for urban projects to cover water supply, sanitation, district heating and waste management. Water related projects often deal with urban development. Other sectors, such as energy, education, health, and environment, are also often associated with water sector programmes.

@ P.Batimaa

PART ONE

CLIMATE CHANGE AND ITS IMPACTS ON WATER RESOURCES


Sand dune Ereen lake

@ Ts.Tsetsegee

CHAPTER 3

CHANGES IN CLIMATE AND ITS IMPACTS ON WATER RESOURCES

CHANGES IN CLIMATE AND ITS IMPACTS ON WATER RESOURCES

The understanding of climate change processes is supported by extensive scientific consensus that has been growing consistently over the last twenty years. It will not be repeated here. This consensus has been led by the Intergovernmental Panel on Climate Change, which issued the Fourth Assessment Report (AR4) in 2007. Its key concerns include the impacts of climate change on ecosystem vulnerability and water resources.

3.1 CHANGES IN TEMPERATURE

The Mongolian climate is characterized by diversity. There is a long-lasting cold winter, a dry and hot summer, low precipitation, high temperature fluctuations (day and night, summer and winter), and a relatively high number of sunny days (260 days per year). There are four sharply distinct seasons and the months in each season are quite different from each other. The annual average air temperature for Mongolia is 0.7°C. The annual average temperature is +8.5°C in the warmest regions of the Gobi and south Altai deserts and -7.8°C in the coldest region of the Darkhad depression.

Annual mean temperatures have risen by 2.14°C during the last 70 years (MARCC, 2009). The warming has been most pronounced in winter, with a mean temperature increase of 3.6°C, while spring, autumn, and summer mean temperatures have risen by 1.8°C, 1.3°C, and 0.5°C respectively. However, it should be noted that the rate of winter temperature increase has slowed down, while in summer it has accelerated (Figure 4), with increased heat waves.

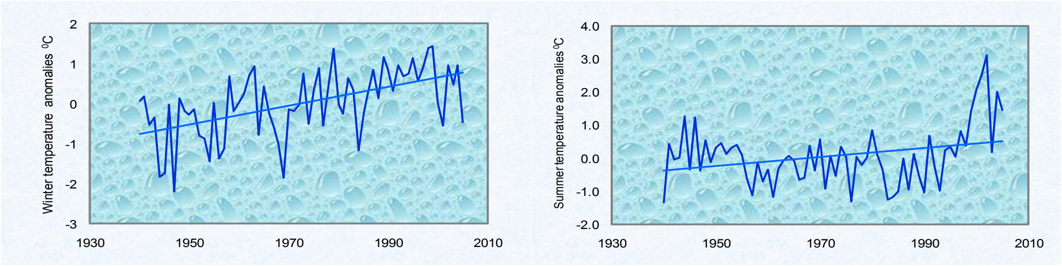


Figure 4. Winter and summer temperature trends (anomalies to the long-term average, 1940-2007) (Source: Natsagdorj, 2008)

3.2 CHANGES IN PRECIPITATION

Mongolia's climate is semi-arid to arid. Precipitation varies both in time and space. The annual mean precipitation is 300-400 mm in the Khangai, Khentiin, and Khuvsgul mountainous region, 150-250 mm in the steppe, 100-150 mm in the desert-steppe, and 50-100 mm in the Gobi Desert. About 85% of the total precipitation falls from April to September, of which 50-60% falls in July and August. Although annual precipitation is low, its intensity is high. For example, a locally intense rainstorm of 40-65 mm may fall in a day.

Annual precipitation changes are quite variable, decreasing at one site and increasing at another nearby. Seasonally, autumn and winter precipitation has increased by 4-9%, while spring and summer precipitation has decreased by 7.5-10%. Spatially, since 1961, precipitation in the Altai mountain region, the Altai Gobi, and in the eastern part of the country has increased, while in all other regions it has decreased by 0.1-2.0 mm/year (MARCC, 2009). The trend of annual mean precipitation is shown in Figure 5.

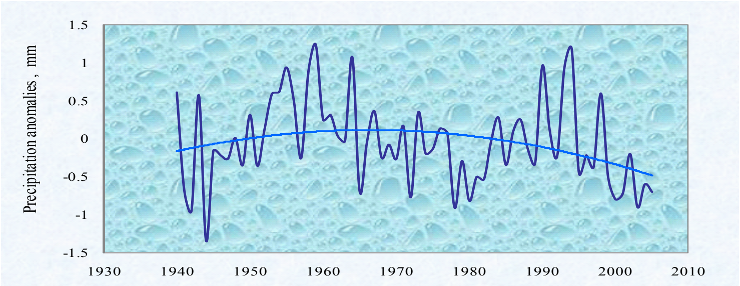


Figure 5. Trends in annual mean precipitation (anomalies to the long-term average, 1940-2007) (Source: Natsagdorj, 2008)

One of the specific traits of annual precipitation distribution in the arid areas of Mongolia is that it can decrease at one site, while increasing at another nearby. Certainly, precipitation changes at the local level have more practical implications than changes in the country averaged precipitation. Spatially, annual precipitation decreased by 30-90 mm on the north-eastern slope of the Khangai mountains, in the western slope of the Khentii mountains, and downstream from the Orkhon and Selenge river basins. Precipitation increased by 2-60 mm in the Mongol Altai, in the Uvs lakes basin, and on the western slope of the Khangai mountains; and by 30-70 mm in the southern part of the Eastern steppe region (Gomboluudev *et al*., 2005). The magnitude of change in precipitation (regardless of increase or decrease) is 5-25%. Trends, significant at a 90%-level, were found where changes are more than 40 mm or more than 20% of the annual mean value (Batimaa, 2005).


Khovd aimag Khar lake @ Ts.Tsetsegee

Water balance studies with river discharge and precipitation data have revealed that on average, 70-90% of the precipitation evaporates from the land surfaces into the atmosphere, while remaining parts recharge groundwater and rivers (Batimaa, 2000; Sugita, 2003). This is because the potential evaporation is so large that most of the rainfall ends up evaporating as soon as it falls. The potential evapotranspiration has increased by 12, 10, 9, and 7% in the forest-steppe, steppe, Mongolia Altai mountains and Gobi respectively (Gantsetseg and Bolortsetseg, 2003). This is equivalent to increases of 74, 70, 50 and 63 mm of potential evapotranspiration in these respective areas. The increased evapotranspiration causing soil moisture decline and greater aridity will lead to water balance changes in not only water limited regions, such as Gobi and Gobi-desert, but also steppe and forest steppe areas of the country.


Gobi-Altai aimag Ereen lake @ Ts.Tsetsegee

Clear skies in winter due to high anticyclone dominance results in less snowfall. Snow contributes less than 20% to total annual precipitation. The first snowfall occurs in the middle of October to the beginning of November. Usually, the first snowfall is short-lived and disappears due to late autumn warming. Sometimes, late first snowfall persists as snow cover in mountainous regions. Snow cover forms in mid October in the forest-steppe and Mongol Altai mountains, in the second half of October in the steppe, and in the first half of November in the Gobi Desert. Snow cover clears up in late April in the forest-steppe and Altai mountains, mid-April in the steppe regions, and in February in the Gobi Desert. Snow that falls in late spring (after the winter snow cover clears up) usually stays for 1-2 days, covering large areas. Sometimes, the last snow cover occurs as late as June. The stable snow cover formation date occurs earlier in the forest-steppe and the eastern part of the country and later in other areas.

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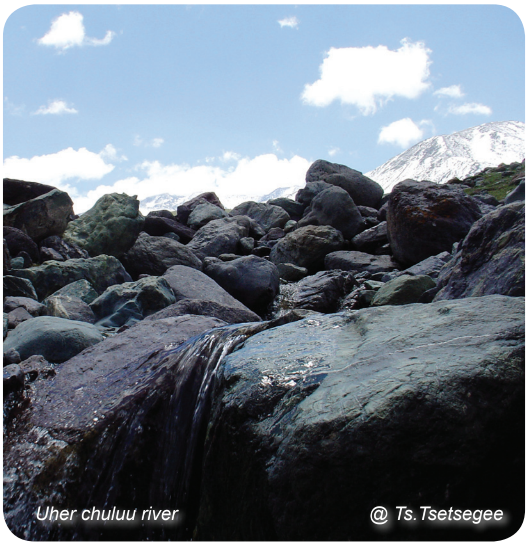
Uher chuluu river @ Ts.Tsetsegee

Sometimes, the last snow cover occurs as late as June. The stable snow cover formation date occurs earlier in the forest-steppe and the eastern part of the country and later in other areas.

Snow-records of the last 30 years show that the first significant snowfall of autumn tends to occur earlier. The last snow cover that occurs at the end of spring or beginning of summer tends to last longer. The snow cover date starts 10 days earlier in western Mongolia, and 3-5 days earlier in central and eastern Mongolia

3.3 IMPACTS ON SURFACE WATER

Studies on the impacts of climate change on Mongolian water resources are limited. This chapter summarizes studies mostly done under the Netherlands Climate Change Support Programme (NCCSP) (Batimaa 2000) and the Assessment of Impacts and Adaptations to Climate Change (AIACC) (Batimaa, 2005).

Characteristics of the river flow: The rivers in Mongolia are of mountainous origin and their major source of water is rainfall. Mongolia has around 4100 rivers with a total length of 67,000 km and average channel density of 0.05 km/km^2. About 60% of the river runoff formed in the Mongolian territory drains into Russia and China and only 40% flows into lakes of the Gobi, partially recharging groundwater aquifers.

The runoff in the rivers draining from the Khuvsugul, the Khangai, and the Khentei mountains is formed mainly from rainfall (56-75% of annual runoff), while in the rivers originating in the Mongol Altai Mountain is from snow and ice melting waters (50-70%). Other rivers are fed from snow melting or rainfall and ground water. This indicates that the specific proportion of runoff components varies in time and space. The base flow component fed by groundwater has been estimated as 15-40% with an average of 36.1% of the total annual runoff in the country (Myagmarjav and Davaa, 1999). River discharge is variable in Mongolia. The rivers show little runoff in the warm period of the year. This is because in most of Mongolia, river water is easily lost through high evaporation rates and infiltration into the ground. During the winter period, rivers freeze so there are no or only small flows. There are four main seasonal water regimes observed in the rivers of Mongolia. These are:

1. Winter low-flow period, which lasts approximately from December to April;

2. Spring-runoff period due to snow melting, which lasts approximately from April to June;

3. Summer-runoff period due to rainfall, which lasts approximately from June to September; and

4. Warm season low-water period, which usually follows the rainy season and lasts to the winter low-flow period, which also includes the short periods between intermittent floods.

These four regimes can be observed separately or together, depending on the basin characteristics and seasonal climatic factors. The regime 1 and 2 are usually combined, the rivers flowing from the Mongol Altai mountains are an example of this.

Changes in the spring high water period due to melting of snow: In Mongolia, river water levels increase due to melting of winter snow and glaciers in April-May. Spring high water flows contribute 10-35% of the annual water

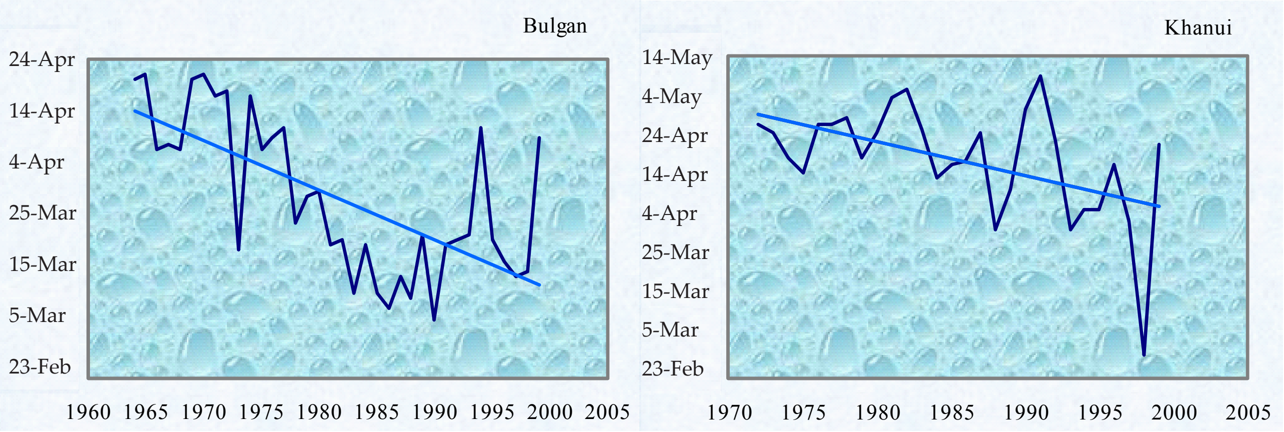

Figure 6. Trends in ice break-up dates in the Bulgan river (Linear regression: slope=-0.93 day/year) that flows from the southern slope of the Mongol-Altain mountans and Khanui river (Linear regression: slope=-0.85 day/year) that flows from the northern slope of the Khangain mountains (Source: Batimaa, 2005)

resources from rivers. Increased air temperatures in winter and earlier snowmelt have changed the starting date of spring high water. This event now begins 20 days earlier in the rivers flowing from the Mongol Altai mountains and in rivers flowing from the southern slopes of the Khangai mountains; 5-10 days earlier in the rivers flowing from the Khuvsgul and western slopes of Khangai mountains; 15 days earlier in the rivers flowing from the northern slopes of the Khangai mountains and in the Khalkhgol river; and about 5 days earlier in the rivers flowing from the Khentii mountains. Spring high water flows also last about 10 days longer in most of the rivers (Batimaa *et al.*, 2005, 2009).

Changes in the summer high water period due to rainfall: About 60-80% of annual precipitation falls in summer. Consequently, the maximum river flows occur in July-August, contributing 40-70% of annual runoff. Rainfall with an intensity of more than 40 mm within 12 hours usually leads to flooding.

Freeze-up and break-up dates in rivers: An increase in air temperatures of autumn (1.3°C) and spring (1.8°C) have changed ice phenology dates (Batimaa *et al.*, 2004). Freeze-up and break-up dates have also changed. Specifically, changes include a 10-30 day later start of freeze-up in the rivers flowing from the Mongol Altai mountains; a 5-10 day later freeze in the rivers flowing from the Khangai and Khentii mountains; and a 2-5 days later freeze in the rivers flowing from the Khan Khukhii mountains.

Similarly, dates of river ice and break-up and disappearance in spring started earlier by 5-30 days: 10-30 days earlier break-up in rivers flowing from the Mongol Altai and Khangai mountains; 8-12 days earlier in the rivers flowing from the western slopes of the Khentii mountains; but only 3-5 days in the rivers flowing from the eastern slopes of the Khentii and Ikh Khyangan mountains (Figure 6). The largest change in ice break-up has occurred in the Mongol Altai mountains and in the Khanuin river flowing from the northern slope of the Khangain mountains.

Changes in dates of freeze-up and break-up were similar for lakes and rivers (Batnasan, 2001; Batimaa *et al.*, 2004). These changes in lake and river ice dates reflect clear trends in the regional climate – temperatures are increasing. Changes in the timing of the break-up were greater than changes in the freeze-up. With a delayed start of autumn ice and an earlier ice break-up in spring, the duration of ice cover on the rivers has shortened considerably.

Maximum ice thickness: Ice cover develops with the formation and growth of border ice in the rivers that becomes sufficiently thick at the end of January to be stable to grow out across the river. Growing slowly it reaches its maximum in March. During the ice cover growth, frazil, anchor ice and hanging dams are common.

The climate in Mongolia shows large fluctuations between day and night temperatures. Freeze-up dates are sensitive to cooling during night and break-up dates are more sensitive to warming during the day, while ice thickness may reflect the average of day and night. Thus, annual maximum ice thickness could be a more accurate measure of climate change than are ice phenology dates.

The annual maximum ice thickness decreased from the 1960s to 2000. The decrease was 40-100 cm in rivers flowing from the Mongol


Hentii aimag   Hagiin har lake   *@ Elbegzaya*


Tsambagarav mountain   *@ Ts.Tsetsegee*

Altai mountains; 20-80 cm in rivers flowing from the Khangai and Khuvsgul mountains; and 20-40 cm in rivers flowing from the Khentii mountains. The dates of annual maximum ice thickness showed no clear trends over the years.

Changes in timing of ice phenology dates, and ice thickness differed depending on the geographical location: rates of change were much higher in colder regions than in warmer regions.

Changes in Lakes: Changes in permafrost, seasonal freezing and thawing grounds in Khangai-Khuvsgul mountains, Dornod steppe, and changes in glaciers in Mongol Altai mountains leads to a rise of water level of lakes in these regions (Figure 7). For instance, the water level of the Uvs lake, the biggest lake by surface, fed mostly by rivers flowing from the Mongol Altai and Khan Knokhii mountains, has risen by 200 cm. The water level of the Khuvsgul lake, the deepest lake located in the continuous permafrost zone, has increased by 60 cm in the last 40 years.

Lake ice freeze-up and break-up dates have also changed. Autumn ice freeze-up dates have shifted forward by 5-20 days while spring ice break-up dates have shifted backward by 5-10 days (Batnasan, 2002).

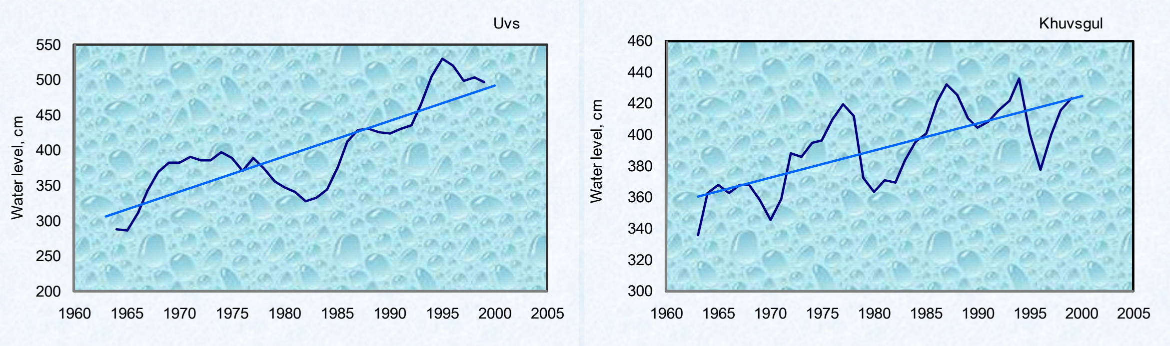

Figure 7. Changes in water level of Uvs and Khuvsgul lakes
(Source: Batnasan, 2002)

3.4 IMPACT OF FROZEN GROUND AND PERMAFROST

Permafrost occurs in the subsurface of about 63% of the total territory of Mongolia. The Mongolian permafrost is classified into seven categories: continuous, discontinuous, widespread, rare, sporadic, and seasonal.

The Mongolian permafrost is thinner, less cold and distributed more sparsely when compared to permafrost in northern Russia, Canada, and Alaska. Therefore it is relatively sensitive to air temperature. In the last 10-24 years in the regions of Byrenkhaan, the Khusgul mountain, the Theterhyin hollow and Bagakhuur, the permafrost annual mean temperature has increased by 0.01°C per year and the melting depth has increased by 0.4-0.6 cm. It's possible these changes have resulted in increased formation of marshes. Some pastures have already been converted into marsh. (Tumurbaatar, 2002).

Different kinds of phenomena can be observed as a result of permafrost melting and freezing. Permafrost phenomena such as melting mounds, thermokarst[1], and solifluction[2] occur more frequently. Extensive thermokarst processes have been discovered in the continuous and discontinuous permafrost zone of the Khangai-Khuvsgul mountains. The average rate of thermokarst varies from 5-10 cm/yr, with the maximum rate of 20-40 cm/year. Extensive solifluction has been observed in the continuous permafrost zone of the Khuvsgul and Khangain mountains, at a minimum rate of 2 cm/yr. The thickness of seasonally frozen ground has decreased by 10-20 cm in the Dornod for the last 30 years.

The date of the autumn freeze was delayed by 2-6 days while the date of the spring thaw advanced by 2-6 days. Longer shifts in timing occurred in the forest-steppe and shorter shifts in the Gobi Desert (Natsagsuren, 2003).

Changes in timing of the seasonal frozen ground and ground temperature of permafrost indicate that as warming trends continue, the active layer of permafrost will thaw more readily, affecting ecosystems, carbon reservoirs in the upper part of permafrost and hydrology. It is also worth knowing that whether permafrost forms depends on how well the surface is insulated from the underlying soil or rock. Peat bogs are remarkable in this respect. Permafrost is found in peatlands throughout the discontinuous permafrost zone of Mongolia and serve as reservoir of organic carbon, which may be released in the form of greenhouse gases if the permafrost thaws.

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[1] lake formation during the slow process of permafrost melting, at first concave cups are formed, which get filled by water.

[2] occurs when permafrost melts and soil moves or shifts along the mountain slopes

3.5 IMPACT ON GLACIERS

Over the period 1945-1985, the area of glacier cover decreased by 6% (Baast, 1999). The retreat of glaciers has intensified in recent decades. Changes in glacier areas at different sites are given in Table 2.

Table 2. Changes in glaciar areas, (percentage decrease since 1940)

Name of glaciers	25 June1992	10 September 2000	8 August 2002
Kharkhiraa	-	26.6	37.6
Turgen	-	42.5	21.4
Tsambagarav	13.4	28.8	31.9
Sair	87.0	-	92.6

Source: Davaa et al., 2008

Under the prevailing climate conditions, retreat of the glacier front was 54 cm/yr and 89 cm/yr in 2004 and 2005, respectively. The Tsambagarav region shows the largest loss of glacial area (Figure 8). The loss can very likely be attributed to climatic warming. Flat-top-type glaciers are more sensitive to ELA (Equilibrium Line Altitude) change than valley-type glaciers. This is because small shift of ELA affects a large area of a flat-top-type glacier which most common in Mongolia.

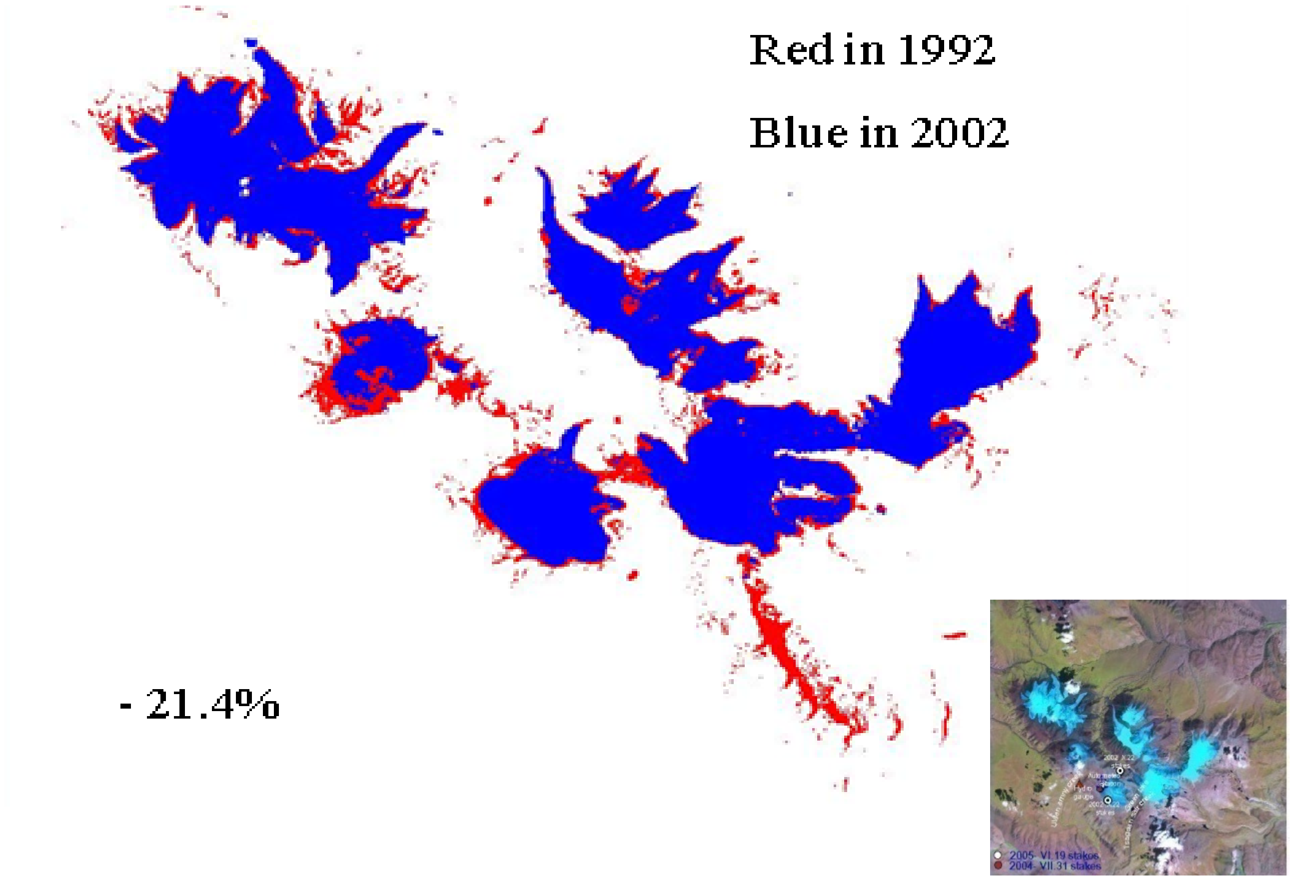


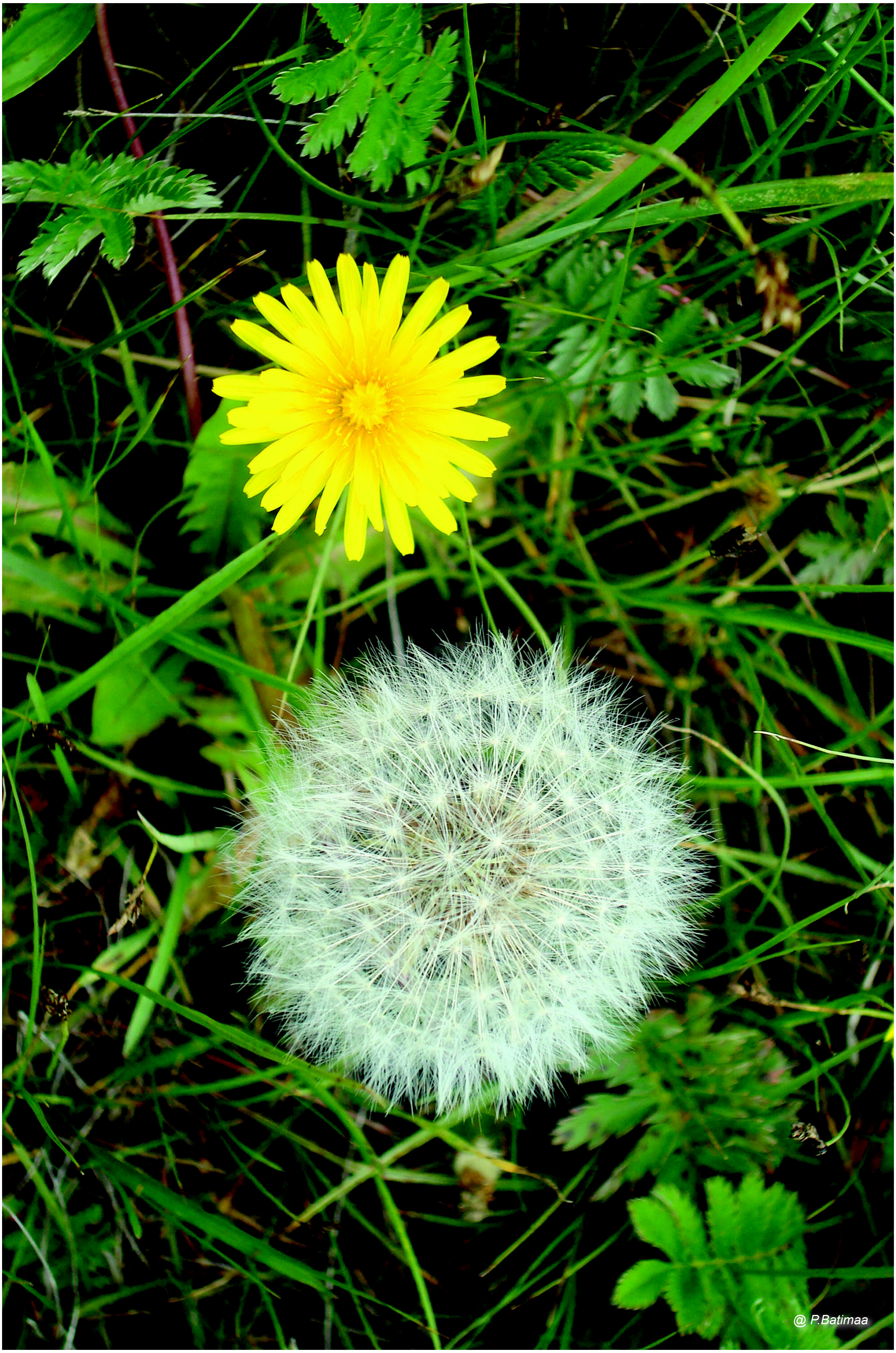
Figure 8. Glacier changes between 1992-2002 at Tsambagarav mountain in Mongolia (Source: Davaa *et. al.*, 2008)

3.6 IMPACTS ON GROUNDWATER

All surface water in Mongolia is covered by ice for about six months a year. Thus groundwater is the primary source of water supply for major urban and industrial centres and the extensive animal husbandry sector. It is easy to access and often of high quality. Alluvial aquifers contain groundwater at the shallowest depths. The shallow alluvial deposits along the river basins are the main source of water for the major cities such as Ulaanbaatar, Erdenet and Darkhan.

Unfortunately, the effect of climate change on groundwater recharge in Mongolia is unclear. Many factors affect the recharge: alterations in precipitation, evaporation and temperature regimes, soil properties and their changes, urbanization and changes in forest management and agricultural practices. Climate change will affect groundwater resources throughout the country. It is expected that aquifer recharge is reduced, just as ground water levels are reduced, especially in the shallow aquifers. Higher temperatures and droughts will result in increased evapotranspiration. Recharge will also suffer from more extreme precipitation events, because more water will runoff before it can percolate into the aquifers. Therefore, even when overall precipitation increases, aquifer levels may decrease, as a result of having less precipitation events that are more extreme.

Mining gold Ulziit river *@ Wim van der Linden*



@ P.Batimaa

PART ONE

CLIMATE CHANGE AND ITS IMPACTS ON WATER RESOURCES

Altai tavan bogd

@ P.Batimaa

CHAPTER 4

VULNERABILITY OF WATER RESOURCES TO CLIMATE CHANGE

4.1 PROJECTIONS IN CLIMATE

The most recent climate change study results show an increase in monthly mean temperature and a small increase in precipitation. The country is projected to experience: 1) increased annual temperatures (0.9-8.7°C), 2) increased precipitation during winter (12.6%-120%), 3) increased potential evaporation during summer (13-90%) and 4) greater frequency and magnitude of extreme events, such as droughts and the extreme harsh winter pattern called Dzud (Table 3).

Table 3. Average climate change projections under SRES A2 and B2 scenarios in Mongolia relative to baseline 1961-90 (T is temperature, P is precipitation)

Model	A2-medium-high emissions						B2-medium-low emissions					
	2020		2050		2080		2020		2050		2080	
	T, ^{O}C	P, %	T, ^{O}C	P, %	T, ^{O}C	P, %	T, ^{O}C	P, %	T, ^{O}C	P, %	T, ^{O}C	P, %
Winter												
HadCM3	0.9	23.6	2.4	38.7	3.9	67.0	1.0	16.5	1.7	34.4	2.5	54.7
ECHAM4	3.6	59.0	5.7	80.9	8.7	119.4	3.7	11.5	6.0	82.0	6.6	90.3
CSIRO-Mk2b	1.7	12.6	2.9	27.2	5.2	49.0	1.7	14.2	2.7	24.9	3.7	36.8
Summer												
HadCM3	2.0	-2.5	3.8	7.1	6.4	6.4	2.2	3.1	3.3	8.7	4.7	4.5
ECHAM4	1.9	7.2	3.7	6.5	6.6	11.3	2.1	7.6	3.8	5.7	4.9	8.6
CSIRO-Mk2b	1.3	-2.1	2.9	0.5	5.5	-2.3	1.9	0.4	3.0	-1.4	4.1	-1.3

Source: Gomboluudev, 2005

As can be seen from Table 3, winter precipitation will increase considerably, potentially having serious implications for winter conditions and spring water regimes. Currently, the area where the snow cover remains for 100-120 days accounts for 30% out of the total area that is covered by snow, and 37.5% and 32.2% where snow cover stands for 121-140 days and longer than 140 days, respectively. According to the HadCM3 scenario, snow cover duration longer than 140 days is projected to halve by 2050 and shrink to nearly one third by 2080, while snow cover duration of 121-140 days would increase from the current 37.5% to 50% by 2050, and 58% by 2080 (Erdenetsetseg, 2003, Table 4).

Table 4. Projected changes in snow cover duration (%)

Snow cover duration	Current	HadCM3, A2			HadCM3, B2		
		2020	2050	2080	2020	2050	2080
101-120	30.0	34.1	32.2	28.6	34.2	32.2	29.2
121-140	37.5	35.9	50.5	58.3	35.9	50.5	57.4
>140	32.2	30.0	17.3	13.1	29.8	17.3	13.4

Source: Erdenetsetseg, 2003

An earlier study showed that the area with snow cover for at least 50 days would reduce to 33.4% and 22.6% by 2040 and 2070 respectively (Mijiddorj and Ulziisaikhan, 2000). Snow cover in winter can have both positive and negative impacts on animal husbandry. Long-lasting thick snow cover adversely affects animal raising, limiting the available pasture size. On the other hand, lack of snow cover means no water source for animals, because all surface water is covered by thick ice. Projections for 2070 suggest winter water shortages for animals, particularly in the steppe and western part of the country.

The Orhon and Selenge river basins are the major crop-land areas in Mongolia. Late formation and earlier melting of snow cover would lead to a decrease in soil moisture that can adversely affect crop yield. Addressing this challenge will require explicit measures in crop technology and pasture water supply to overcome climate impacts. Also, higher temperatures will have several major consequences. They will increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt and shorten the overall snowfall season.

Evapotranspiration is one of the water balance parameters. In Mongolia, the projected increase in evapotranspiration is going to outrun the projected increase in precipitation (Table 5).

4.2 PROJECTED CHANGES IN RIVER RUNOFF

Many of the most critical impacts of global climate change will manifest themselves through the hydrologic system. The impacts include increasing temperature resulting in increased evaporation, changing precipitation patterns that may result in more severe droughts and/or floods, and changing snowpack amount and elevation will all result in shifts of the stream flow regimes.

Initial results of an impact and vulnerability assessment for the water resources in the country show that if the annual precipitation drops by 10% while the temperature remains constant, the average river flow decreases by 7.5%, 12.5% and 20.3%, in the IDB, the AOB and the IDB respectively. If the average temperature increases by 1°C, 2°C, 3°C, or 5°C, additional flow reduction will occur. According to these findings for each degree temperature increase, there is at least 2% decrease of annual flow (Table 6) (Batimaa, 2000). The table also shows that river runoff is more sensitive to the precipitation changes than to the temperature changes.

Climate change can be approached as a new sector of water consumption as it is projected to decrease the water resources of a country. Different GCMs suggest that changes in temperature and precipitation will result in a runoff decrease of 29.3% to 15.3% increase (Table 7) (Batimaa *et al.*, 2005, 2009).

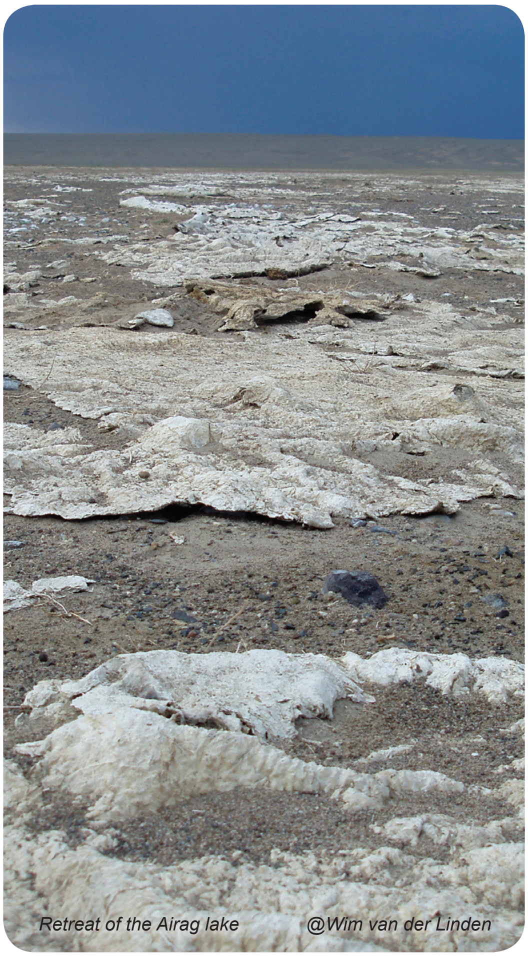
At one extreme, higher temperatures imply that areas already subject to drought may see more extensive drought and heat wave events, while at the other, areas accustomed to extreme snowfall will see warmer winters. Warmer and shorter winters have already led to a reduction in the amount of water stored as ice in glaciers and in seasonal snow packs. The shorter cold season means that the spring melt will arrive much earlier with significant implications for stream flows available downstream in late summer and early fall.

The current aquatic ecosystem is accustomed to the present water temperature regime. Rising water temperature, resulting from a rise in the air temperature, will have a significant effect on the aquatic life.

Future dry conditions are also expected to increase evaporation from open water surfaces such as lakes. One study projects that annual evaporation from water surfaces will increase by 66.1 mm in 2020, 72.7 mm by 2050 and 193.4 mm by 2080 by HadCM3 A2; and 39.7 mm by 2020, 50.2 mm by 2050 and 106.4 mm by 2080, by HadCM3 B2 (Davaa *et al.*, 2008).

Although the exact effects of climate change on water resources are uncertain and will vary by region and by basin, utilities responsible for managing water resources for local communities - including drinking water, wastewater, flood management, and storm water - will face serious challenges.

Khovd aimag Buyant river *@ Ts.Tsetsegee*



Retreat of the Airag lake *@Wim van der Linden*

Table 5. Evapotranspiration projections (mm/yr) under SRES A2 and B2 scenarios in Mongolia relative to baseline 1961-90

Ecosystem region	A2-medium-high emissions			B2-medium-low emissions		
	2020	2050	2080	2020	2050	2080
HadCM3						
Forest-steppe	17.7	33.9	68.6	21.8	32.5	49.4
Steppe	17.1	30.1	62.6	19.3	28.6	44.3
High mountains	19.7	37.9	72.9	23.1	36.4	51.8
Desert-steppe	15	27.0	53.6	16.9	25.2	37.5
ECHAM4						
Forest-steppe	23.2	46.5	86.9	24.4	48.2	61.3
Steppe	20.9	40.6	77.3	21.2	42.4	54.7
High mountains	22.5	49.0	90.9	24.1	49.1	66.5
Desert-stepp	17.1	34.3	63.5	17.1	35.0	38.9
CSIRO-Mk2b						
Forest-steppe	14.8	33.3	68.7	21.0	34.3	47.8
Steppe	13.0	27.8	61.5	18.6	30.0	42.9
High mountains	17.4	39.7	79.5	25.0	44.3	52.6
Desert-stepp	11.4	25.9	54.4	16.3	27.7	37.8

Source: Bolortsetseg, 2005

Table 6. River run off sensitivity to changed temperature and precipitation

	Changes in precipitation					
		P-20%	P-10%	P=0%	P+10%	P+20%
changes in temperature	Internal drainage basin					
	T+0	**-20.2**	**-7.5**	**0.0**	**21.2**	**37.3**
	T+1	-17.3	-5.9	**6.1**	26.2	40.0
	T+2	-20.2	-8.9	**3.7**	21.3	36.3
	T+3	-22.8	-12.1	**0.2**	17.0	30.6
	T+5	-30.1	-21.7	**-13.1**	-3.2	6.2
	Arctic Ocean basin					
	T+0	**-22.3**	**-12.5**	**0.0**	**12.8**	**27.4**
	T+1	-23.5	-14.1	**-3.8**	9.1	22.9
	T+2	-27.2	-18.4	**-9.3**	1.9	14.5
	T+3	-29.0	-21.6	**-13.5**	-3.0	7.9
	T+5	-39.4	-17.6	**-22.3**	-16.7	-8.6
	Pacific Ocean basin					
	T+0	**-29.3**	**-20.3**	**0.0**	**17.7**	**31.2**
	T+1	-36.9	-26.9	**-15.1**	5.0	21.2
	T+2	-40.1	-31.9	**-20.7**	-5.5	8.2
	T+3	-42.1	-31.6	**-23.1**	-9.8	6.1
	T+5	-42.0	-37.1	**-33.2**	-22.9	-12.8

Source: Batimaa, 2005, 2007

Table 7. Projected river runoff changes

	A2			B2		
	2020	2050	2080	2020	2050	2080
Internal Drainage Basin						
HadCM3	-1.4	9.1	-8.6	7.2	9.6	-0.3
ECHAM4	15.3	10.9	-10.1	16.2	6.2	-2.8
CSIRO-Mk2b	-1.3	-0.6	-5.1	0.8	-1.7	-7.1
Arctic Ocean Basin						
HadCM3	-13.9	-5.4	-12.6	-0.5	-2.6	-19.2
ECHAM4	1.4	-7.3	-26.9	1.4	-3.2	-17.5
CSIRO-Mk2b	-6.4	-13.2	-24.7	-9.1	-14.6	-17.9
Pacific Ocean Basin						
HadCM3	-23.5	-20.9	-27.5	-19.1	-23.6	-29.1
ECHAM4	-9.8	-18.3	-24.7	-4.2	-18.8	-26.1
CSIRO-Mk2b	-17.5	-22.9	-35.6	-20.5	-24.2	-29.3

Source: Batimaa, 2005, 2009

4.3 PROJECTED CHANGES IN PERMAFROST

Different methods and different scenarios have been used to project changes in permafrost. According to the climate change scenario, the area with permafrost will be reduced to 24-28% of Mongolia's territory by 2040 and reduced even further to 16-25% in 2070 from that in 1990 (Mijiddorj, 2000). According to this study, sporadic permafrost will disappear before 2040, while the other permafrost areas decrease considerably.

The SRES projections show that the area with continuous permafrost will be limited by 1-4.4% by 2020, and will disappear by 2050-80. The seasonal frozen area, or the area where no permafrost exits, will nearly double by 2020 and triple by 2080 (Ganbaatar, 2003). The cool temperature zone in the Khentein mountain region will be reduced drastically by 2040 and will be replaced almost completely by a warm temperature zone by 2070 (Bolortsetseg, 2005). The permafrost boundary will rapidly shift to the north as well as upslope and will nearly disappear by 2070 (Ganbaatar, 2003; Mijiddorj and Ulziisaikhan, 2000).


Retreat of the Potanin glacier @ P.Batimaa

4.4 PROJECTED CHANGES IN GLACIERS

Air temperatures above 3050 m would be 1.0°C higher by 2020, 2.9°C by 2050, and 5.8°C by 2070 (Davaa *et al*., 2008). Following the increase in air temperatures, annual ablation rates (the total loss from melt and from sublimation or evaporation) of flat-top glaciers will be about 130 cm by 2020, 370 cm by 2050, and 730 cm by 2070. Therefore, glaciers less than 50 m thick could be completely gone by 2040, glaciers less than 100 m thick could be completely gone by 2050, and glaciers less than 150 m thick could be completely gone by 2070 (Davaa *et al*., 2008).


Retreat of the Potanin glacier @ P.Batimaa

The populations of three western aimags about 269.5 thousands as at 2008 (Mongolian Statistic Yearbook, 2008), live in glacier-fed water catchments, are vulnerable to climate change. Increasing rates of glacial melting will lead to great reductions of water availability. In the future, high peak flows in glacial-fed rivers are expected, as the rate of glacier-mass loss increases, followed by dramatic reductions in river flow and freshwater availability as glaciers progressively disappear (Batimaa, 2000, 2005).


Retreat of the Potanin glacier @ P.Batimaa

The combination of permafrost melting and glacier melting will initially increase in river run-off, but eventually will decrease as a result of loss of ice resources. Consequences for downstream, which relies on this water, will be unfavorable in most western and northern parts of Mongolia . The thawing volume and speed of snow cover in spring is projected to accelerate in western Mongolia and the thawing time could advance, which will increase some water sources and may lead to floods in spring. None significant shortages in water availability for agriculture in other seasons is likely expected.

PART ONE

CLIMATE CHANGE AND ITS IMPACTS ON WATER RESOURCES

Zurkhen mountain, upper Orkhon river @ P.Batimaa

CHAPTER 5

CONCLUSION

CONCLUSION

Observed changes described above are consistently associated with changes in components of the hydrological cycle such as: changing precipitation patterns, intensity, and extremes; widespread melting of snow and ice; increased evaporation; and changes in soil moisture and runoff. These changes in climate have already resulted in the decrease of river discharge in the last two decades.

The Mongolian climate will continue to change dramatically over the next century. Study results are emerging on the likely pattern of this future climate. Projections suggest higher temperatures all year round, with more snow in winter and less rain in summer.

The water resources in Mongolia will alter in late winter or early spring due to the seasonality of the precipitation changes and the earlier spring snowmelt caused by the projected warming under climate change. Rising temperatures affect annual water discharge by increasing evapotranspiration, thereby reducing the contribution of overland flow to stream flow and groundwater recharge. This combination results in a marked increase in water discharge during late winter and early spring and in some cases a reduction in water discharge during the summer. If there is no general increase in precipitation, the early snowmelt will lead to shortages of water in summer. The hydrology will be controlled by the timing and intensity of the spring snowmelt, and is affected principally by the degree of warming during this time period.

There are also clear changes in the dates of autumn and spring ice phenology occurrence, ice cover duration, and ice thickness at rivers and lakes. Changes in ice phenology dates correspond to an increase in air temperatures of autumn and spring months when river ice processes take place. Shifts in freeze-up and break-up dates range from three days to a month. The changes in the timing of ice phenology dates and ice thickness differed depending on geographical location: rates of change are much higher in colder regions (western region) than in warmer regions (central and eastern regions). Consequently, the ice cover duration shortens from 10-30 days. Maximum ice thickness decreases by 40-100 cm.

The impact of precipitation changes will be substantially greater than the impact of temperature fluctuations. If the annual precipitation drops by 10% while the temperature remains constant, the average river flow reduction will range between 7.5-20.3% depending on the basin. If, besides the lower precipitation, average temperature increases are taken into account, an additional flow reduction is expected: for each degree of temperature increase, the annual flow decreases by at least 2%. The scenario results are confirmed by sensitivity analysis results, especially at high altitudes. The river flows tend to increase with temperature if precipitation is unchanged. This is explained by the hydrological characteristics of the Mongolian rivers - higher temperatures enhance snow and glacier melting, leading to increased spring runoff, which can be equal to or even exceed the summer runoff from rainfall alone. At some point in time, the snow and glaciers will have completely melted and many small rivers that are fed by snow and glaciers will disappear. This will result in a decrease of water resources regionally and in Mongolia as a whole.

Changes in precipitation, evaporation and temperature regimes, and in soil and other environmental factors, will affect groundwater resources throughout the country. Climate change will reduce aquifer recharge and water levels, especially in shallow aquifers. Higher temperatures and droughts will result in increased evapotranspiration. Aquifers will also suffer from the trend of heavier precipitation events, because more water will go to runoff before it can percolate into aquifers. Thus, even in a future where overall precipitation increases, aquifer levels may decrease.

Even though Mongolia's annual water resources will likely decrease, the annual supply will remain similar to current supply patterns. This has implications for water shortages, which will worsen in low water periods.

@ P.Batimaa

PART TWO

URBAN WATER VULNERABILITY TO CLIMATE CHANGE


Ulaanbaatar city @ .Elbegzaya

CHAPTER 6

URBANIZATION IN MONGOLIA

6.1 URBANIZATION

About half of the world's population lives in urban areas (WB, 2004). Mongolia is no exception to this trend, despite Mongolia being one of the most sparsely populated countries in the world, with a population of 2.7 million over a territory of 1.56 million km^2. Mongolia ranks as the 233rd country in the world for population, with a population density of 1.6 p/km^2. By the end of 2008, about 1.66 million people (roughly 60% of the total population) were living in urban areas in Mongolia (Table 8) (NSO, 2008).

Development in Mongolia has been greatly influenced by the country's rapid rate of urbanization in recent years. Increased demand by residential and commercial consumers of urban services has outstripped supply, particularly in Ulaanbaatar and in aimag centres. This has become a constraint to the growth of economic activity. Mongolia's fastest growing urban area is Ulaanbaatar. Aimag centres like Erdenet, Darkhan and Choibalsan show urban expansion because aimag centres are the cultural, industrial, financial, and air-way centre of a province.

Table 8. Urban and rural population (in thousand)

year	2004	2005	2006	2007	2008
Urban total	**1498.2**	**1 543.3**	**1 579.5**	**1 601.0**	**1 659.2**
From which in Ulaanbaatar	928.5	965.3	994.3	1 031.2	1 071.7
Rural	**1034.9**	**1 019.1**	**1 015.3**	**1 034.2**	**1 024.3**
Total	**2 533.1**	**2 562.4**	**2 594.8**	**2 635.2**	**2 683.5**

Source: NSO, 2008

6.2 THE CAPITAL CITY OF ULAANBAATAR

6.2.1 Population

Ulaanbaatar is the capital city and located at about 1,400 m above sea level in the north-central part of the country. It is the cultural, industrial, financial and railway network centre of the country. Ulaanbaatar accounts for the majority of the increasing urban population. Its population is estimated at 1.071 million, which is 40% of the total population and 65% of the urban population (Table 8). The average annual growth rate of Ulaanbaatar's population during 2003–2008 was around 3.6%, which was three times the growth rate of total Mongolian population (1.2%) and nearly four and a half times that of the aimag centres (0.8%).

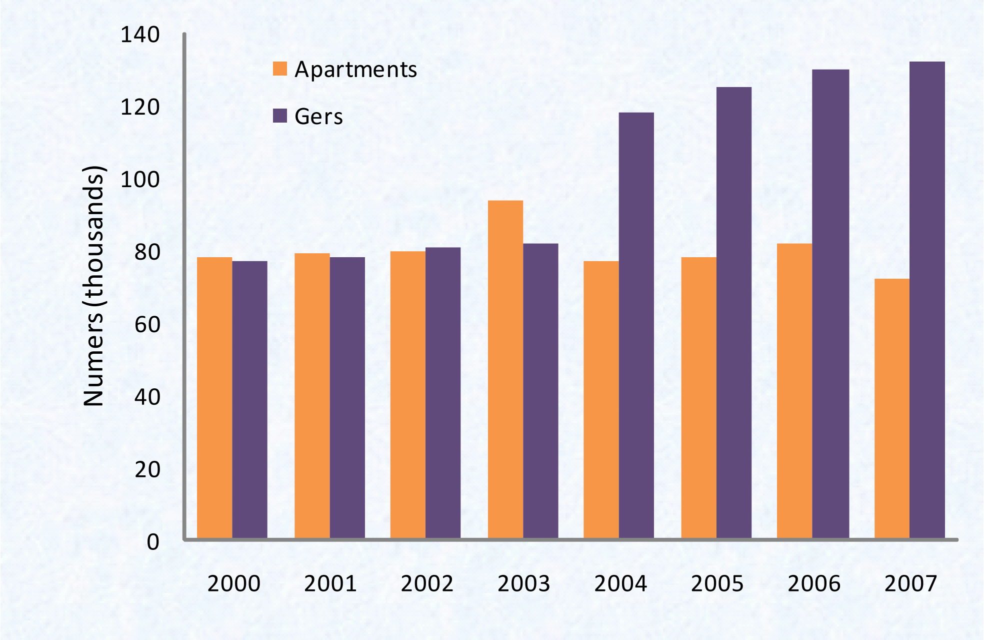


Figure 9. Number of households live in apartments and gers in Ulaanbaatar (Source: Basandorj and Singh, 2009)

More than half of the population live in 22 informal settlements with traditional housing made of felt, canvas, and wood known as ger areas that are characterized by a low level of public services (Basandorj and Singh, 2009) (Figure 9).

Due to this rapid urbanisation, Ulaanbaatar faces serious environmental impacts. These include air pollution, water pollution, and land degradation, all of which affect human health and safety. In terms of urban air quality, Ulaanbaatar is currently one of the most polluted cities in Asia. Furthermore, during the long winter season, when residents resort to coal burning, the air quality of Ulaanbaatar falls to well below the recommended national standard for indoor and ambient concentrations (Figure 10).

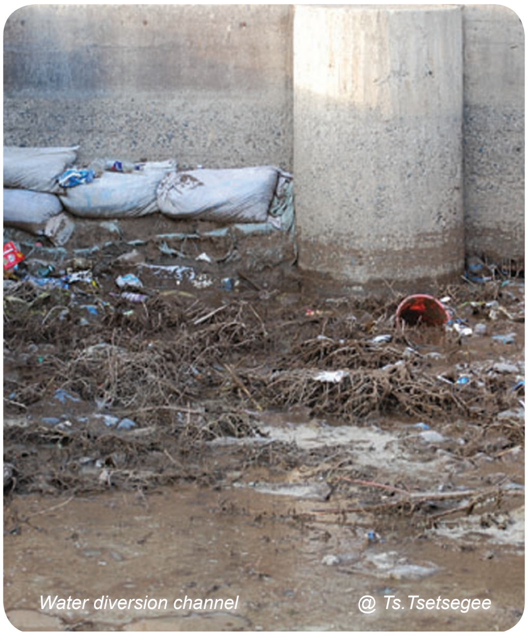
6.2.2 Water supply

The daily water consumption of Ulaanbaatar is about 150-170 thousand m^3 (Table 9). This exceeds the average of that in developed countries. The water is pumped from four well fields along the Tuul river, with 100 km of raw water pipes connecting wells and pumping stations and 350 km of distribution lines supplying the city core. Of particular concern is that, there are irregular repairs and maintenance of the municipal water supply lines.

Water supply disparity between apartments and ger areas remains one of the most difficult challenges for Ulaanbaatar (Table 9). The daily water consumption of a ger area is between 5–10 l/capita, which is much less than that recommended by the WHO. Daily water consumption in apartments is more than 250 l/capita. A significant number, but less than 10%, get at least some of their water from private wells, springs and rivers. Very few are connected to the distribution network of pipes. Both apartment and ger areas suffer from limited urban land use planning.

6.2.3 Water treatment

Seventy percent of urban sewage is treated and no water is being recycled in Mongolia. However, domestic waste-water in rural areas is mostly discharged into the environment without any treatment. The central cores of all major urban areas are served by sewer collection systems and waste water treatment plants. According to government statistics, less than 25% of the total population is serviced by sewers (MDG, 2007). Many of the sewage treatment plants and collection systems built before 1995 are generally not functioning due to a lack of proper operation and maintenance. As a result, wastewater is often discharged directly into a river or onto the ground. Collection networks are in equally poor condition. Consequently, raw sewage leaks from buried pipes into the soil, potentially contaminating local groundwater. In Ulaanbaatar, a 158 km sewer system discharges into a biological treatment plant, which for many years has functioned poorly. In ger areas, sewage treatment is generally non-existent and most residents use unimproved open pit latrines or open field defecation, both of which pose public health hazards.



Water diversion channel @ Ts.Tsetsegee

Water kiosk @ Wim van der Linden

Waste water treatment in Ulaanbaatar @ B. Odbayar

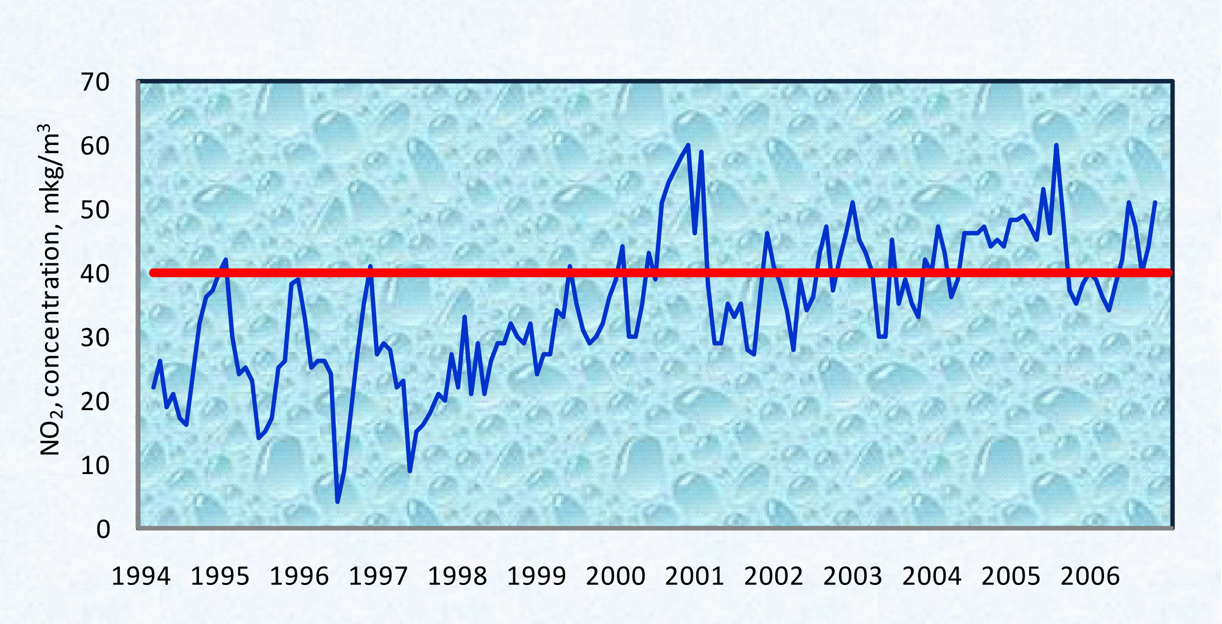


Figure 10. Monthly mean concentration of NO_2 in Ulaanbaatar (Red line is the health standard) (Source: MNE, 2007a)

6.2.4 Urban water infrastructure

Mongolia has an extensive infrastructure given the country's level of economic development (WB, 2007). Access to roads, electricity, and mobile phones has expanded rapidly and is higher than might be expected of a country with its income and geography. But considerable infrastructure gaps remain to be filled, especially in water and sanitation, and specifically in informal and rural settlements.

These gaps will not be filled easily. High technical standards are required for equipment to operate in Mongolia's environmental extremes. Also, the construction season is short, and the distance from international markets large. This all makes the construction and maintenance of infrastructure very expensive by global standards. The long winters, with temperatures between -20 to -35°C and an absolute minimum of -49°C, pose fundamental challenges for engineers. For example, water pipes need to be laid some 3m or more below ground freezing level.

Nevertheless, all of Mongolia's principal settlements have relatively sophisticated water supply systems dating back to the 1960s and 1970s. However, they all exhibit gross

Table 9. Water consumption in Ulaanbaatar

Years	Daily water supply, m^3/day	Annual consumption, million m^3	Daily per capita use, l/day	
			Apartments	Ger
1997	161 000	58.2	420	4.6
1998	165 500	60.4	450	4.8
1999	167 200	61.0	430	4.9
2000	168 400	61.5	358	4.7
2001	158 700	57.9	318	5.3
2002	152 000	55.5	287	5.7
2003	151 080	55.0	325	5.8
2004	154 400	56.5	315	5.4
2005	157 300	57.4	286	6.3
2006	151 757	55.4	291	7.3
2007	153 692	56.3	285	6.9

Source: Jargalsaikhan et al., 2008

infrastructure inequalities between the formally developed core areas, which alone are served by these networked systems, and the surrounding self-built ger areas, in which the majority of the urban population live.

6.2.5 Water services

In Ulaanbaatar and the aimags, water-related urban services are provided by public urban services organizations (PUSOs). Ulaanbaatar's Water and Sewage Company (USUG) was established as a State enterprise in 1959 and incorporated in 1997 with responsibility for water supply and sewerage in the city and its three satellite towns (Nalaikh, Baga-nuur and Baga-Khangai). USUG is self-financing with respect to operations and routine repairs, but any major repairs require additional allocations from municipal or central government, or from donor funds. USUG services to domestic consumers are provided through the Housing & Communal Service Authority (OSNAAG), responsible to the City Governor's Office, which manages 19 serving groups of apartments and organizations with water bought wholesale from USUG. The ger areas are supplied by communal water collection kiosks or in a minority of cases by natural sources. However, the centralized systems' infrastructure has deteriorated significantly and there is a need for rehabilitation to improve efficiency and to ensure regular supplies. Centrally supplied water is taken to the ger area kiosks by trucks, which are slowly being replaced by networked supply. The Municipality of Ulaanbaatar is directly involved in water supply and sanitation policy matters, planning, tariff setting, capital funding, technical design, contract preparation and bidding and construction supervision.

Water pump @ Wim van der Linden

PART TWO

URBAN WATER VULNERABILITY TO CLIMATE CHANGE

Upper Tuul @ Jan Bron

CHAPTER 7

THE TUUL RIVER BASIN

7.1 THE TUUL RIVER BASIN

Administratively, the Tuul river basin serves five aimags: 59% of total territory of Tov (aimag center: Zuunmod), 20% of total territory of Bulgan (Erdenet), and less than 10% of total territories of Uverkhangai, Arkhangai, and Selenge aimags, as well as Ulaanbaatar. The total population in the Tuul river basin is 1,107,292 (NSO, 2008). Hydrological changes in the Tuul basin may have major impacts on the water resources in Ulaanbataar.

The study of the Tuul river basin focuses on the urban water vulnerability to climate change. Analysis of the climate is based on observed data at the Ulaanbaatar meteorological station, while analysis of hydrology is based on observed data at the Zaisan hydrological gauging station. Both stations are located in the centre of Ulaanbaatar.

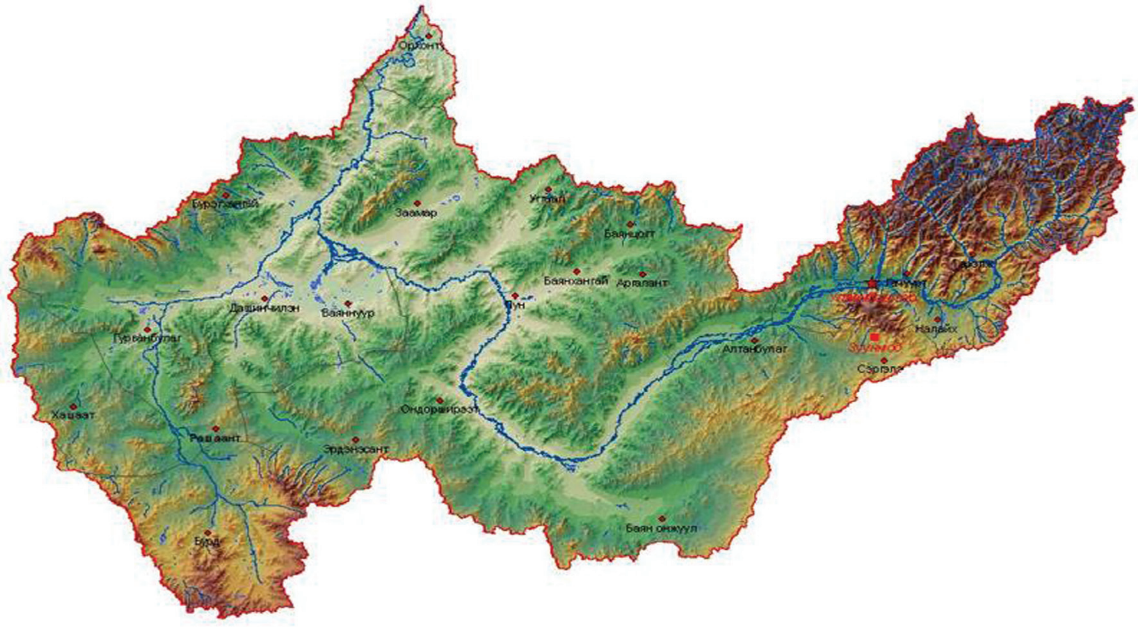


Figure 11. The Tuul river basin

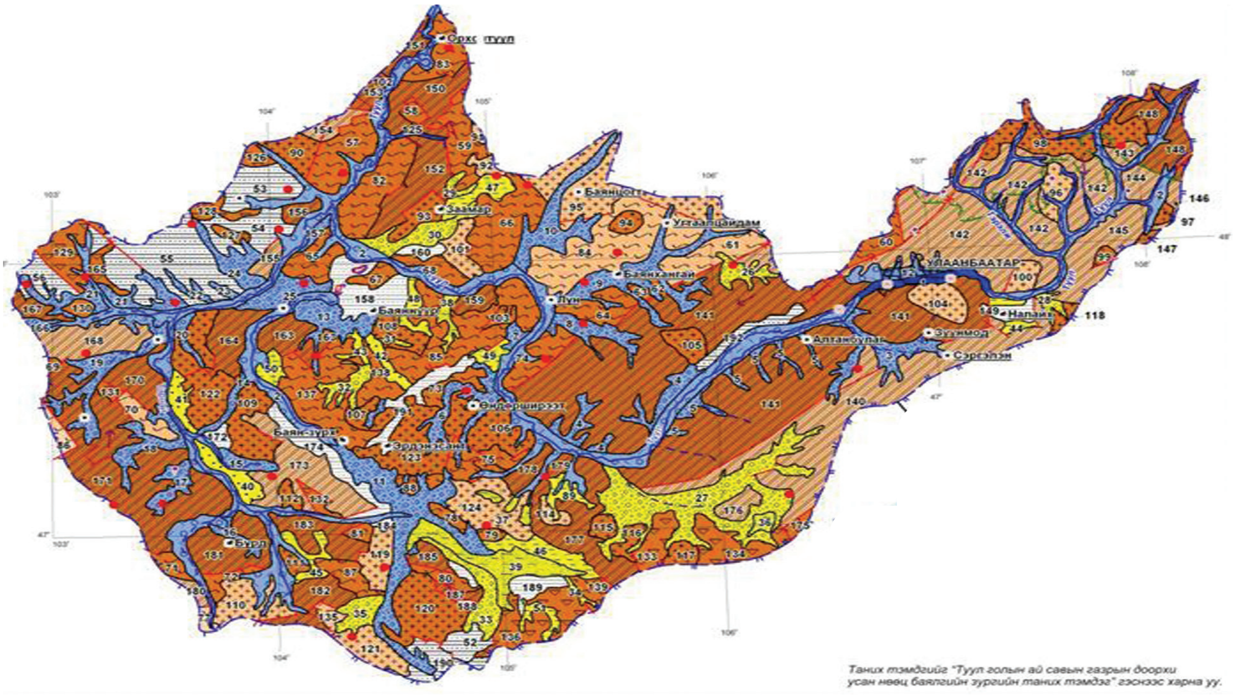
Hydrology: The Tuul river has a drainage area of about 49,840 km^2. It flows westwards for about 704 km, passing through Ulaanbaatar.

The Tuul river has about 790 first-order tributaries, 160 second-order tributaries, 30 third-order tributaries and 5 fourth-order tributaries (Figure 11). The rainfall regime in the Tuul river basin is characterized by a pronounced annual cycle. Most of the annual runoff is formed between June and September. For about 140-170 days of the year, the river is covered by ice. The annual hydrological regime and changes in the water along the river shows that the Tuul river is fed by ground water during summer high and autumn low water, resulting in a river discharge increasing downstream. In contrast, during the spring low water period the river water feeds the ground water, resulting in a decrease of discharge along the river.

The average annual surface water supplied by the Tuul river is estimated at about 800 million m^3 around Ulaanbaatar.

Groundwater: The hydrogeology of the Tuul river basin varies. It comprises alluvial deposits, Cambrian and Precambrian limestone formations, granites of varying ages, sedimentary rocks (including wide variety of deposits and rock formations distributed throughout the basin that contain groundwater. Conversely, there are zones in the basin where groundwater is very sparse. These include areas with loamy sedimentary deposits, granite and metamorphic formations, hard rock formations in the subsurface, steep rocky mountain slopes, and some permafrost areas.

Confined groundwater is generally distributed along inter-mountain depressions. Alluvial aquifers along the river contain considerably higher amounts of groundwater at the shallowest depths (Figure 12). The groundwater resource allocations within the basin are shown in Table 10. The annual groundwater resources around Ulaanbaatar are estimated to be approximately 91 million m^3.



Таних тэмдгийг "Туул голын ай савын газрын доорхи усан нөөц баялгийн зургийн таних тэмдэг" гэснээс харна уу.

Figure 12. Groundwater resources map within the Tuul river basin
(Source: Jadambaa, 2010)

Table 10. Groundwater resources

Classification of groundwater resources	Groundwater resources		% in area	% in water resources
	l/s*km²	mln m³/year		
High	3-30	366 100 000	8	44.5
Medium	1-3	358 700 000	13	43.6
Moderately	0.3-1	11 100 000	<1	1.3
Small	0.03-0.3	85 500 000	29	10.4
Extremely small	0.003-0.03	25 000	<1	0.0
No water	<0.003	2 100 000	46	0.3
Total		**823 525 000**		

Source: Jadambaa, 2010

7.2 CHANGES IN CLIMATE AS THEY RELATE TO WATER – CURRENT OBSERVATIONS

7.2.1 Changes in temperature

The climate of the river basin is harsh and continental, characterized by clearly defined seasons and high annual and diurnal temperature fluctuations. Extreme temperatures span from -49.6°C in winter to +34.5°C in summer. Due to its high altitude, the Tuul river basin is generally colder than other regions at this northern latitude. The average temperature in the basin varies from a minimum of –24.2°C in January to the maximum of 16.7°C in July in Ulaanbaatar.

The daily average air temperature in the Tuul river basin for the period from 1986 to 2006 was analyzed for 8 meteorological stations. According to the analysis, the spring, summer and autumn mean temperatures have increased over the last 20 years, especially in summer. However, winters became colder in Ulaanbaatar for the 1986-2006 period. Figure 13 illustrates the trends in seasonal temperatures at Ulaanbaatar station.

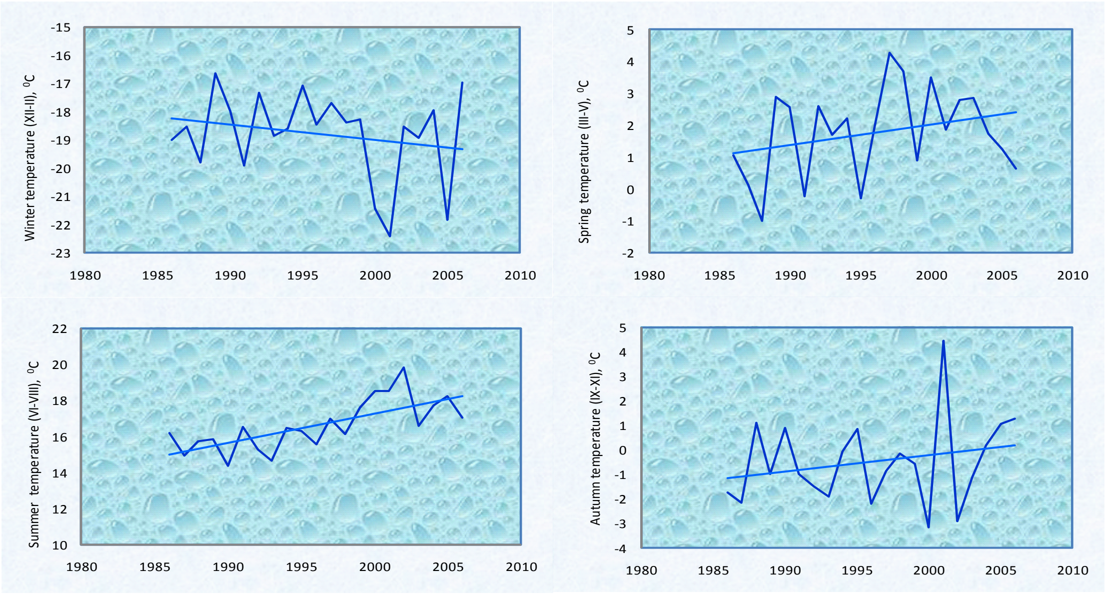


Figure 13. Trends in seasonal mean temperatures (winter, spring, summer, autumn)

7.2.2 Changes in precipitation

In winter, cold and dry polar air enters into the river basin due to the weather pattern governed by the stable Siberian anticyclone. Ground frost appears from October to early May and only a thin snow cover protects soils and vegetation. In summer, the South Asian continental cyclone allows for warmer temperatures and an increase in precipitation. The mean precipitation in the warmest period of year is about 240 mm, falling dominantly in the form of thunderstorms.

Both monthly and annual mean precipitation were analysed. The length of the precipitation series is comparable with the length of the air temperatures series. Trends in seasonal precipitation at Ulaanbaatar are presented in Figure 14. Winter and spring precipitation has increased: especially the precipitation in May, which has more than doubled since the mid-1980s. Conversely, summer mean precipitation has decreased by more than 100mm mostly due to a sharp decrease of August precipitation. There is a very slight decreasing trend in autumn mean precipitation. However, the times series used are short and should be interpreted with extreme care.

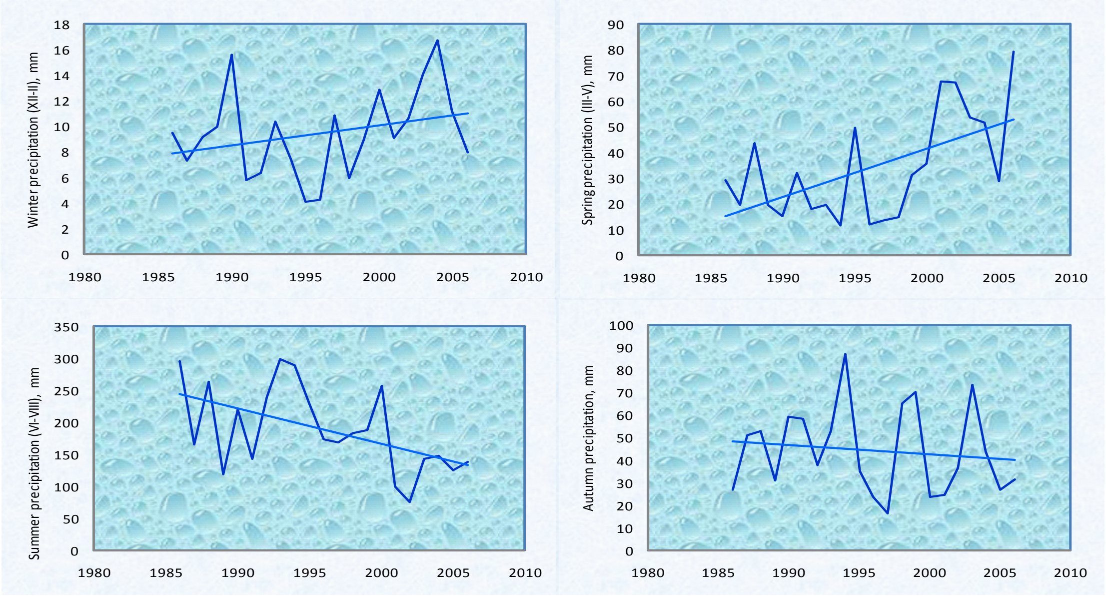


Figure 14. Trends in precipitation at Ulaanbaatar station (LR: winter, spring, summer, autumn)

7.2.3 Changes in relative humidity

Annual mean relative air humidity in the Tuul river basin is 62% and ranges from 70-74% in December and January. It reaches its lowest value of 48% in April. During the last two decades humidity has decreased due to increased temperature and decreased precipitation (Figure 15). Although Spring precipitation has increased, humidity decreased as the increase in precipitation did not compensate the increase in temperature.

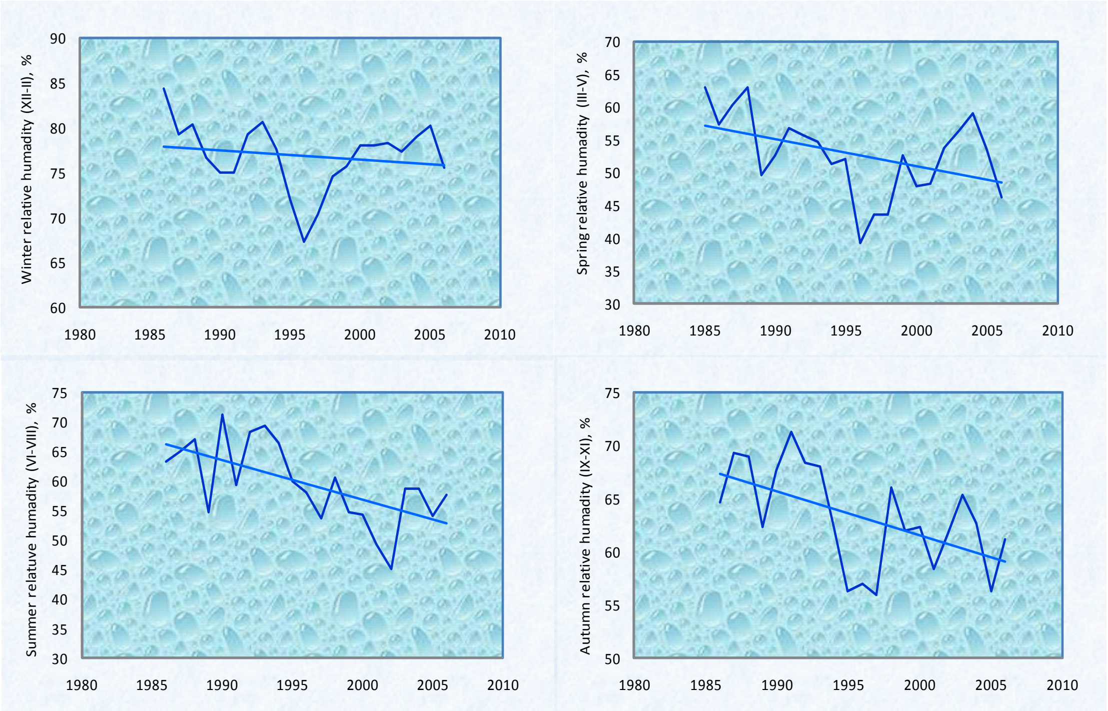


Figure 15. Changes in relative humidity (LR: winter, spring, summer, autumn)

7.2.4 Changes in potential evapotranspiration

Evapotranspiration depends mostly on the air temperature and air humidity. There are no direct measurements of actual evapotranspiration in the river basin. Thus, potential evapotranspiration was estimated using Ivanov's equation (1954) when temperature exceeds 5°C and the equation of Blaney and Criddle (1950) when temperature drops below 5°C. The result shows an increase in potential evapo-transpiration in warm seasons, most pronounced in summer (Figure 16).

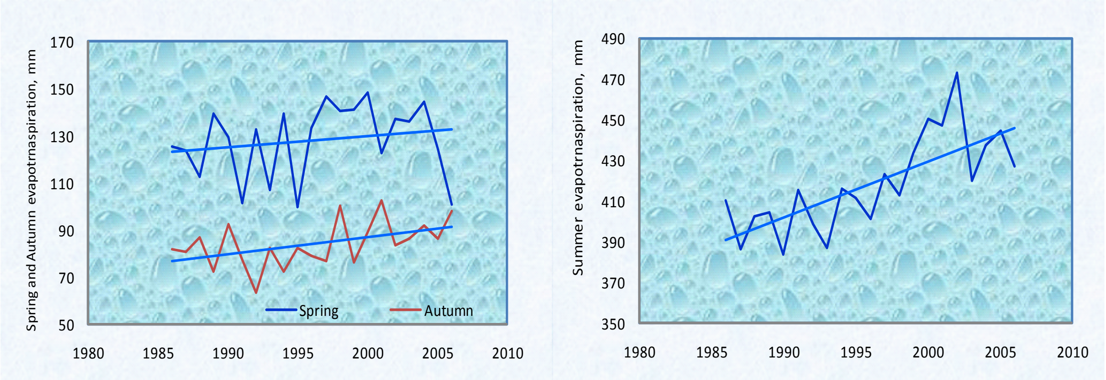


Figure 16. Changes in potential evapo-transpiration (LR: spring, autumn and summer)

7.3 CURRENT IMPACTS OF AND VULNERABILITY TO CLIMATE CHANGE

7.3.1 What hydrological changes can be expected in the Tuul river

Impacts of climate change and anthropogenic pressures such as fire, overgrazing, and deforestation are causing changes to the hydrological characteristics of the Tuul river basin.

River flow: River flow has been decreasing since the mid-1990s, particularly in the last decade. The average flow between 2001-2008 is not only much less than the long-term average, but also less than any previous decade except for the 1945-1950 period (Table 11). Currently, the Tuul river summer discharge is less than one third of that in 1991-2000.

According to the observation data, flash floods have also become more frequent in the last decade. The duration of a single flood due to rainfall has decreased by 3 days since the early 1940s. However, it should be noted that maximum discharges have not exceeded 200 m^3/s since 1996 (Figure 17) and the average is less than one third of what it was in the previous two decades.

Observations of low water levels show not only a reduction but also a lengthening of the duration by 24 days since 1945. From 2000 onward, there have been no cases of the Tuul river downstream from Ulaanbaatar drying up just after the ice cover disappeared (MNE, 2005).

The average number of days with ice cover and ice phenomena over the last 60 years has decreased by 15 and 7 days (Table 12) compared to the average over 1945-1950. The ice depth decreased by about 80 cm since 1945 (Figure 18).

Table 11. The Tuul river average discharge in decadal intervals (m^3/s)

Interval	Spring (IV-VI)	Summer(VII-IX)	Autumn(X-XI)	Winter(XII-III)
1945-1950	11.5	34.2	5.6	0.09
1951-1960	25.7	66.5	10.3	0.20
1961-1970	32.6	71.1	10.4	0.21
1971-1980	35.7	66.3	13.1	0.53
1981-1990	32.9	87.2	11.7	0.21
1991-2000	25.4	98.6	12.3	0.47
2001-2008	19.8	28.6	7.16	0.10
Long term average	27.5	68.3	10.5	0.28

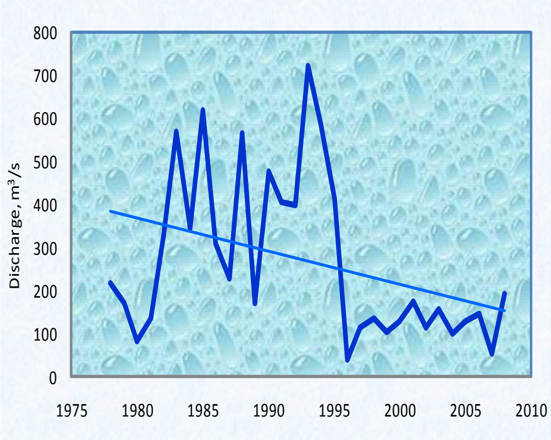


Figure 17. Time series of the Tuul river maximum discharges

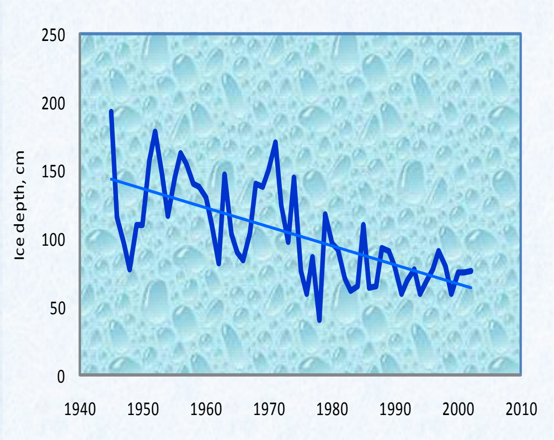


Figure 18. Change in ice depth of the Tuul river (Source: Davaa *et al.*, 2007)

Table 12. Changes in duration of ice cover and phenomena

Decades	Duration of ice cover, days	Duration of ice phenomena, days
1945-1950	159	191
1951-1960	160	194
1961-1970	154	192
1971-1980	153	194
1981-1990	149	186
1991-2000	150	184
2001-2008	144	184

7.3.2 Projected water availability

We have used the HBV model to project water resources for the Tuul river. Projections of future climate were discussed in Chapter 5. No regional climate change model has been developed for Mongolia. Thus, we used results in Table 13 as a scenario for the Tuul river. The HBV model results show an increase in river runoff of 5% by 2020 by ECHAM4 and a decrease of up to 25% by 2080 by CSIRO-Mk2b (Table 13) is projected.

Table 14 illustrates the sensitivity of the Tuul river to climate change. As can be seen from the table, if the annual precipitation drops by 10%, while the temperature remains constant, the average river flow reduces by 31.3%. If, besides the precipitation drop, average temperature increases of 1°C, 2°C, 3°C or 5°C are taken into account, an additional flow reduction is expected: for each degree of temperature increase, annual flow decreases by another 10%.

Table 13. Projected river runoff changes of the Tuul river

Model	A2-medium-high emission			B2-medium-low emissions		
	2020	2050	2080	2020	2050	2080
HadCM3	-18.3	-4.9	-14.8	-6.1	-9.5	-12.1
ECHAM4	4.8	-4.7	-4.9	-1.7	-6.6	-6.6
CSIRO-Mk2b	-11.1	-13.3	-25.2	-9.4	-16.5	-19.7

Table 14. The Tuul river run off sensitivity to changed temperature and precipitation

	Changes in precipitation (%)					
		P-20	P-10	P=0	P+10	P+20
Changes in temperature (°C)	T+0	-54.4	-31.3	0.0	32.7	72.5
	T+1	-60.5	-40.0	-14.2	17.0	53.6
	T+2	-65.3	-46.9	-23.5	4.8	38.3
	T+3	-69.5	-52.8	-31.7	-5.9	24.9
	T+5	-75.6	-61.8	-44.1	-22.2	4.0

7.3.3 The water resources around Ulaanbataar, characteristics, trends and vulnerability

Water supply: The vulnerability of Ulaanbaatar's urban water to a change in climate depends not only on climate change, but also on the utilization of the resources; and the operation, maintenance and the institutional organisation of the water management in and around the city. Impact can be direct, such as there being less water available when water demand is at its highest; or indirect, for example, an increase of diseases due to a reduction in water quality. Indirect effects may be more significant than the direct impacts.

More than a million people, more than 10,000 hectares of irrigated farms, more than 3,000,000 livestock, hundreds of industries and businesses, and four power plants in Ulaanbaatar depend on water supplied from the Tuul river (NSO, 2008). In 2009, the demand for water in the Tuul river basin exceeded 105 million m^3 (Davaasuren, 2009). About 5-10% of water supply comes from private wells.

Groundwater tables in Ulaanbaatar have been showing a marked decline over the last 50 years (Basandorj and Davaa, 2005). Water is being withdrawn faster than the rate of recharge (Unurjargal, 2009). As the city grows, and water demand increases, this problem continues to intensify. Water use in Ulaanbaatar ranges from 151,000 to 170,000 m^3/d (Table 9), and is predicted to reach 290,000 m^3/d in 2010, 358,000 m^3/d in 2020, and 458,000 m^3/d by 2030. However, existing wells are designed to supply only around 250,000 m^3/d at full capacity (Jargalsaikhan *et al.*, 2008). Thus, the demand for water will outstrip the capacity of the existing wells in the near future. Seasonal water shortages (during low water periods) are growing ever more common and various studies warn that sometime within the next 10 years, Ulaanbaatar will be facing a critical shortfall in water availability (Unurjargal, 2009).

Flooding: Housing, commerce, and transport compete for shrinking open space in Ulaanbaatar. Also, settlement areas and especially the ger areas are expanding due to migration (WB, 2006). Currently, the open space includes the flood plain of the Tuul river and parts of Bogd Khan National Park. Changes in rainfall patterns will have a direct impact on human settlements, especially where these are expanding into the dried river channel. Most of the flood protection work in Ulaanbaatar was done after the 1966 flood event, the highest recorded since the 1940s. The current flood protection system in Ulaanbaatar is hardly functioning because of poor maintenance (Davaasuren, 2009; WB, 2007). The system can neither bear increased intense rains (Figure 19) nor spring melting flows (Figure 20).

Increasing effects of climate change will strain the storm drainage system of Ulaanbaatar even further. As mentioned above, both high discharges of the Tuul river and summer precipitation have decreased. However, Ulaanbaatar is experiencing flash floods every year and the frequency, as well as the damage, of flash floods is increasing from year to year. For example, rainfall of 17-51.6 mm lasting 30-60 minutes on 17 and 21 July 2009 affected about 2000 households (Figure 21) and the total damage was valued at 2.7 billion Tug (1.93 million USD, 1USD = 1400 Tug) (Namsrai, 2009).

Figure 19. Flood protection channel functioning during rain in Ulaanbaatar (Source: Davaasuren, 2009)

Figure 20. Over road flow due to snow melt mater (Source: Davaasuren, 2009)

Figure 21. Overview of the flash floods and their impacts of 16 and 21 July 2009 in Ulaanbaatar (Source: Namsrai, 2009)

Figure 22. No-flow event for the Tuul river (Source: Udenbor, 2009)

Likely changes in the permafrost situation will cause damage to flood protection, drainage works and transport infrastructure, affecting road and rail safety. In particular, flooding of roads that have inadequate drainage and physical damage in roads may worsen even further due to melting of permafrost.

Droughts: Despite an average of 240 mm of rainfall a year, the Tuul river basin experiences periodic low-flow and no-flow events. Since 1996, the flows have been lower than the long-term average. According to the result of the 2007 water inventory, eight rivers, 26 springs and seven spas have dried out. In April 2007, the river itself downstream of the city became dry (Figure 22). The groundwater table has also been decreasing as the annual mean discharge decreased.

Water quality: The Tuul river has a mountainous origin and its upland watershed has low flow, with little sediment entering from the predominantly forested area. The water is cool and clear and contains barely any organic matter because the river has received neither discharge of municipal or industrial wastewater, nor run-off from urban or agricultural areas. Concentrations of nitrogen and phosphorus are low and limit the production of phytoplankton, making the water low in biomass content. The upper part of the Tuul river water is identified as clean (Figure 23, MNET, 2008).

As the river flows downstream of Ulaanbaatar it gains drainage area, its slopes become flatter, reducing velocities and bottom scour, and its depth and width become greater. Run-off from farmlands, croplands, as well as municipal and industrial waste-waters add suspended sediments, nutrients, and organic matter to the stream. Water temperature and turbidity are also increasing downstream.

There are currently 26 wastewater treatment plants in Ulaanbaatar, but 14 are not functioning (Tuvshinjargal, 2009). All of the remaining 12 treatment plants are discharging into the Tuul river. Stretches of the Tuul river, downstream of Ulaanbataar, are among the most polluted river stretches in Mongolia (Figure 23, MNET, 2008) Other major Tuul river polluters include gold mines, gravel extracts, livestock and tourist camps (Figure 24).

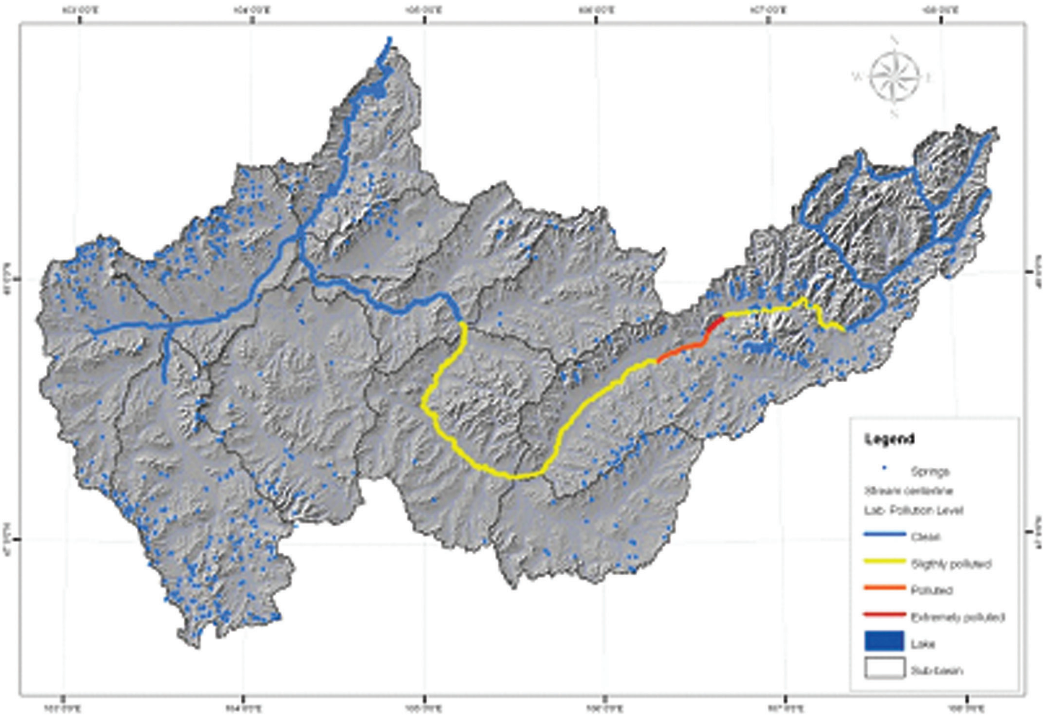


Figure 23. Water quality classification of the Tuul river

As shown in Figure 25, the concentrations of BOD have increased rapidly since 2000, but as highlighted in Table 11 the Tuul river flow was rapidly decreasing after the middle of the 1990s. The self-purification capacity downstream of the central water treatment plant effluent is six times less than the upper stream (Batimaa, 2002). The capacity of the Tuul river to dilute and neutralize water polluted by urban waste is dependent on the quantity of water flowing in it. During observed lower summer flows, dissolved oxygen concentrations are reduced, as well as the dilution of pollutants. This leads to an increase of the polluted zones along the river length. As water flow is projected to further decrease under future climate change scenarios, the river's capacity to dilute wastes will diminish and pollution concentration will increase without additional measures (Davaa *et al.*, 2008; and Basandorj and Davaa 2005, Batimaa, 2000, 2005).

Producing over 50% of the country's total exports, mining is one of the most rapidly growing and leading industrial

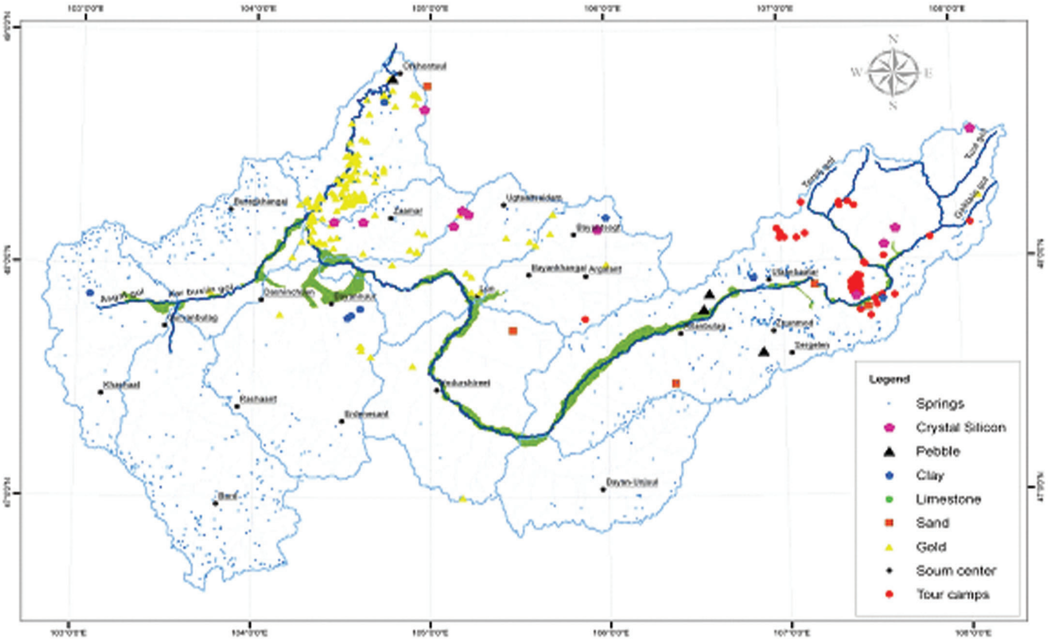


Figure 24. Mining and tourist camps in the Tuul river basin (Source: Tumerchuder, 2009)

activities in Mongolia. But mining is causing an almost complete destruction of the natural ecosystems in large floodplain stretches. No proper rehabilitation measures in the floodplains are being taken by enterprises during or after mining. The gold mining in Zaamar soum of Tov aimag (mostly downstream) is the centre of mining activities in the Tuul river basin. It degrades land and pollutes water resources (MNET, 2008). The water treatment plants of tuner industries are not functioning and they release untreated water to the central treatment plant and occasionally discharge into the Tuul river directly (MNET, 2008).

River water temperatures show an increasing trend. For example, the July water temperature of the river has increased by 1.9°C for the last 60 years (IHM, 2009). Furthermore, there is a clear negative linear relationship between July water temperatures and river discharges (Figure 26), with slower currents, the water heats up more. No-flow events for the Tuul river (Udenbor, 2009) may result in water quality effects that either render water unusable for any purpose or impose additional treatment costs.

Land use and ecosystem: The Tuul river covers territories of 34 soums in five aimags and represents steppe (82.0%), forest steppe (11.8%), and mountain regions (5.4%). The land use of the Tuul river basin can be classified as pasture (85.9%), cropland (1.3%), hay area (1.6%), abandoned land (2.2%), urban area (1.0%), roads (0.3%), forested area (6.8%), and water (0.3%) (Figure 27).

About 11.7% of the Tuul river basin is covered by protected areas: the Khan Khentii Strictly Protected Area, the Gorkhi-

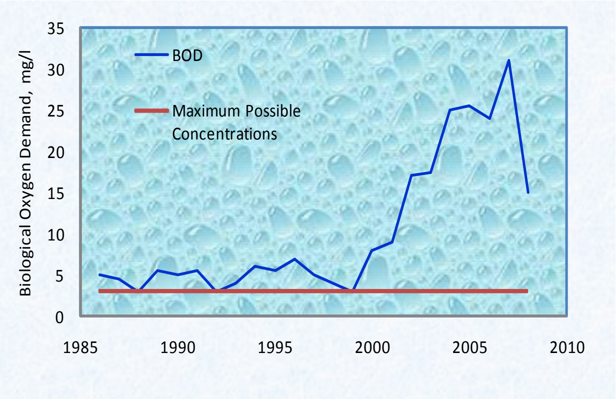


Figure 25. Time series of monthly Mean biological oxygen demand at Songino station (just after the central water treatment effluent) of the Tuul river, versus the standard maximum

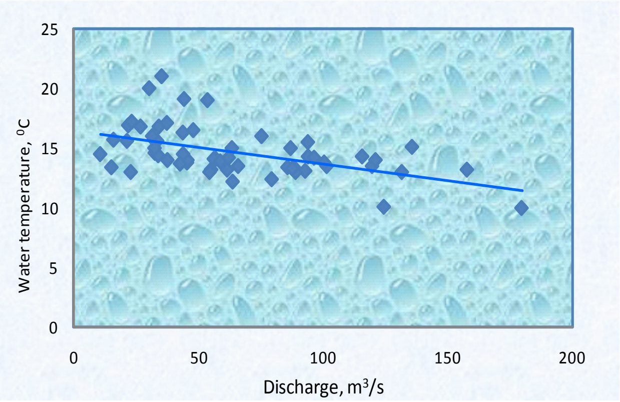


Figure 26. Relationship between discharge (river gauging station at Zaisan) and water temperature (at Ulaanbaatar meteorological station) in month of July (1978-2008)

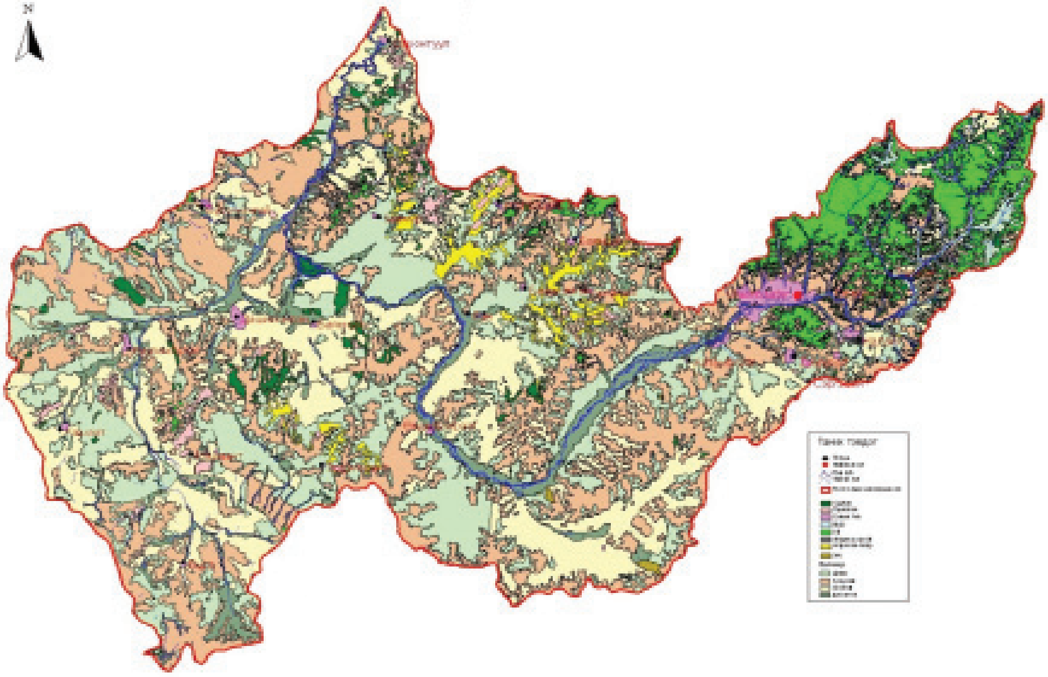


Figure 27. Map of land use in Tuul river basin (Source: Khishigsuren, 2009)

Terelj National Park, the Moltsog els, the Hustain nuruu, the Batkhaan mountain and the Khogno Khan mountain. A variety of environmental regulations and land and resource restrictions govern their use.

The most recent study on the economic value of the upper Tuul ecosystem found that the land and resources of the upper Tuul currently contribute income and marketed products worth around Tug[3] 28 billion (20 million USD) a year in tourism, herding and forest-based activities (Emerton *et al*., 2009). Meanwhile, the current value of water use in Ulaanbaatar is estimated to be worth a minimum of 90 billion Tug (64.3 million USD).

Conservation of the two protected areas that cover most of the upper watershed of the Tuul river, Gorhki-Terelj National Park and Khan Khentii Strictly Protected Area, has high social benefits and economic value because it helps to safeguard downstream water supplies for Ulaanbaatar. Overall, improved conservation of the Upper Tuul ecosystem is estimated by the study to be worth some Tug 1,370 billion (979 million USD) in present value terms, through the provision of water, tourism, herding, and forest products.

In contrast, continuing ecosystem degradation and biodiversity loss will prove extremely costly in terms of water and other services lost. Even taking into account the costs of the additional protected area budgets and the losses in value that would be required to bring land and resource uses to ecologically sustainable levels, conservation would give rise to substantial economic gains over a situation where the ecosystem is further degraded.

Conservation is estimated to generate an additional Tug 76 billion (54.3 million USD) net present value over 25 years compared to continuing gradual degradation of the watershed and Tug 125 billion (89.3 million USD) over and above a situation of no protection. Compared to the current situation, the study findings suggest that every Tug 1 invested in the conservation of the upper Tuul ecosystem has the potential to generate an additional Tug 15 in water, land and resource use benefits over the next 25 years (Emerton *et al*., 2009).

Human health: Water is the habitat or breeding site of many disease vectors that mediate the host-to-host spread of disease-causing organisms. Key gaps in knowledge include a lack of data in health-related exposures and a lack of research on health outcomes concerning impact assessment.

The main health effects from lack of access to clean water and sanitation are diarrhoea and other waterborne diseases. Poor drainage in human settlements increases exposure to contaminated water and provides a habitat for mosquitoes, which leads to increased incidence of water-borne and vector-borne diseases. Worldwide, incidences of waterborne infections are increasing due to the contamination of water with pathogenic viruses and bacteria and use of contaminated water for drinking and preparation of food (WHO, 2005).

The major water-borne diseases in Mongolia are diarrheal diseases like dysentery and salmonella. Drying up small

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[3] Mongolian currency

tributaries and springs, decreased flow of the Tuul river (Table 11), and degraded water quality (Figure 25) has certainly increased health risks. The number of occurrences of dysentery increased in the last decade, especially in the warm season (Figure 28). The Tuul river water is not used directly for drinking purposes. However, it is a practice in Mongolia to use open water sources such as rivers, springs and others for both drinking and domestic use when the water is not covered by ice. People living in suburbs of the city and ger areas use any available open water source. This might be the cause of the high increase of diarrheal diseases in the warm season.

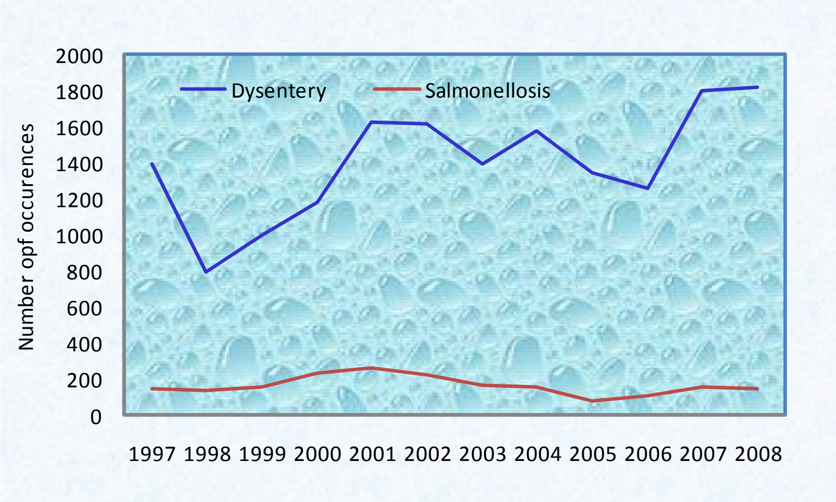

Figure 28. Trends in dysentery and salmonellosis occurrences in Ulaanbaatar for the period from 1997 to 2007

The maximum occurrences of dysentery and salmonella were in 2001-2003, coinciding with a very severe three years drought during which many springs and small rivers dried up (Batimaa *et al*., 2009). The diarrheal diseases, the decline in water quality and the decrease in flow will have serious implications for human health vulnerability. Under future climate change, it is expected public health risks will result from higher water temperatures (breeding higher concentrations of certain organisms), from changes in ambient water quality, and from more intense rainfall events.

Summary on the vulnerability of the Tuul river basin: Very few comprehensive studies on freshwater vulnerability for Northeast Asia have been done except for a book entitled "Freshwater under threat Northeast Asia" (Huang *et al*., 2008). This assessment identifies the Tuul river basin as very vulnerable, exhibiting water resources problems, continuous deterioration of water quality, poor water use efficiency and lack of management. The vulnerability assessment results show that the Tuul river basin will be even more vulnerable from climate change.

The first objective of this vulnerability assessment was to identify urban communities that will be most affected by climate change. Inhabitants in Ulaanbaatar, especially those living in ger areas, are identified as most vulnerable to flooding and water shortage as well as changes in open water resources. They are also most vulnerable to health risks from the continued deterioration of water quality under future climate change. Trends in climate and water resources strongly suggest that the natural conditions for Mongolia's water regime are changing. Although the uncertainties are still huge, there is strong evidence that the evaporation during the summer period is becoming larger. This may very well lead to less water availability when the demand is largest. Also, there is evidence that extreme climate events will intensify as the projections suggest an increased variability. It can be reasonably assumed that this will lead to more droughts and floods. Under the current conditions, the pressure on water resources is already high, particularly in the densely populated region around the capital city Ulaanbataar in the Tuul basin. Also, the pressure on the environment is high due to water pollution and mining activities in the floodplains. Furthermore, population rises and urban migration will continue to increase the pressure on the natural system into the future. Reports already suggest decreasing trends in water resources around Ulaanbatar. The current state of the urban water supply, drainage, water treatment plants, and flood protection works shows a series of shortcomings. Moreover, relatively few people are connected to the drinking water distribution system and sewer collection system. This already leads to damage during storms, to substantial water pollution, and difficulties in obtaining clean water easily. Climate change and population projections suggest that the pressure on the available resources and water management utilities will increase. Therefore, adaptation measures are urgently required. Options for such adaptation are presented in the next, last Chapter.

@ P.Batimaa

PART TWO

URBAN WATER VULNERABILITY TO CLIMATE CHANGE

Frozen Tuul @ Ts.Tsetsegee

CHAPTER 8

ADAPTATION TO CLIMATE CHANGE

ADAPTATION TO CLIMATE CHANGE

This assessment clearly shows that the traditional management of water resources, development approaches, and technologies cannot provide sustainable water resources under future climate change. Accordingly, new approaches are needed to reconcile conflicting interests on the use and conservation of water resources to adapt to climate change.

Adaptation refers to all those responses that ensure survival and prosperity under changing conditions. Human adaptation to climate change generally involves building resilience and developing a selection of options. Adaptation can also refer to actions designed to take advantage of new opportunities that arise as a result of climate change (Leary *et al*., 2008b). This means that having a variety of responses available is good policy.

The annual water resources of the Tuul river are likely to decrease, but the annual distribution will remain similar to the current distribution patterns. This means that water shortages will continue and even worsen in low water periods. Considering the existing scarcity of natural water supplies and their anticipated decrease, adaptation measures are formulated and summarized below.

The principle adaptation recommendation of this report is to develop an Integrated Urban Water Management (IUWM) plan for the Tuul river basin, harmonizing the interests of stakeholder groups and environmental constraints, and providing a sustainable future for water resources in the basin. Land use and human activities must be actively planned and managed. The Water Authority is currently implementing a project to develop an Integrated Water Resources Management Plan at the national as well as at the Orkhon-Tuul river basin level. This project could take care of this principle adaptation measure by expanding the study to the Tuul river.

More specific adaptation measures related to urban water resources and supply in Ulaanbaatar can be divided into two categories:

- adaptation of the supply
- adaptation of the demand

These are actions in two directions. The first is linked to the reduced availability of water resources, while the second is linked to the increasing water demands. The adaptations related to water supply refer to modification of the existing physical infrastructure and alternative management of the existing water supply systems. The adaptations related to demand focus on water conservation and improved efficiency, water pricing and technological change. Both benefit from an improved knowledge on climate change.

8.1 Domestic Water supply

The physical condition of existing water supply systems is inadequate. This results in intolerable water losses, especially in the face of climate change. The proposed adaptation measures can be divided into physical and management measures, with great emphasis on the reduction of water losses.

(1) Physical measures:

- *rehabilitate the existing water supply network to reduce water losses in the distribution pipes;*
- *introduce automated control of water supply systems; and*
- *construct plants to recycle water from beverage industries for non-potable use (for example, for watering the green areas of the city)*

(2) Management measures:

- *start pricing of water;*
- *raise public awareness in using water saving technologies such as water metering, low-flow toilets and showers, efficient appliances like low pressure potable and rainwater collection for garden and other uses; and*
- *improve the management of water supply utilities*

8.2 Hydrological extremes

It is projected that extreme hydrological events such as flash floods and droughts will occur more frequently. Even more certain is that increasing numbers of people will continue to occupy the floodplains around Ulaanbataar, as this is the only open space left in the city. In order to mitigate the impacts and to reduce the population's vulnerability to extremes, the following adaptation measures have been identified:

(1) Physical measures:

- *constrict river water regulation works (for example: erection of cascade basins along the main river to regulate runoff and prevent floods would be more appropriate than building a big dam);*
- *rehabilitate existing flood protection and drainage systems;*
- *maintain drainage systems;*

- *construct new flood protection and drainage systems in flood prone areas of the city; and*
- *install an early warning system*

(2) Management measures:

- *review existing plans on road, housing, settlement and spatial plans;*
- *prepare flood defence and protection plans;*
- *raise public awareness and education; and*
- *promote insurances*

Many recent floods damaged infrastructure significantly. This could have been prevented if the drainage systems were functioning (Namsrai, 2009). The proposed measures cover rehabilitation and regular maintenance of the flood protection and drainage systems. The preparation of an operational plan for protection and its coordination is required, including a review of existing plans on the floodplains, roads, housing, settlements and protection of the river banks and valleys. The higher frequency of floods must be taken into consideration when spatial and housing plans are prepared.

8.3 Water quality

Climate change affects water quality in three ways: 1) less water means less flow and dilution in the river, leading to degraded water quality or increased investment in wastewater treatment, 2) higher temperatures reduce the dissolved oxygen in water bodies and 3) in response to climate change, the water use of industries, mining and tourist camps may increase the concentration of pollution being released to the rivers.

(1) Physical measure:

- *rehabilitate wastewater treatment plants, especially the industrial water treatment plants in Ulaanbaatar*

(2) Management measures:

- *enforce the legal framework on water supply, sewage, disposal, and treatment of wastewater;*
- *strengthen the capacities of the public utilities for sewage and wastewater;*
- *establish a water discharge permits system for different users; and*
- *introduce practices to reuse/recycle wastewater*

8.4 Human health

While much is known about the real and potential impacts of climate change, even more is unknown. Taking this into account, most of the adaptation measures are to improve research on climate change impacts and vulnerability on:

- *climate driven changes in water resources and the consequences for human health.*
- *health effects of changes in water quantity and quality, distribution of toxicants, and new mixtures of water pollutants formed by changing water temperatures and quantities.*
- *mathematical modelling at the local and regional levels to assess risk and develop predictive and preventive strategies and*

Tuul river @ Ts.Tsetsegee

Tuul river - Zaisan @ Ts.Tsetsegee

Tuul river - Zaisan @ Ts.Tsetsegee

development of monitoring systems to assess health impacts.

- *physical impacts of water pollution exposure especially in aging and other vulnerable populations.*
- *behavioural and social science research on preventative strategies for vulnerable populations and groups, health impacts of floods and droughts and economic analyses to understand long term effects of climate change on human health.*
- *change in the range of vector-borne and zoonotic pathogens and in the transmission of water-borne pathogens.*

8.5 Monitoring and research

Improved observation and research are important. Without assessment of on-going adaptations, researchers could overestimate the potential threats of climate change. Gaps in knowledge exist in terms of observations and research needs related to climate change and water. In Mongolia observed data and data access are prerequisites for adaptive management, yet many monitoring networks are lacking matching time series of different parameters. There is a need to improve the understanding and modelling of changes in climate related to the hydrological cycle at scales relevant to decision making. Information about the water-related impacts of climate change is incomplete, especially with respect to water quality, aquatic ecosystems, and groundwater, including their socio-economic dimensions.

@ P.Batimaa

PART TWO

URBAN WATER VULNERABILITY TO CLIMATE CHANGE


@ P.Batimaa

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND ECOMMENDATIONS

The Report validates the existence of challenges and links between climate change and water availability in Mongolia, through solid scientific evidence and assessment findings.

Effects of climate change on the Tuul River hydrology

The assessment concludes that the major impacts of climate change on water resources will manifest themselves through the hydrological systems of the Tuul River in many ways. These include: an earlier start of spring snowmelt, a shortening of ice phenomenon, a decrease of summer higher flow, and an increase in summer flood frequency. Increased air temperature and more intense rainfall are also affecting not only the annual flow of the river, but seasonal distribution as well.

To minimize the overarching threats of climate change on water resources in Mongolia, it is thus recommended:

- ***to develop and implement adaptation strategies for water resources as a key element in upcoming climate change and water legislations, and to ensure they are mutually supportive; and***
- ***to empower and strengthen the water organizations with the tools and resources necessary to address the climate change challenges.***

Water infrastructure in need for significant investment

The report confirms that the level of performance and maintenance of the existing drinking water facilities, storm and flood water management, and wastewater treatment infrastructure in Ulaanbaatar is unsatisfactory. This existing infrastructure will also experience serious repercussions from the effects of climate change, such as reduced snow cover and increased frequencies of storm and drought. To maintain current levels of service over the coming decades will require significant investment. Climate change only exacerbates the need for additional resources. **Thus, it is recommended to fully consider and integrate the effects of climate change and adaptation actions into all elements of water management plans and projects (building dams, diversion of rivers, developing irrigation schemes, and others).**

Decreasing water supplies confronted by an increasing demand

Water resources of the Tuul River are projected to decrease by 1.3-9.4%, 6.6-16.5%, 6.6-19.7% by 2020, 2050 and 2080, respectively. A longer dry period with lower flows in the low flow seasons and a shorter period with higher flows in the rainy season in the Tuul River are expected, according to models based on projected changes of temperature and precipitation from selected IPCC scenarios. Simultaneously, water use in Ulaanbaatar is predicted to increase significantly from 290,000 m3 in 2010, to 358,000 m3 in 2020, and 458,000 m3 by 2030. This will have serious implications on water supply in the low water period. Changes in the availability, timing and reliability of rainfall, and the water resources that flow from it, will critically affect all sectors who use water, especially in the dry season. The magnitude of these impacts extend to the national economy, as well as environmental services and social needs. Consequently, water suppliers will have difficulties in meeting water demand. A number of adaptation measures identified in this report would reduce climate change impacts on urban water resources. **Thus it is recommended to provide a continuum of decision-making on adaptation, beginning with reducing vulnerabilities by adopting and implementing the adaptation measures identified in this study.**

Increasing costs of water services

Another possible serious impact of climate change on water resources in the Tuul River basin and Ulaanbaatar is the increase of the price of water services, and in particular, the cost of achieving reliability in delivery service. This will be the case not only for drinking water, but also for agriculture, industry, and services, as well as for power production. It is even more important to realize that the impacts of climate change in Ulaanbaatar will not be limited to the suppliers and users. These impacts will also challenge the capacity of wastewater disposal and treatment facilities, infrastructure systems constructed for flood protection, storm-water drainage networks, and even transportation infrastructure.

Therefore, organizations and agencies responsible for components of integrated water resource management need to have clear responsibilities, adequate tools and capacity - notably data access and the ability to analyze and interpret this data - to guide planning and better inform the broader community on climate change implications. Currently, Mongolia's urban water management system is not robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic systems. It is not yet clear whether this is the fault of water management or socio-political institutions within which water managers operate. **Thus it is recommended to set up an appropriate institutional framework and increase capacity building to integrate adaptation actions into River Basin Management Strategies and Plans.**

@ Ts.Tsetsegee

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