Climate Change Vulnerability and Adaptation in the Livestock Sector of Mongolia

A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AS 06

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About AIACC

Assessments of Impacts and Adaptations to Climate Change (AIACC) enhances capabilities in the developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities. These activities are supporting the work of the United Nations Framework Convention on Climate Change (UNFCCC) by adding to the knowledge and expertise that are needed for national communications of parties to the Convention.

Twenty-four regional assessments have been conducted under AIACC in Africa, Asia, Latin America and small island states of the Caribbean, Indian and Pacific Oceans. The regional assessments include investigations of climate change risks and adaptation options for agriculture, grazing lands, water resources, ecological systems, biodiversity, coastal settlements, food security, livelihoods, and human health.

The regional assessments were executed over the period 2002-2005 by multidisciplinary, multi-institutional regional teams of investigators. The teams, selected through merit review of submitted proposals, were supported by the AIACC project with funding, technical assistance, mentoring and training. The network of AIACC regional teams also assisted each other through collaborations to share methods, data, climate change scenarios and expertise. More than 340 scientists, experts and students from 150 institutions in 50 developing and 12 developed countries participated in the project.

The findings, methods and recommendations of the regional assessments are documented in the *AIACC Final Reports* series, as well as in numerous peer-reviewed and other publications. This report is one report in the series.

AIACC, a project of the Global Environment Facility (GEF), is implemented by the United Nations Environment Programme (UNEP) and managed by the Global Change SysTem for Analysis, Research and Training (START) and the Third World Academy of Sciences (TWAS). The project concept and proposal was developed in collaboration with the Intergovernmental Panel on Climate Change (IPCC), which chairs the project steering committee. The primary funding for the project is provided by a grant from the GEF. In addition, AIACC receives funding from the Canadian International Development Agency, the U.S. Agency for International Development, the U.S. Environmental Protection Agency, and the Rockefeller Foundation. The developing country institutions that executed the regional assessments provided substantial in-kind support.

For more information about the AIACC project, and to obtain electronic copies of AIACC Final Reports and other AIACC publications, please visit our website at www.aiaccproject.org.

Summary Project Information

Regional Assessment Project Title and AIACC Project No.

Climate Change Vulnerability and Adaptation in the Livestock Sector of Mongolia (AS06)

Abstract

In Mongolia the risk of climate change and/or extreme climatic events have dramatic impacts on its economy and natural systems. The objective of the project was to assess *Potential Impacts of and V&A to Climate Change of Livestock in Mongolia*.

Different kind of approaches such as *analytical analysis* existing long-term plant dynamics, animal and climate database, ecosystem animal *modeling*, *remote sensing and GIS technology*, *field* and *participatory survey* were used for investigation of climate changes effects on grassland and livestock structure and function.

Observations from 60 sites distributed across the country show that the Mongolian climate has already changed significantly. Annual mean temperatures have risen by 1.80C between 1940-2003.

Mongolia is projected to be dry and hot, while winter will be milder with more snowfall. The rate of future winter warming in Mongolia varies from 0.9^{0}C to 8.7^{0}C, while the summer temperature increase varies from 1.3^{0}C to 8.6^{0}C. Winter precipitation will increase by between 12.6 per cent and 119.4 per cent when the summer rainfall varies from 2.5 per cent decrease to 11.3 per cent increase.

More than 80 per cent of the county's territory was defined as highly vulnerable to climate extremes.

This study stretches out the potential impacts of climate change upon the natural environment and upon the livestock sector, which is the major economic activity of Mongolia. Climate change will make an impact on all aspects - from the natural grasslands to the competitiveness of the livestock economic capability; ultimately it may also change the pattern of our individual and community lifestyles.

Administering Institution

Institute of Meteorology and Hydrology, Ulaanbaatar, Mongolia

Participating Stakeholder Institutions

Ministry of Nature and Environment, Ulaanbaatar, Mongolia

Countries of Primary Focus

Mongolia

Case Study Areas

Livestock sector

Sectors Studied

The primarily addressed sector in our study is *Agriculture-livestock*.

Systems Studied

The primarily addressed system in our study is *pasture/grassland ecosystem.*

Groups Studied

Subsistence herders are the livelihood groups we studied.

Sources of Stress and Change

The primary sources of stress and change was addressed in our study are *climate change, climate variability and extremes like drought, dzud, and storms*

Project Funding and In-kind Support

AIACC US$ 210, 000, USAID US$ 15, 000, Institute of Meteorology and Hydrology US$ 4800 in-kind support, and the Local Governor' Offices of Umnogobi, Bayankhongor and Khuvsgul aimags, US$6000 in-kind support.

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Executive Summary

Research problem and objectives

In Mongolia the risk of climate change and/or extreme climatic events such as drought and *dzud* have dramatic impacts on its economy and natural systems. Agriculture, livestock, grassland ecosystem, and water resources are among the most vulnerable systems. Resilience and adaptive capacity of traditional networks and land use systems to cope with climate variability/extremes are weakening, while frequency and magnitude of climate variability and land use intensity are in rise, what enhance vulnerability of the Mongolian rangelands, livestock and people.

Taking into account the countries specific circumstances of nature and agricultural development, the overall objectives of this project was *Potential Impacts of Climate Change and V&A Assessment for Rangeland and Livestock in Mongolia*. Therefore, priority were giving to the study of interactions between climate, grassland and pastoral systems, and integration of social factors in this analysis. The scientific understanding of past climate change impact on grassland ecosystems and livestock sector, and assessment of their vulnerability and adaptation were also the focus of our study.

Approach

Different kind of approaches such as ***analytical analysis*** existing long-term plant dynamics, animal and climate database, ecosystem animal ***modeling, remote sensing and GIS technology***, ***field*** and ***participatory survey*** were used for investigation of climate changes effects on grassland and livestock structure and function.

Scientific findings

This study stretches out the potential impacts of climate change upon the natural environment and upon the livestock sector, which is the major economic activity of Mongolia. Climate change will make an impact on all aspects - from the natural grasslands to the competitiveness of the livestock economic capability; ultimately it may also change the pattern of our individual and community lifestyles. Key findings of our research are summarized bellow.

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

- Annual mean temperatures have risen by 1.80C between 1940-2003. The warming has been most pronounced in winter, with a mean temperature increase of 3.60C, while spring, autumn, and summer mean temperatures have risen by 1.80C, 1.3 0C, and 0.5°C respectively.
- The heat wave duration increased by 8-18 days, depending on the geography. A greater increase (15-18 days) was observed in the region of the Khan-Khokhii mountains of the Great Lakes Basin and in the western part of the Khangain mountains; about 10-12 days in the Mongol-Altai and Khentii mountainous area; and 6-8 days in the Gobi Desert.
- The cold wave duration has shortened by 13 days. A greater decline has been observed of up to 20 days in the Khangain mountainous region, while it is even shorter in the Gobi Desert.
- Annual precipitation changes are quite variable, decreasing at one site and increasing at a site nearby. Seasonally, autumn and winter precipitation has increased by 4-9 per cent, while spring and summer precipitation has decreased by 7.5-10 per cent.
- Spatially, annual precipitation decreased by 30-90 mm in the central region and increased by 2-60 mm in the most western part and by 30-70 mm in the most south-eastern part of the country. The magnitude of alteration changes in precipitation regardless of increasing or decreasing is 5-25 per cen.
- Statistically, there were no significant changes in the maximum number of consecutive dry days on an average. The maximum number of consecutive dry days increased slightly in central

Mongolia, where annual mean precipitation was decreased. It decreased in south-eastern Mongolia where annual mean precipitation was increased.

- Potential evapotranspiration has increased by 7-12 per cent for the last 60 years.

The future climate: In our study, we used the Special Report on Emissions Scenarios (SRES), of the Intergovernmental Panel on Climate Change (IPCC) scenario runs performed with three coupled General Circulation Models (GCMs) such as the HadCM3, ECHAM3, and CSIRO Mk2. For all the models, we analysed the response to the middle forcing scenarios A2 and B2. 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.

The applicability of the GCM models to the Mongolian climate was validated by comparing observed temperature and rainfall data over the country for 1961-90, with modelled results for the baseline period. Among the three models, the HadCM3 gave the closest result to observed data. The models suggest that:

- The rate of future winter warming in Mongolia varies from 0.9^0C to 8.7^0C, while the summer temperature increase varies from 1.3^0C to 8.6^0C.
- Winter precipitation will increase by between 12.6 per cent and 119.4 per cent when the summer rainfall varies from 2.5 per cent decrease to 11.3 per cent increase.
- Against a small increase of summer rainfall, there is a much higher increase of evapotranspiration by 13-90.9 per cent, depending on ecosystem regions.

Natural environmental impacts: Climate change represents an important additional stress to the natural environment that is already affected by pollution, increasing resource demands and unsustainable management practices. The climate change studies conducted in Mongolia concluded that global warming would have a significant impact on natural zones, water resources, snow cover and permafrost.

Water resources: 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.

Snow cover: The climate of Mongolia is cold, with an annual mean temperature of minus 0.8° C. Clear skies in winter due to high anticyclone dominance over Mongolia results in less snowfall.

Key findings: Water resources

- 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 were much higher in colder regions (western region) than in warmer regions (central and eastern regions). Consequently, the ice cover duration has shortened from 10 days to 30 days. Maximum ice thickness has decreased from 40 cm to 100 cm.
- There is no clear decreasing and increasing trend in river runoff over the past 60 years. It is projected to decrease slightly further by HadCM3 and CSIRO-Mk2b due to decrease in summer precipitation accompanied by increasing temperature.
- Estimates of river runoff exhibit considerable variability. Summer peak discharge has increased by 30-50 m^3/s in the rivers in the IDB and decreased by 50-150 m^3/s in the rivers in the AOB.
- There is from one to three weeks advance in spring snowmelt runoff that has occurred since the 1980s.
- The impact of precipitation changes will be substantially greater than the impact of temperature fluctuations; if the annual precipitation drops by 10 per cent while the temperature remains constant, the average river flow would reduce from 7.5 per cent to 20.3 per cent. If, besides the precipitation drop, average temperature increases of 1ºC, 2ºC, 3ºC, and 5ºC are taken into account, an additional flow reduction is expected: for each ºC temperature increase, there is at least 2 per cent of annual flow decrease.

Snow contributes less than 20per cent to the total annual precipitation. The first snowfall occurs in the middle of October to the beginning of November and is usually short-lived, disappearing due to late autumn warming and wind. Sometimes, late first snowfall persists as snow cover in the mountainous regions. The annual snow cover duration is 120-150 days in the mountainous regions, 70-120 days in the eastern steppe and 30-60 days in the Gobi Desert. About 62 per cent of the country's territory is covered by snow for more than 50 days in a year. Snow plays an important role in livestock herding, since it serves as water resources for animals in winter but too much snowfall has an adverse affect.

Key findings: snow cover

- The date of snow cover appears to have shifted earlier by about 3-10 days since 1981 and is projected to shift by 20 days in 2080 relative to current levels.
- There were no clear changes observed in the extent of snow cover. .
- Any changes in snow depth have also been observed.
- Future declines from 27 to 56 per cent in snow cover extent have been projected by 2020-2080.
- The area of continuous snow cover with duration of more than 140 days will decline while the area of snow cover with duration of 120-140 days will increase.

Frozen ground: Frozen ground characterizes permafrost, seasonally frozen ground and surface soil freeze. The permafrost region occupies about 63 per cent of the total territory of Mongolia and may be classified into categories: *continuous, discontinuous, widespread, rarespread, sporadic, and seasonal.*

Key findings: frozen ground

- Permafrost temperature has increased from 0.05^0C to 0.15^0C from the 1970s.
- Permafrost phenomena such as melting mounds, thermokarst, and solifluction occur more frequently.
- Extensive thermokarsting has been discovered in the continuous and discontinuous permafrost zone of the Khangai-Khuvsgul mountains. The formation of thermokarst lakes were observed close to the Darkhad depression and the Chuluut river valley. The average rate of thermokarst varies from 5-10 cm/year 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 with a minimum rate of 2 cm per year.
- The thickness of seasonally frozen ground has decreased by 10-20 cm for the last 30 years.
- There are also clear changes in surface soil freeze in autumn and spring thaw. The date of the freeze in autumn was delayed by 2-6 days when the date of the thaw in spring advanced by 2-6 days. Longer shifts in timing have occurred in the forest-steppe and shorter shifts in the Gobi Desert.

Ecological and Economic Impacts

Pasture: About 80 per cent of Mongolia's total land area, or 127,307,000 hectares are used for pasture. Pasture growth begins in late April and biomass peak is usually reached in August. Mongolian livestock obtains over 90 per cent of its annual feed intake from the annual pastures. In winter, the grass dries off and its quality deteriorates. During this period, the animals take only 40-60 percent of their daily feed requirements. Pasture yields are strongly affected by climate and weather conditions.

The four main pasture ecological zones are high mountains, forest-steppe, steppe and desert.

Key findings: pasture

- The peak of pasture biomass has declined by 20 to 30 per cent during past 40 years. Pasture plant monitoring observation began in 1964 within the national network of meteorological observation. Pasture plant observations were carried out in the fenced fields, thus this reduction could be considered as the result of climate change only.
- The analysis of the Normalized Difference Vegetation Index (NDVI) trends of the third decades of July for the period of 1982-2002 at each pixel of 8x8 km resolution data shows a clear decline of the NDVI in 69 per cent of the country's territory for the last 20 years.
- Currently, fodder production is estimated at about one third of that in 1986.
- Climate change has had an effect on not only peak standing biomass but also spring biomass. Biomass in April and May was decreased in the forest-steppe and the steppe.
- Pasture plants emergency tends to begin earlier in the forest-steppe and the steppe. Particularly, the emergency date for *Agropyron sp.*has become earlier by three days in the steppe and 10 days in the Altai mountains and the desert for last 20 years.
- During the last 60 years in Mongolia, high nutrient plants decreased by 1.5-2.3 times. Low nutrient plants like *Carex duriuscula-Artemisia* became dominant in pasture communities.
- It is projected that pasture biomass will decrease in the forest-steppe and steppe and increase in the high mountains and desert. For instance: HadMC3 projects a pasture biomass decrease from 0.6 to 37.2 per cent in the forest-steppe and steppe by 2020-2080, more than 20 per cent increase in the high mountains and a much greater increase in the desert.

The most widely used and essential measure of ecosystem functioning is Net Primary Productivity (NPP) and any change in the NPP of an ecosystem indicates a change in the health of the ecosystem. Taking into account that vegetation is a key factor in determining the exchange of heat and moisture between the earth's surface and atmosphere, we have made an effort to analyse the effects of climate change on ecosystem zones in Mongolia using the NPP. For this purpose, we used the CENTURY model and determined the current NPP and Aridity Index that corresponds to each natural zone. The country was divided into 899 grid cells sized $0.5^0X0.5^0$ to match the resolution of the climate change scenarios to assess the climate change effects.

Enhanced dryness that resulted from air temperature increase would lead to a shift in the boundaries of current ecological regions to the north of the country. In particular, the desert area will extend to the north by 2080.

Livestock: The pastoral livestock sector directly engages half of the Mongolian population and provides food and fibre to the other half. Livestock and livestock processed exports amount to about one- third of foreign exchange earnings. Mongolia's development is highly dependent on pastoralism. Mongolian rangeland sustains livestock activities, subsistence farming, and is a key factor in the economy of the country.

Climatic conditions that prevent animal grazing are projected to increase in both summer and winter seasons. Unfavourable conditions in summer are expected to increase in the eastern and central steppe, while unfavourable conditions in winter would increase in the north-western mountainous region.

Key findings: livestock

- The observed data shows a decline of the average weight of sheep, goat and cattle by an average of 4 kg, 2 kg, and 10 kg, respectively, from 1980 to 2001 (Bayarbaatar and Tuvaansuren, 2002).
- Animal productivity also has decreased slightly. Sheep wool productivity has decreased by more than 8 per cent, while cashmere productivity has decreased by about 2 per cent over the last 20 years.
- With climate warming, the temperature stress on animals was observed.
- Post-climate change summer conditions are expected to have a more adverse impact on animals than the changed winter conditions. Summer ewe live-weight is likely to decrease by about 50 per cent, while winter ewe live-weight is expected to decrease by 15 per cent by 2080. Many environmental factors affect the animals in a complex way. Animal live- weight is a major manifestation of this combined effect because many of their features such as growth and development, fertility and birth, productivity, resilience, and adaptive capacity, depend on animal's weight. In other words, an animal's live-weight is dynamic depending on pasture and climatic conditions.

Vulnerability: A major driving factor of livestock dynamics in Mongolia appears to be climatic variability. The rising temperature and uncertainties in rainfall associated with global warming are likely to increase the frequency and magnitude of climate variability and extremes. On the other hand, changes in climate would also increase the risk of unexpected changes in nature and environment. The key risks from climate change to livestock are increased incidence of drought and dzud. More than 80 per cent of the county's territory was defined as highly vulnerable to climate extremes.

Drought: Drought has increased significantly at the level of 95 per cent in Mongolia for the last 60 years. In fact, the drought situation has worsened rapidly in the last decade. The worst droughts Mongolia experienced was in the consecutive summers of 1999, 2000, 2001, and 2002, which affected 50-70 per cent of the territory. Such long-lasting and severe droughts have not been observed in Mongolia in the last 60 years. During the past four years, about 3,000 water sources including 680 rivers and 760 lakes, have dried up. Such environmental degradation in turn has affected the level of primary production of vegetations/plants and water resources, which support livestock as well as human populations.

The animals in Mongolia take the necessary energy and nutrients for growth in summer and autumn. Animals start to gain weight in early summer when high quality grass is available and attain their maximum weight at the end of autumn. If there is dry summer or prolonged drought, animals cannot build sufficient strength and energy to overcome winter. Herders used to relax in the summer months after the long and severely cold winter, whether the summer conditions were good or bad. On the other hand, animals do not die even during very severe drought conditions. Thus, drought in Mongolia was not regarded as a natural disaster, unlike in many African and South Asian countries. However, drought results in *(a)* the decrease of pasture plants; *(b)* the decrease of palatable species in pasture plant; *(c)* reduced water availability; and *(d)* the absence of grass on pasture. Also, drought prevents herders from preparing hay and other supplementary feed for animals and dairy products for themselves. Most importantly, animals are unable to build up the necessary strength (i.e., calories/fat) during the drought period in summer to enable them to cope with the harsh winter and spring windstorms and therefore, they die in large numbers.

Dzud: *Dzud* is purely a Mongolian term. The *dzud* is a very complex and long-lasting phenomenon that is mainly caused by natural elements such as sudden spurts of heavy snowfall, long-lasting or frequent snowfall, extremely low temperatures, or drifting windstorms that reduce or prevent animals from looking for fodder. . Reduced or no access to grazing negatively impacts the food security of livestock and human populations in winter. In other words, the term *dzud* can be described as `livestock famine', and the widespread death of animals because of hunger, freezing and exhaustion. *Dzud* also represents a high risk to humans in the affected areas. The larger the scale and the longer the duration of *dzud*, the higher the mortality of the livestock. There are several forms of *dzud*, depending on the characteristics, contributing factors and causes: *Tsagaan* (white); *khar* (black); *tumer* (iron); *khuiten* (cold); and *khavsarcan* (combined).

Key findings: *dzud*
In the years 1944-45, 1967-68, 1978-79 and 1999-2002, very severe *dzud* occurred during which time an abnormally high number of animals were killed. During the *dzud* in 1944, 32.2 per cent or 8,76 million domestic livestock were killed. Also, 2.6 million (11.9 per cent) livestock died in the 1967-68 *dzud*. Mongolian herders in particular, experienced the worst *dzud* in the last 30 years, in 1999-2000, where they lost more than 25 per cent of the total number of their livestock, which was 10 times higher than the normal year loss (*Mongolian Statistical Yearbook*, 2001). The government funding for a disaster of this magnitude was inadequate to meet the urgent demands of the affected population. Therefore, Mongolia even requested international relief assistance in February 2000. Unfortunately, Mongolia also faced severe *dzud* in following years (2000-2001, and 2001-2002), affecting 50-70 per cent of the total territory. This series of *dzud* caused the death of more than 12 million livestock. Also, more than 12,000 herders' families lost all their animals, while thousands of families had to subsist below the poverty line. Some people who lost all their animals even committed suicide. Such long-lasting (three consecutive years) winter *dzud* followed by summer drought have not occurred in Mongolia in the last 60 years. Mongolia's gross agricultural output in 2003 decreased by 40 per cent compared to that in 1999 and its contribution to the national gross domestic product (GDP) decreased from 38 per cent to 20 per cent (*Mongolian Statistical Yearbook*, 2003). The livestock sector has become more destitute.

Usually, livestock losses occur every year during the winter period; abnormally high livestock deaths occur in the case of a *dzud*. Livestock production is the major source of income of pastoral households. Livestock is the basis of Mongolia's entire rural economy. Apart from providing major nutritional sources, livestock is widely bartered in exchange for all kinds of non-animal products. Hence, the financial capability of households depends directly on the livestock population they keep. In the event of a *dzud*, a large number of herders lose a high percentage of their livestock. The loss of larger animals means that there will be no food and no cash.

Key findings: vulnerability
According to the climate change scenarios projected by HadCM3, the summer in Mongolia is going to be dry and hot while the winter will be milder with more snow. The projected evapotranspiration is much higher than the projected increase in precipitation. Accordingly, soil moisture to rehabilitate plant growth is going to be insufficient. Grasslands are the natural vegetation in Mongolia and its current productivity is low because of insufficient moisture. In the face of climate change due to increased heat and decreased moisture, the aboveground biomass and pasture quality is projected to be even less in 2020-2080.

The area where climatic conditions would occur making it hard for animals to graze is projected to increase from the current 40 per cent to about 70 per cent by 2050, and 80 per cent by 2080.

Projected drought index trends estimated by HadCM3 scenarios are high enough to double the severity of these extremes by 2080.

In case any adaptation measures are not taken, the animal mortality will reach about 12 per cent by 2020, 18-20 per cent by 2050 and 40-60 per cent by 2080.

Adaptation: Mongolia's development is highly dependent on the livestock sector. The study in Mongolia under the project of Assessments of Impacts and Adaptations to Climate Change (AIACC) concluded that the increased extremes resulting from climate change are a significant barrier to livestock sector development and this impediment could grow significantly over the next 80 years. It is, therefore, essential to recognize and maximize the potential linkages between adaptation in the livestock sector and development of the country. With this imperative in understanding, it is need to move from assessment to implementation of adaptation measures with clear natural conservation goals and strong aims for development. Mongolia pastoral livestock production system has three primary components: (a) natural resources, including the physical and biological environment or primary resources and climatic conditions; (b) livestock, including the bio-capacity of processing and converting feeds to products (i.e., milk, meat, fibre) at a rate sufficient to meet animal needs and provide a surplus for human needs; and (c) herders who take management over livestock production. Therefore, the identification of adaptation options focused on first, what should be done for conservation of the natural resources against the changing climate; second, what should be done for strengthening animal bio-capacity to cope with adverse impacts of climate change; and third, what should be done by the herders to ensure better management to enhance the livelihood of Mongolia's rural community.

Impacts of climate change on pasture productivity are gradual but long term, and are often associated with increasing intensity of extreme events, particularly droughts and *dzud*. Therefore, the selected adaptation measures relate to two types of impacts of climate change: *(a)* gradual long-term changes (degradation of quantity and quality of pasture) that focus on changing the trends; and *(b)* changes in the frequency and intensity of extreme events (drought and *dzud*), which mainly focus on increasing the efficiency and effectiveness of current measures.

The demands of the animal to survive and be productive must continually be balanced with the availability of feed and water. Therefore, its vulnerability depends on sustainable pasture management. The latter is aimed at increasing livestock productivity, as well as the high-level maintenance of pastures.

Adaptation measures to reduce the impact of long-term changes on the livestock sector will mainly focus on improved pasture yield including the *revival of traditional pasture management*, which involves the use of one pasture only for the length of one season; *restoration of degraded pasture* including reforestation of flood plains and increased vegetation cover; *expansion/rehabilitation of pasture water supply; development of irrigated pasture; modifying the schedule of grazing* and others. It is also important that the livestock do not exceed the carrying capacity of the pasture

Capacity building outcomes and remaining needs

We have made considerable progress in capacity building in following:

- Data collection and management is improved
- Key and activity data gaps reduced
- National information exchange network established
- A multi-disciplinary team of scientists has created
- Permanent climate-animal observation site established

National communications, science-policy linkages and stakeholder engagement

The ministry most closely involved in climate change and environmental problem is the Ministry of Nature and Environment (MNE). The National Agency for Meteorology, Hydrology and Environment Monitoring (NAMHEM), which is directly under the responsibility of the MNE, is responsible for coordinating the work under the NCCSAP. The Agency has been designated by the government as the lead agency for climate change issues in the country. The Institute of Meteorology and Hydrology (IMH) which is directly under the responsibility of the NAMHEM, conducts climate change research, which includes departments dealing with agricultural climate and water resources management and others. The final, annual, and semi-annual reports and all other outcomes of the project have been submitted to the MNE, HAMHEM and IMH. MNE is now the implementation organization of the second national communication. Thus the results of our project will be the direct input to the second national communication.

Policy implications and future directions

This project has contributed largely in implementing of climate change response activities identified in Mongolia National Action Programme on Climate Change that had been developed in accordance with the UNFCCC, and approved in July 2000 by the Government.

1. Introduction

In Mongolia the risk of climate change and/or extreme climatic events have dramatic impacts on its economy and natural systems. Livestock is among the most vulnerable systems. Resilience and adaptive capacity of traditional networks and land use systems to cope with climate variability/extremes are weakening, while frequency and magnitude of climate variability and land use intensity are in rise, what enhance the vulnerability of the livestock sector of the country. Taking into account the countries specific circumstances of nature and agricultural development, the overall objectives of this project is *Potential Impacts of Climate Change and V&A Assessment for Rangeland and Livestock in Mongolia*. In order to fulfilling the objective our study focused on following three main inter-related studies:

- *Past and future climate change assessment;*
- *Impact and V&A assessment of grassland ecosystem;*
- *Impact and V&A assessment of livestock productivity*

2. Characterization of Current Climate and Scenarios of Future Climate Change

2.1 Activities Conducted

Major activities conducted to characterize current climate were to: *(a)* assess recent and past climate change on the basis of observed data; *(b)* to study the historic climate records on the basis of the relevant literature, including research papers, archive materials, and technical reports; *(c)* changes in extremes; and *(d)* select the most appropriate climate change scenarios to assess the future climate of Mongolia.

2.2 Description of Scientific Methods and Data

Data: The climatological data as monthly mean air temperature in ºC and monthly precipitation in mm for the years 1961-2002 were collected from the 'Clicom data base', which operates in the Institute of Meteorology and Hydrology. For the trend analysis, monthly mean data have been collected from the paper archives dating back to 1940, in order to present the changes that have occurred over for as long a period as possible. Observed daily maximum and minimum air temperature in ºC, as well as the monthly maximum and minimum precipitation in mm was collected for the analysis of extremes. These data are available from 1961 to 2002, as also from the 'Clicom data base'. Trend analysis have been conducted at 60 meteo-stations (Figure 2.1). Extremes indices like Heat Wave Duration, Cold Wave Duration and Max number of consecutive dry and wet days calculated from daily data for 1961-2001 period at 25 meteo-stations (Figure 2.2).

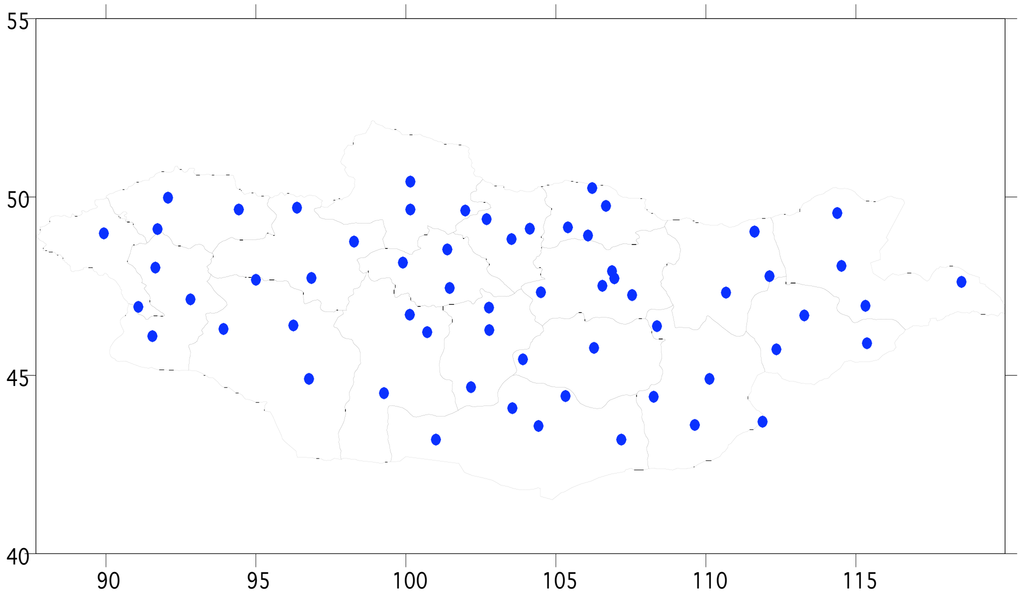


Figure 2.1: Locations of meteo-stations where trend analysis for temperature and precipitation have been conducted

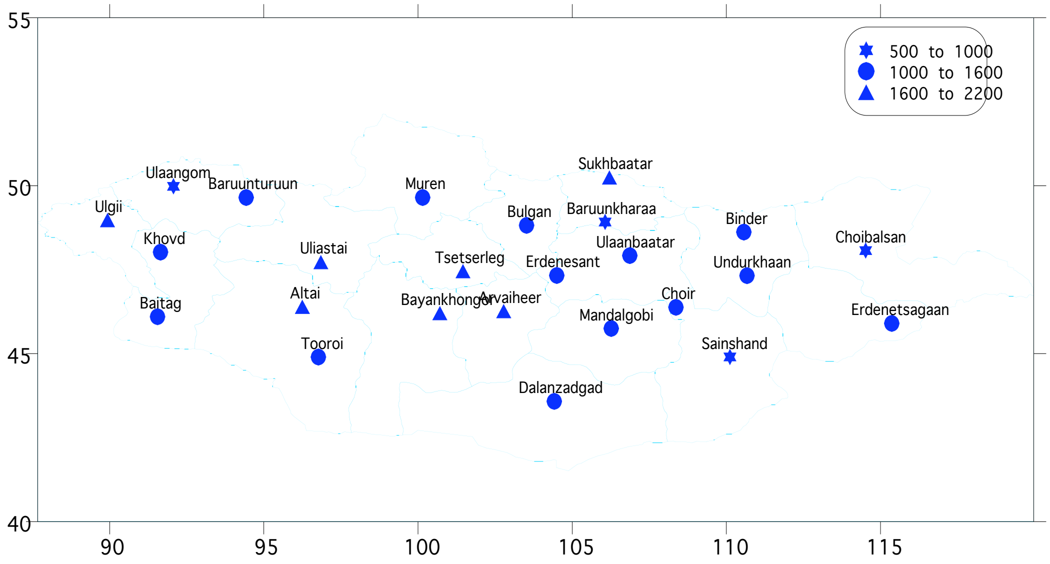


Figure 2.2: Locations of meteo-stations where extremes indices have been calculated

(✶ stations located at 500-1000 m above see level, ✸ stations located at 1000-1600 m above see level, ▲ stations located at 1600-2200 m above see level)

2.2.1 Methodologies

Linear regression (in some cases, second order Polynomial) data have been used to analyze trends of the observed monthly mean data of temperature, precipitation and extremes indices. Since the time series lengths of meteo-stations are different, the normalized anomalies of temperature for the country have been calculated as given in the equation below:

$$D_T = \frac{1}{N}\sum_{i=1}^{N}\frac{\left(T_i - \overline{T}\right)}{\sigma_T}$$

D_T refers to the normalized temperature anomaly; Ti is the observed temperature; is the mean temperature; N is the number of meteo-stations; and □$_T$-refers to standard deviation. $\overline{T}$

The same equation has been used to calculate the normalized precipitation anomalies for the country.

The heat wave duration, cold wave duration , the maximum number of consecutive dry days, and the maximum number of consecutive wet days were analysed to study the changes of climate extremes. For this purpose, the extremes indices have been calculated using the STARDEX extremes indices software (Version 3.0). The methodology of calculating the indices is described in the web site: http://www.cru.uea.ac.uk/project/stardex. The STARDEX extremes indices software was developed from the programme ClimateIndices, originally written at the US National Climatic Data Centre (NCDC) by Tom Peterson and Byron Gleason in 1999. The first version included about 20 climate indices. A further 20 indices were added by Malcolm Haylock from the Australian Bureau of Meteorology in 2000, on a visit to NCDC. Work for STARDEX was then undertaken by Colin Harpham of King's College London, after receiving the code from the European Climate Assessment (ECA). A further dozen indices were added relating to wet and dry spells. The code was tidied and converted to a subroutine by Malcolm Haylock, now with the Climatic Research Unit. Finally, two further indices were added relating to the cold wave duration and no-defrost days.

The STARDEX extremes indices software comprises two elements: a Fortran subroutine extremes_index that calculates all the indices for a single location; and a programme station_index that uses the above subroutine to process station data in a standard input format. All the extremes indices are calculated in a single station. In the file, the indices set the start and end years (min. yr = 1950; max. yr = 2002) for the analysis. Data outside of this period are ignored and do not have to exist over the entire period. There are several user-defined parameters that need to be set in the programme before compiling. The parameters that have been selected in our calculation are:

- start year of base period for normals =1961
- end year of base period for normals =2001
- minimum rain for wet day classification (wd_cutoff) =1.0

The heat wave duration refers to the number of days per period where, in intervals of at least six consecutive days:

$$T_{xij} > T_{xinorm} + 5$$

T_{xij} refers to the daily maximum temperature at day i of period j, and T_{xinorm} is the calendar day mean calculated for a five-day window centred on each calendar day during a specified period.

The cold wave duration is the number of days per period where, in intervals of at least six consecutive days:

$$T_{nij} < T_{n\ inorm} - 5$$

Here, T_{nij} is the daily minimum temperature at day i of period j, and T_{ninorm} is the calendar day mean calculated for a five-day window centred on each calendar day during a specified period.

The maximum number of consecutive dry days is the largest number of consecutive days, where:

$$R_{ij} \leq \text{wd\_cutoff}$$

R_{ij} is the daily precipitation amount for day i of period j, and wd_cutoff is a user-specified variable.

The maximum number of consecutive wet days is the largest number of consecutive days where:

$$R_{ij} > \text{wd\_cutoff}$$

R_{ij} is the daily precipitation amount for day i of period j and wd_cutoff is a user-specified variable.

Climate change scenario: In our study, we used the SRES of the IPCC, which was formally approved in April 2000. SRES was based on a set of four narrative storylines labeled A1, A2, B1, and B2.

The SRES scenario runs were performed with five coupled atmosphere-ocean general circulation models (AOGCMs) such as the HadCM3, ECHAM4, CSIRO Mk2, CGCM3 and GFDL (Table 4.1). The main properties of the models are given in Table 4.1. For all the models, we analyzed the response to the middle forcing scenarios, A2 and B2:

A2- Globally inhomogeneous economic development with a medium-high rise in Greenhouse Gases (GHGs). The underlying theme is high population growth, and less concern with rapid economic development.

B2- Emphasis is on regional economic, social, and environmental sustainability with slower but continuous increase in the world's population and a medium-low rise in GHG.

The applicability of the GCM models to the Mongolian climate was validated by comparing observed temperature and rainfall data over the country between 1961-90, with modeled results for the baseline period. The following equation is used for this analysis:

$$bias = \frac{1}{N}\sum_{n=1}^{N}\left(X_n^o - X_n^m\right)$$

where X_n^o is observed data; and X_n^m is modeled data.

Future climate change was presented for three 30-year time slices, centered on the 2020s, 2050s, and 2080s, each relative to the climatological baseline period 1961-90.

Source	Country	Resolution	Scenarios	Data Type	Baseline Year
Mongolian Climate Data	Mongolia	0.5x0.5	1961-1990	TEM. and PRE.	1961-1990
CSIRO Mk2	Australia	5.6x3.2	2010-2099	TEM. and PRE.	1961-1990
CGCM3	Canada	3. 8x3.8	2010-2099	TEM. and PRE.	1961-1990
ECHAM4	Germany	2.8x2.8	2010-2099	TEM. and PRE.	1961-1990
GFDL	USA	2.2x3.8	2010-2099	TEM. and PRE.	1961-1990
HadCM3	United Kingdom	2.5x3.8	2010-2099	TEM. and PRE.	1961-1990

TEM.-temperature; PRE.-precipitation.

Table 2.1: The CGM's scenarios used for the current study

2.3 Results

2.3.1. Overview of the Mongolian climate

The Mongolian climate is characterized by a long-lasting cold winter, dry and hot summer, low precipitation, high temperature fluctuations (day and night, summer and winter) and a relatively high number of sunny days (on an average, 260 days) per year. Accordingly, there is not only four sharply distinct seasons but also, the months in each season are quite different. The annual average air temperature for Mongolia is 0.7°C. It 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.

January is coldest month, with average temperatures of –15^{0}C to –35^{0}C. In particular, the temperature ranges between -30 to -34^{0}C in the valleys of the Altai, Khangai, Khuvsgul and Khentii mountains; -25 to -30^{0}C in the high mountainous areas; -20 to -25^{0}C in the steppe; and –15 to -20^{0}C in the Gobi Desert. The absolute minimum temperature of -56^{0}C was recorded at the Uvs lake depression on 31 December 1972.

July is the warmest month. The average air temperature in July is lower than 15^{0}C in the Altai, Khangai, Khuvsgul and Khentii mountainous area; 15-20^{0}C in the valleys of the mountainous areas; and 20-25^{0}C in the southern part of the eastern steppe and the Gobi Desert. The absolute maximum temperature is 28.5-44.0^{0}C, depending on the region. A temperature of +44^{0}C was observed at Khongor *soum* of Darkhan-Uul *aimag* on 24 July 1999.

Systematic meteorological observations began in the early 1940s. There is not much recorded or published information on the historical climate of Mongolia. Only some spot points on short period extremes have been recorded in a few old books.

There have been quite a few efforts to reconstruct the historical climate of Mongolia on the base of a tree-ring analysis (Lobelius, et al., 1993; Gordon et al., 1996; Jacoby et al., 1996, 1999; Enkbat and Mijiddorj 1996; Namhai and Mijiddorj, 1993). The Mongolian-American Tree-Ring Project (MATRIP) has reconstructed the longest duration. In this study, the Mongolian proxy record for temperature extends back over 450 years and has sampled the three main species such as Siberian pine (*Pinus sibiricaDu Tour*), Scots pine (*P.sylvestris L.),* and Siberian larch (*Larix sibiricaLedebour*). One of the sampling sites was the Tarvagtain mountain area that is located in western Mongolia. The Tarvagatay tree-ring-width index series matches the large-scale reconstructed and recorded temperatures for the Northern Hemisphere and the Arctic. Figure 4.3 illustrates the plot of the Northern Hemisphere temperature reconstruction with the Mongolian (Tarvagtain mountain) series (Jacoby et al., 1996) which has clearly seen an increased temperature over the past 100 years.

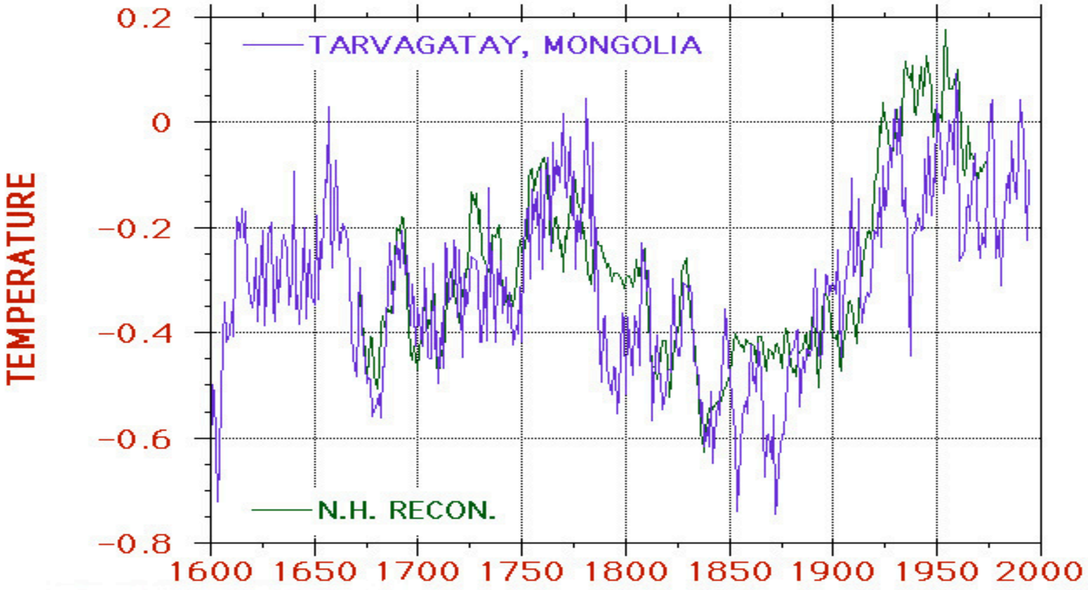
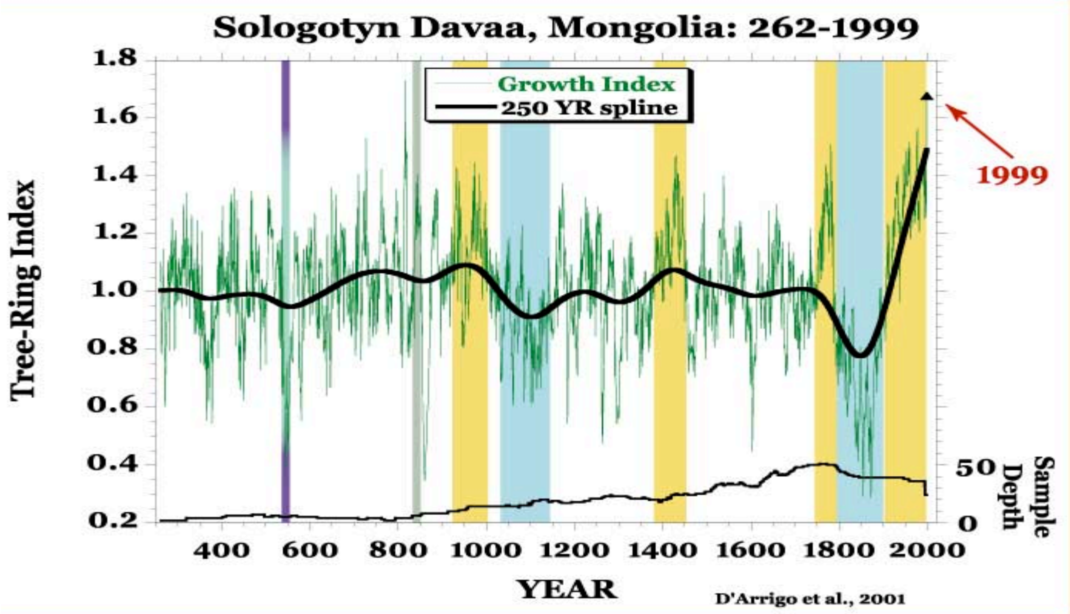


Figure 2.3: The Northern Hemisphere temperature anomaly reconstruction with the Mongolian series.

(– is Northern Hemisphere temperature anomaly, – Mongolian temperature anomaly)

The longest reconstruction was made on the sample that was taken from Sologotyn Davaa (which is located in north-central Mongolia) that is shown in Figure 4.4. This (Pederson et al., 2001) record reflects the new inference of temperature for the past 1,700 years and shows that the 20th century is the warmest century of the last 1,000 years in Mongolia.


Sologotyn Davaa, Mongolia: 262-1999

D'Arrigo et al., 2001

Figure 2.4: Tree-Ring Index for Mongolia (Source: D'Arrigo et al., 2001)

The yellow bars represent periods of above average warmth.

The blue bars represent periods of above average cool temperatures.

The country is semi-arid to arid. Precipitation varies both in time and space. The annual mean precipitation is 300-400 mm in the Khangai, Khentein and Khuvsgul mountainous region, 150-250 mm in the steppe, 100-150 mm in the steppe-desert and 50-100 mm in the Gobi Desert. About 85 per cent of the total precipitation amount falls from April to September, about 50-60 per cent of which falls in July and August. The maximum precipitation (138 mm/day) recorded since 1940 occurred on 5 August 1956 at Dalanzadgad, and 121 mm/day on 11 July 1976 at Sainshand. Dalanzadgad and Sainshand are the centre of the Gobian *aimags*. Although annual precipitation is low, its intensity is high. For example, the locally intense rainstorm of 40-65 mm may typically fall in a single hour.

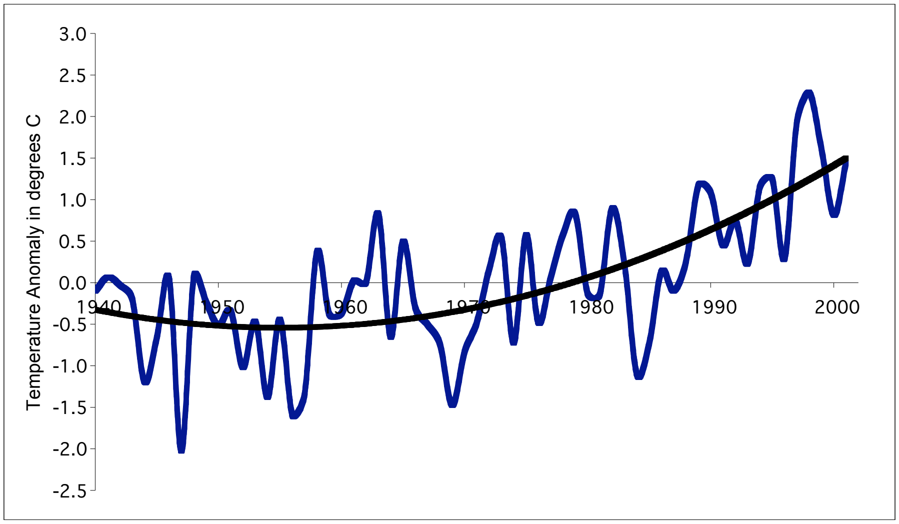
Clear skies in winter due to high anti-cyclone dominance over Mongolia results in less snowfall. Snow contributes less than 20 per cent to the total annual precipitation. The first snowfall occurs in mid October to early November. Usually, the first snowfall is short-lived and disappears due to late autumn warming and wind. Sometimes, late first snowfalls persists as snow cover in mountainous regions.

2.3.2. Observed changes in climate

2.3.2.1 Trends in temperature

Observations show that the Mongolian climate has already changed significantly. The normalized anomalies of annual mean temperatures for Mongolia are illustrated in Figure 2.5. Second order Polynomial application to the entire record shows an average of 1.8^{0}C* increase in air temperature for the last 60 years, with clear warming from the beginning of the 1970s and intensified warming from the end of the 1980s.

Temperature rise has been most pronounced in winter, with a mean temperature increase of 3.6^{0}C, while spring, autumn, and summer mean temperatures have risen by 1.8^{0}C, 1.3 ^{0}C, and 0.5°C respectively (Figure 2.5).



The blue line is Normalized anomalies of air temperature.

The black line is second order Polynomial

Figure 2.5: Temperature trend for the period 1940-2001

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* *For the period 1961-90 (climate change base year) the annual mean air temperature has risen by 1.38^{0}C.*

Spatially, air temperature is much higher in mountainous regions than the steppe and the Gobi Desert. Figures 2.6 and 2.7 show the summer and winter temperatures at Knovd (representation of mountainous region) and Dalanzadgad (representation of the Gobi) stations to illustrate the spatial differences of temperature changes. Linear regression application fitted in the trend at Khovd show a 0.88^{0}C and 4.04^{0}C increase in summer and winter air temperatures, at significant levels of 95per cent and 99 per cent respectively. Linear regression application fitted in the trend at Dalanzadgad shows a 0.49^{0}C increase in the summer temperature and 0.81^{0}C in the winter temperature. Both trends are not statistically significant.

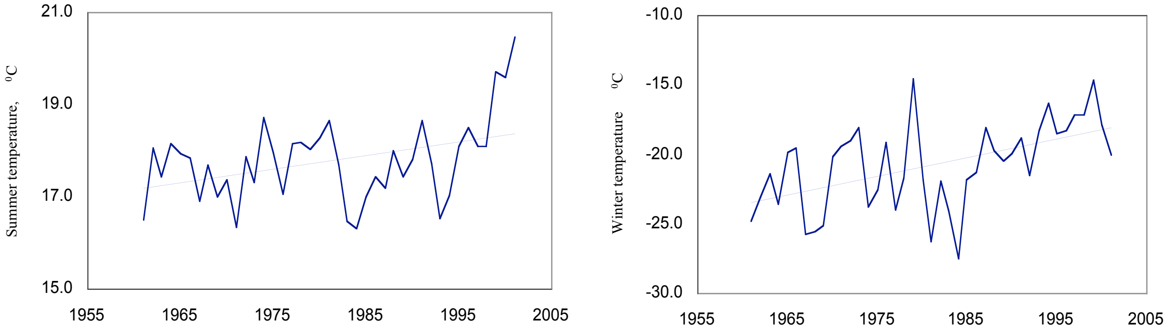


Figure 2.6: Summer (Linear regression: slope=0.029 ^{0}C /year; R^2=0.16, significance level: 95%) and winter (Linear regression: slope=0.135 ^{0}C/year; R^2=0.27, significance level: 99%) air temperature trends at Khovd.

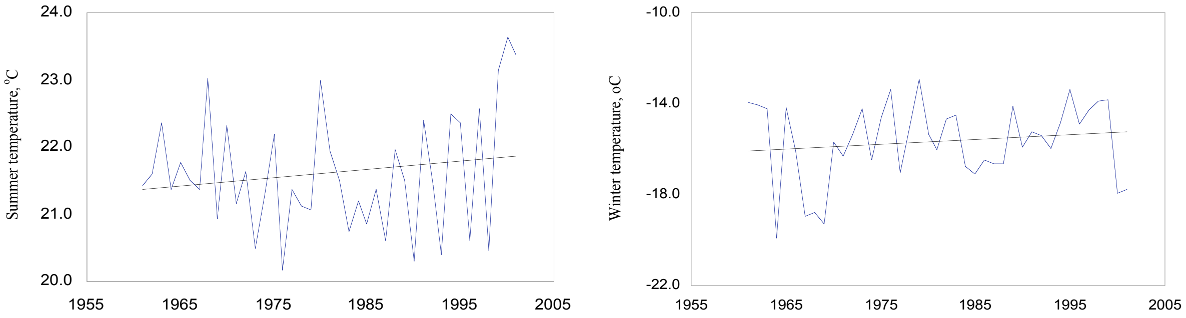


Figure 2.7: Summer (Linear regression: slope=0.012 ^{0}C /year; R^2=0.03) and winter (Linear regression: slope=0.02 ^{0}C / year; R^2=0.02) air temperature trends at Dalansadgad.

2.3.2.2 Trends in extreme temperatures

The average air temperature in the warmest month of July is 15-25^{0}C. So, when the air temperature reaches 25-30^{0}C it is considered a hot day in Mongolia. As shown in Figure 5, there were 30 cases when air temperature anomaly was positive during 1940-2001 but 23 of these cases occurred after 1970. Similarly, all eight cases that exceeded a 1°C anomaly were observed after 1990, including three consecutive years in 1997, 1998, and 1999. The year 1998 was the warmest year ever measured instrumentally in Mongolia too. Accordingly, the number and duration of hot days are increasing.

The trends of the heat wave duration are statistically significant. According to the linear regression, it increased by 8-18 days, depending on the geography. A greater increase (15-18 days) was observed in the

Khan-Khokhii mountainous region of the Great Lakes Basin (Baruunturuun in Figure 2.8) and in the western part of the Khangain mountains (Tosontsengel in Figure 9). In the region of the Mongol-Altai and Khentii mountains, the heat wave duration increased by about 10-12 days (Ulgii, Baruunkharaa and Ulaanbaatar in Figure 2.8) and it is 6-8 days in the Gobi Desert region (Dalanzadgad in Figure 2.8).

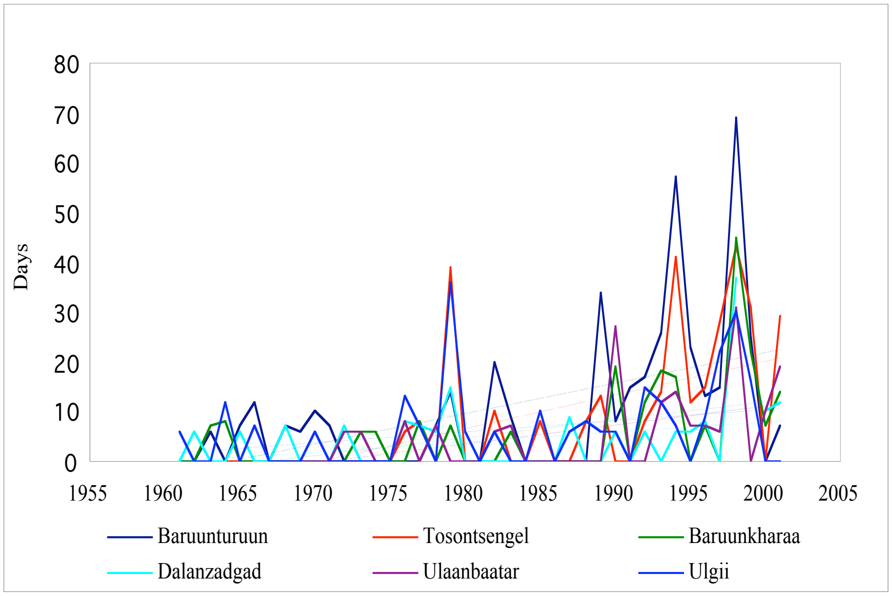


Figure 2.8: Trends in heat wave duration (solid lines) and linier regression (dashed lines) at the representative meteo-stations at Baruunturuun (Linear regression: slope=0.61day/year; R^2= 0.24, significance level=99%), at Tosontsengel (Linear regression: slope=0.68 day/year; R^2= 0.23, significance level=99.9%), at Batunnkharaa (Linear regression: slope=0.33 day/year; R^2= 0.12, significance level=99%), at Dalanzadgad (Linear regression: slope=0.20 day/year; R^2= 0.13, significance level=95%), at Ulaanbaatar (Linear regression: slope=0.38 day/year; R^2= 0.21, significance level=99%), at Ulgii (Linear regression: slope=0.22 day/year; R^2= 0.10, significance level=95%), of different climatic zones.

In 1998, which was warmest year of the last century, the heat wave duration reached 70 days in the high mountains and 30 days in the Gobi Desert - a highly anomalous event that occurred in the last 40 years. The increased air temperature accompanied with the heat wave duration perhaps led to Mongolia experiencing four consequent years of (1999-2002) drought.

Results from the cold wave duration calculations show clear decreasing trends. On an average, it has shortened by 13 days. A greater decline up to 20 days has been observed in the Khangain mountainous (Tosontsengel) region and Uvs lake basin (Baruunturuun), while it was lower in the Mongol-Altain and Khentii mountainous (Ulgii, Ulaanbaatar) region and in the Gobi Desert (Dalansadgad) (Figure 2.9).

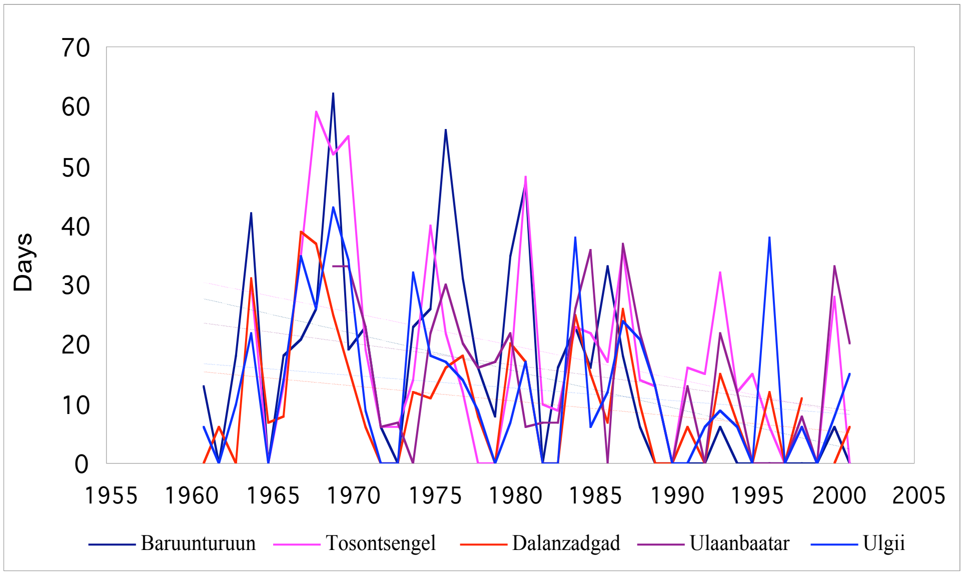


Figure 2.9: Trends in Cold wave duration (solid lines) and linier regression (dashed lines) at the representative meteostations at Baruunturuun (Linear regression: slope=-0.62day/year; R^2= 0.21, significance level=99%), at Tosontsengel (Linear regression: slope=-0.56 day/year; R^2= 0.16, significance level=99.0%), at Dalanzadgad (Linear regression: slope=-0.26 day/year; R^2= 0.12, significance level=95%), at Ulaanbaatar (Linear regression: slope=-0.38 day/year; R^2= 0.09 significance level=95%), at Ulgii (Linear regression: slope=-0.2 day/year; R^2= 0.10, significance level=95%), of different climatic zones

2.3.2.3 Trends in precipitation

Second order Polynomial fitted to the normalized anomalies of annual mean precipitation for the 1940-2001 period show a slight downward trend for the country base (Figure 2.10). Seasonally, winter and spring precipitation has decreased slightly, while there is nochanges in summer and autumn precipitation. All these trends are not statistically significant.

The changes of annual precipitation have a very localized character i.e., decreasing at one site and increasing at a site nearby. That is one of the specific traits of precipitation distribution in the arid areas of Mongolia. Precipitation changes at a local level have certainly had a more practical implication than the averaged precipitation for the country. 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 of the Orkhon, and Selenge rivers basin.

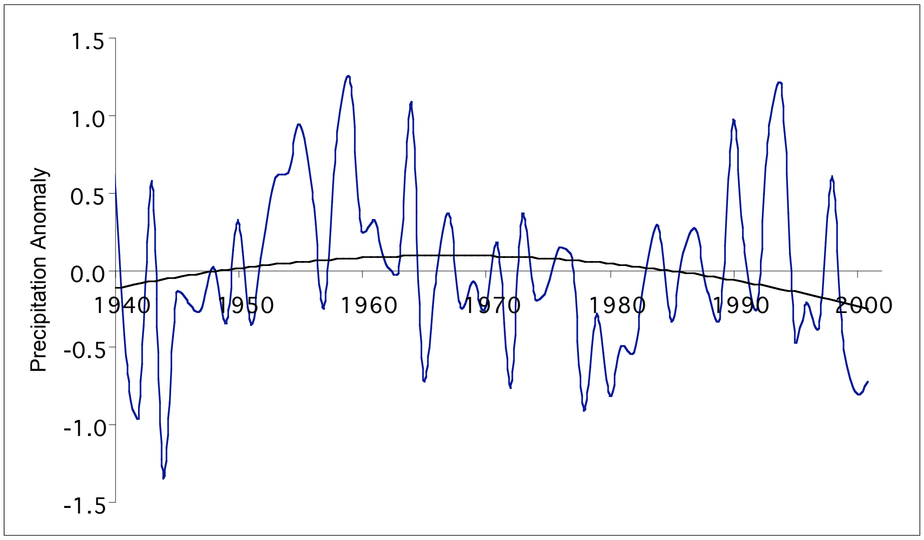


Figure 2.10: Normalized anomalies of annual mean precipitation for 1940-2001 period.

The blue line is Normalized anomalies of air temperature.
The black line is second order Polynomial

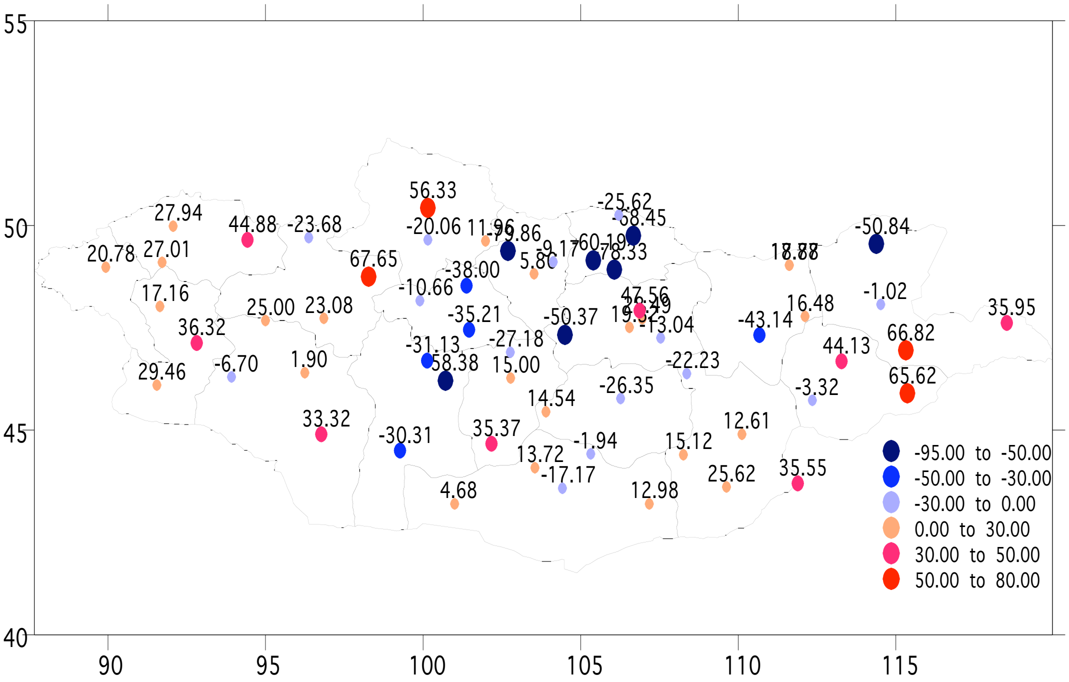


Figure 2.11: Annual precipitation changes in the last 30 years, mm

Precipitation increased by 2-60 mm in the Mongol Altai, Uvs lakes basin and the western slope of the Khangai mountains, and by 30-70 mm in the southern part of the eastern steppe region. The magnitude of alteration changes in precipitation regardless of increase or decrease is 5-25 per cent. Trend, significant at the level of 90 per cent, were found where changes are more than 40 mm, or more than 20 per cent of the annual mean value. Figure 2.11 shows the spatial variations of precipitation. As can be seen from this figure, precipitation has increased by 65 mm, or more than 20 per cent at the Erdenetsagaan station, located in the south-eastern part of the country, and decreased precipitation by 78 mm at the Baruunkharaa station that is located in the northern part of the country.

There was no statistically significant change in the maximum number of average consecutive dry days. The maximum number of consecutive dry days increased slightly in central Mongolia, where the annual mean precipitation decreased. It decreased in south-eastern Mongolia, where annual mean precipitation increased. The maximum number of consecutive wet days remained unchanged in most of the area (Figure 2.12).

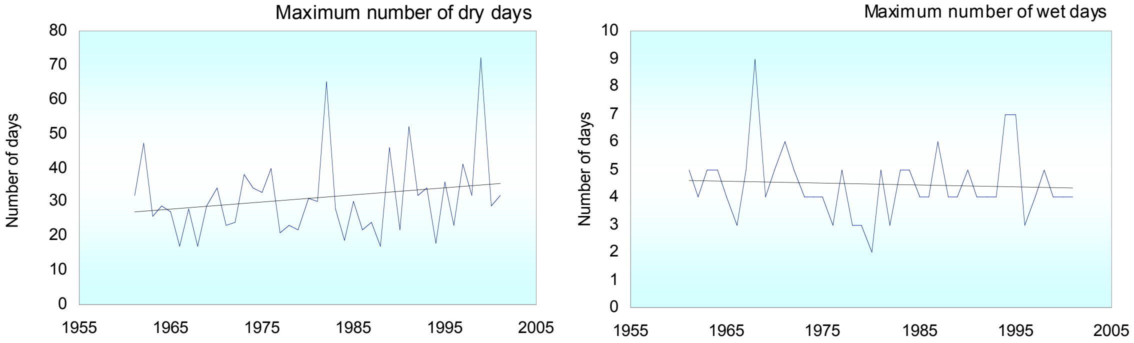


Figure 2.12: Changes in maximum number of consecutive dry and wet days at Baruunkharaa

2.3.2.4 Construction of climate change scenario

Due to the varied horizontal grid resolution among models, the data interpolated to $2.5x2.5^0$ grids for the construction of the scenarios of future climate change for Mongolia. The accuracy of the HadCM3, ECHAM3, and CSIRO Mk2, CGCM3 and GFDL models assessed, compared observed temperature and rainfall data over the country for 1961-90, with modeled results for the baseline period (Table 2.2). Observed and simulated annual mean temperature by HadCM3 and the standard errors that interpolated to $2.5x2.5^0$ grids are shown in Figures 2.13, 2.14 and 2.15. Projections of future changes in air temperature and precipitation were simulated at each $2.5x2.5^0$ grids and averaged over seasons and regions.

No	Models	Annual mean temperature		Error	Standard deviation	Variation
		Observed	Modelled			
1.	HadCM3	0.66	0.44	1.13	1.32	1.75
2.	GFDL	0.66	2.35	-1.63	2.24	5.05
3.	CGCM3	0.66	-7.06	-7.63	4.44	19.74
4.	CSIRO-Mk2b	0.66	-0.86	1.54	3.27	10.75
5.	ECHAM4	0.66	0.85	-0.15	1.89	3.59

Table 2. 2: Observed and simulated annual mean temperature for Mongolia

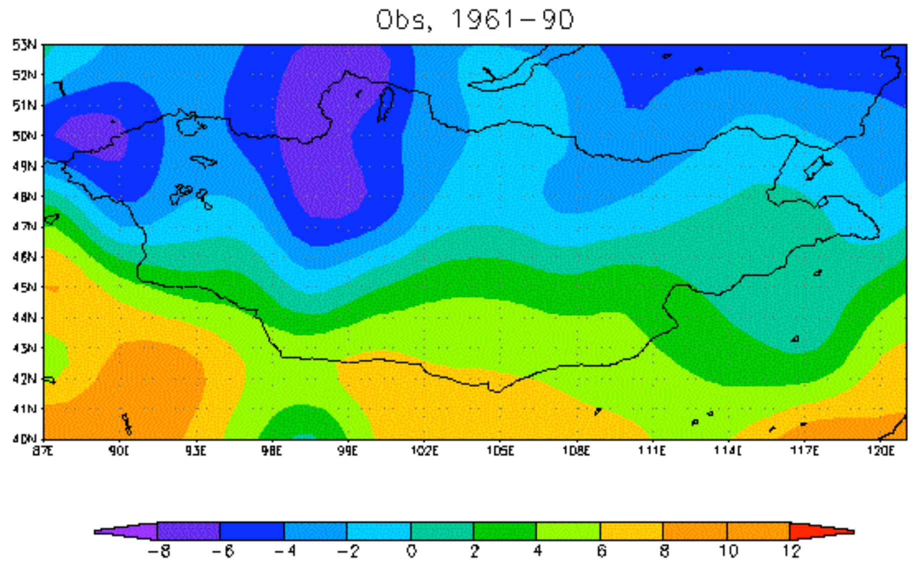


Figure 2.13: Observed temperature interpolated to 2.5x2.50 grids

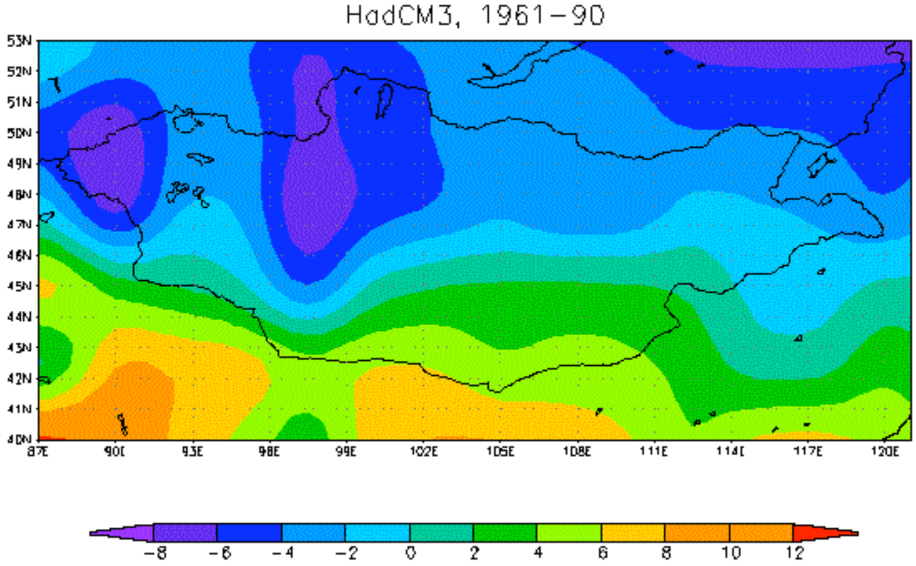


Figure 2.14: Calculated temperature at 2.5x2.5^0 grids by HadCM3

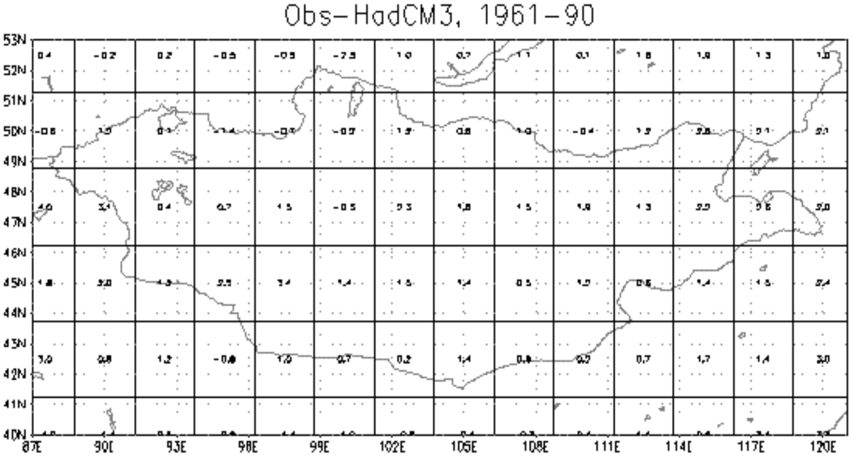


Figure 2.15: Standard errors between observed and calculated air temperature at 2.5x2.5^0 grids

In most cases, simulation for temperature was much more successful than those for precipitation.

As can be seen from Table 4.2, among the models, the HadCM3 gave the closest results to observed data. However, all the models were used to project climate change over Mongolia in the 21st century, using SRES.

2.3.2.5 Future climate change

The projected average changes in winter and summer surface temperature and percentage in precipitation by different models are summarized in Table 2.3 and illustrated graphically in Figures 2.16 and 2.17. The climate change projections obtained with five models differed substantially from one another. However, temperature increases in all seasons and precipitation increases in most cases, though these changes are very small. Among the models, ECHAM suggests a higher increase in both temperature and precipitation in winter compared to other models, while CGCM3 gave a relatively higher increase in the summer temperature.

Model	A2 - medium-high emissions						B2 – medium-low emissions					
	2020		2050		2080		2020		2050		2080	
	T,^{0}C	R,%	T,^{0}C	R,%	T,^{0}C	R,%	T,^{0}C	R,%	T,^{0}C	R,%	T,^{0}C	R,%
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
GFDL	0.9	-1.9	2.4	7.5	4.0	19.2	1.0	1.9	2.4	6.6	2.8	12.8
CGCM3	2.0	3.9	3.8	5.7	5.9	11.3	1.9	-2.8	2.8	1.8	4.2	6.9
Summer												
HadCM3	2.0	-2.5	3.5	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
GFDL	1.4	-2.5	2.8	-2.4	4.2	3.3	1.5	0.5	2.5	2.3	3.2	5.5
CGCM3	2.8	2.2	4.6	6.9	6.9	7.2	3.2	6.1	3.7	5.4	4.8	10.9

Table 2.3: Average climate change projections under SRES A2 and B2 scenarios in Mongolia relative to baseline 1961-90

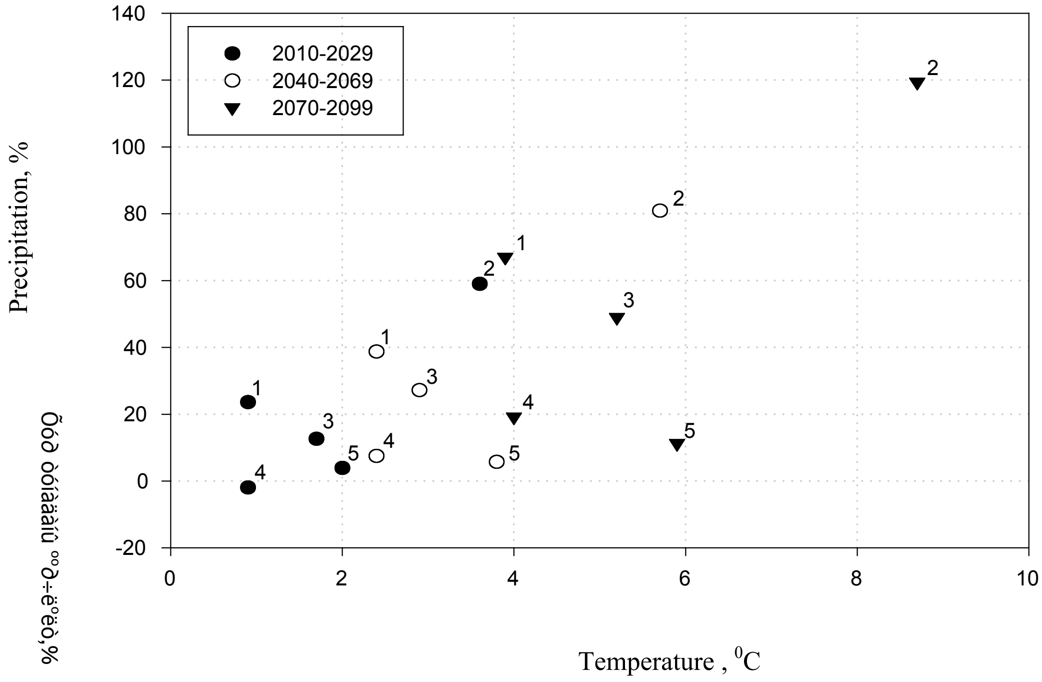


Figure 2.16: Projected changes in winter temperature and precipitation

(1-HadCM3; 2-ECHAM4; 3-CSIRO-Mkb2, 4-GFDL, 5-CGCM3)

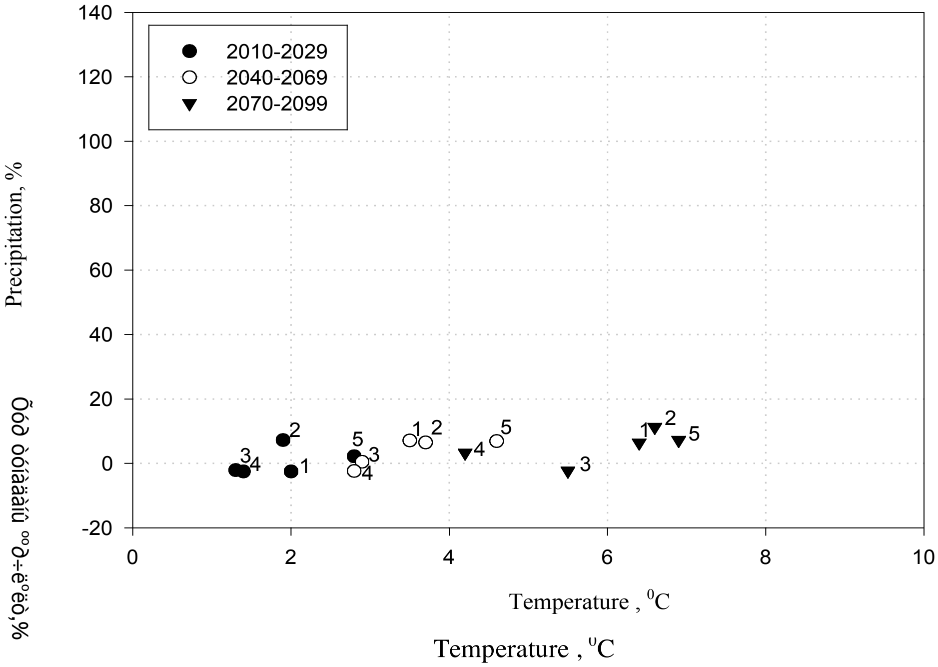


Figure 2.17: Projected changes in winter temperature and precipitation

(1-HadCM3; 2-ECHAM4; 3-CSIRO-Mkb2, 4-GFDL, 5-CGCM3)

In general, an intensive rise of air temperature is expected in the central and western regions of Mongolia, while a steep decline in precipitation is likely to appear in the western region, and an increase is expected in the eastern region of the country.

2.4 Conclusions

The Mongolia climate is getting warmer and slightly dry. Warming is more pronounced in the high mountainous area and its valleys, and less in the Gobi Desert. Precipitation tends to decrease slightly. The objective of the study is the potential impacts of climate change and vulnerability, and adaptation assessment for the grassland ecosystem and livestock sector in Mongolia. In Mongolia, the risk of climate change and/or extreme climatic events could have dramatic impacts on its economy and natural systems. Agriculture, livestock, and grassland ecosystem are among the most vulnerable systems.

Increased air temperature, heat wave duration, and unchanged precipitation are likely to have resulted in drought during summer. Traditionally, animals build up the necessary weight, strength and fat reserves during summer to enable them to cope with the harsh winter and spring. Usually, there is a drought in some areas in Mongolia every year but when the duration and affected area increase, it leads to greater impact on livelihood. Water and forage are the most important resources for livestock. The most direct impact on pastoralists' livelihoods is the drying up of water sources and declining forage resources for livestock. The decline in their availability greatly affects livestock conditions, milk production and ultimately herders' livelihood security, since their lives depend on the livestock and livestock products. Mongolia experienced the worst droughts in the 1999, 2000, 2001, 2002 summers, which consequently affected 50-70 per cent of the Mongolian territory. About 3,000 water sources, including 680 rivers and 760 lakes dried up during these severe droughts (Davaa, 2004).

Initially, it appears herders could benefit from milder winters due to increased winter temperature, shortened cold wave duration and less snow. However, some unexpected and unfavourable phenomenon like sudden rapid warming in winter, unusually high snowfall, surge snow and wind storms have taken place in the last decade in Mongolia. Short, rapid (2-5 days) warming in winter leads to melting snow cover. Melted water does not infiltrate but creates ice sheets on the ground surface, since the ground is still frozen. This phenomenon creates difficulties in the grazing of animals on pasture, limiting their ability to forage for food.

Soil moisture usually does not inhibit vegetation growth in spring. Thus, spring precipitation is especially important for growing pasture grass. Earlier, the melting of the snow cover and decreased spring precipitation most probably resulted in the decrease of the April-May pasture biomass by 20-40 per cent, in the largest grazing areas of the steppe and the forest-steppe.

In our study, we used the SRES of the IPCC scenario runs, performed with five coupled GCMs, such as the HadCM3, ECHAM3, and CSIRO Mk2. For all the models, we analyzed the response to the middle forcing scenarios A2 and B2. Future climate change was presented for three 30-year time slices, centered 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 varies from 0.9^0C to 8.7^0C, while the summer temperature increase varies from 1.3^0C to 8.6^0C.
- Winter precipitation will increase by between 12.6 per cent and 119.4 per cent when the summer rainfall varies from 2.5 per cent decrease to 11.3 per cent increase.
- In general, summer in Mongolia is projected to be dry and hot, while winter will be milder with more snowfall.

3. Socio-Economic Futures

We did not conduct detailed Socio-Economic assessment because of lack of available data and methodologies.

3.1 Activities Conducted

We could only review current Socio-Economic situation to support current vulnerability and adaptation assessment.

3.2 Description of Scientific Methods and Data

Data from Mongolian statistical year book was the main source for the data and simple statistical analysis like to average for the country as a whole and region performed.

There has been developed integrated assessment index of economic and social development taking account GDP per capita, education level, average living age, unemployment, energy supply, transportation level, human development index etc.

Case study on drought with detailed socio-economic survey have been conducted. More than 700 herders' households from 16 *aimags* (Mongolia administratively divided into 21 *aimags*) participated in discussion, interview and questionnaire. The purpose of this case study was to determine the adverse effects of climate extremes on livestock, herders' household incomes, fallback assets and hence, on rural poverty levels and to disaggregate the complex web of causes, which exacerbated the climate hazards. Five *aimags* have been selected for detailed case study.

3.3 Results

Recently, Mongolia is divided into five regions for the purpose of the economic development: Western, Khangai, Central, Eastern and Ulaanbaatar.

Name of regions	Territory /thousand square km/	Population
Western region	415.3	421,608
Khangai region	384.3	545,654
Central region	473.6	443,669
Eastern region	286.2	202,485
Ulaanbaatar region	4.7	755,407
Total	1564.1	

Table 3.1: Characteristics of the regions

3.3.1 Economic development

The regions differ by their economic development. For instance, GDP per capita in the western region is 2.5 times lower than in Ulaanbaatar city (Figure 3.1).

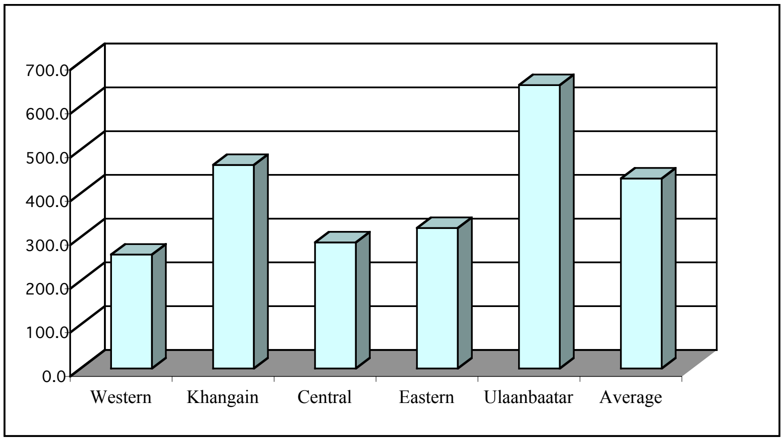


Figure 3.1: GDP per capita for the regions

Unenployment level is also different in different parts of the country. The eastern region has the highest unemployment level and Ulaanbaatar city has the lowest unemployment level (Figure 3.2).

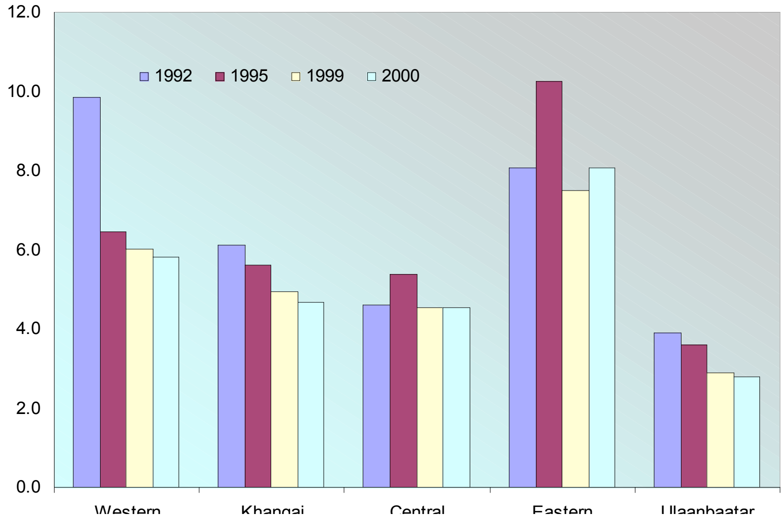


Figure 3.2: Unemployment level for the regions

According to the economic and social development index the economic and social development level of the regions greatly differ (Table 3.2). The Western region turned out to be the least developed, followed by the Eastern, Khangai and Central region. Ulaanbaatar city's development index was almost three times higher than the Central region, indicating a big difference in development level between Ulaanbaatar and rural areas. Thus, economic and social development of the rural area, especially the least developed regions would be key issue to increase their adaptive capacity to climate change.

Regions	Western	Eastern	Khangai	Central	Ulaanbaatar
Assessment Index	1.0	1.5	2.4	2.8	7.5

Table 3.2: Integrated assessment index of development levels for the regions

The study on living standarts (1998) showed that there were 850,000 poor people in the country, of which 26% was living in Ulaanbaatar, 31% - in aimag centers and other cities, and 43% - in rural areas. Poverty level is related to unemployment level. There are also big differences in health services and education opportunities between the rural areas and Ulaanbaatar city.

The difference in economic and social development between urban and rural areas is causing a "big migrarion" from rural areas into Ulaanbaatar and central region. For example, 3615 people (641 households) moved from Uvs aimag to the Central region. The consequences of this migration are:

- Livestock denisty is increasing near Ulaanbaatar and central region, causing ecosystem degradation due to overgrazing;
- Human density in rural areas is decreasing and "brain drain" is occuring.

3.3.2 Food supply and vulnerability of the regions

Mongolia produces 257,700 ton meat (7.6 million of livestock), 3% of which are camel, 13% - horse, 17% - goat meat, 35% - beef and 32% - mutton. The Western region produces 28.7%, the Khangai region – 38.1%, the Central region – 20.3% and the Eastern region – 12.9%. Almost 8% of the produced meat goes for the export and the rest is used for the internal supply.

Mongolia produces 377.3 million liter milk, 2.6% of which are camel, 10% - horse, 2.5% - goat, 84.4% - cow and 0.5% - sheep milk. The Western region produces 19.9%, the Khangai region – 42.3%, the Central region – 18.4% and the Eastern region – 19.4%.

> *One person uses 10 kg of meat and meat products, 10.9 kg of milk and milk products, 9 kg of flour and flour products and 2.8% of vegetable a month in our country. We export meat and meat products, but import flour and flour products, vegetable and little bit of milk and milk products although we produce enough milk.*

Meat supply level in the country is 66.5% (Table 3.3). Ulaanbaatar city has the lowest level of meat and meat products supply compared to rural areas. Flour supply level is uneven cross the regions. The Central region has the best supply level in flour (Table 3.4). Mongolia was able to meet fully demands in flour before 1990, however the agriculture supported by subsidues of the Soviet Union started to fail during the transition period. Now we can't meet the population's demand in flour supply even importing it.

Regions	Demand, thousand tons	Supply, thousand tons				Supply level, %
		National	Export	Import	Total	
Western	50.32	41.75	-	-	41.75	82.9
Khangai	66.51	56.30	-	0.10	56.40	84.8
Central	53.45	51.79	5.0	0.04	46.83	87.6
Eastern	24.18	24.40	3.0	-	21.40	88.5
Ulaanbaatar	94.38	67.16	9.0	0.15	58.31	61.7
Total	288.84	241.4	17.0	0.29	224.69	77.8

Table 3.3: Demand and supply of meat and meat products for the population

Regions	Demand, thousand tons	Supply, thousand tons				Supply level, %
		National	Export	Import	Total	
Western	45.36	1.25	-	18.22	19.47	42.9
Khangai	59.84	13.6	-	23.87	37.94	63.4
Central	48.08	25.9	-	19.08	44.98	93.5
Eastern	21.76	4.15	-	8.79	12.94	59.4
Ulaanbaatar	84.94	23.1	-	34.84	57.94	68.2
Total	259.98	68.0	-	104.8	172.8	66.5

Table 3.4: Demand and supply of flour and flour products for the population

3.3.3 Case study

14 *soums* of 5 *aimags* were selected for case study:

- 2 *soums* of Central *aimag*: Altanbulag, Bayan-O'njuul
- 3 *soums* of Dundgobi *aimag*: Erdenedalai, Gurvansaikhan, O'lziit
- 3 *soums* of Bulgan *aimag*: Bulgan Bugat, Teshig
- 3 *soums* of Khentii *aimag*: Dadal, Bayan-Ovoo, O'mnodelger
- 3 *soums* of Zavkhan *aimag*: Tosontsengel, Do'rvoljin, Aldarkhaan

Sample size is as 6% of the herders' households of the surveyed *soums*. These *aimags*, most severely affected by consecutive harsh winter and droughts of years 1999-2001.

Key Findings of Questionnaire Survey:

54% of out of surveyed person considered that the herders' livelihood worsened since 1998. 92% responders noted climatic hazards is only cause of worsening the their livelihood.

The 77-92% emphasized that frequent occurrence of *dzud*, droughts, heavy snowfall decreased pasture yield are the result of climatic change in their living environment.

53% of them had lost more than the half of their animals, 17% of which had lost all animals due to drought and *dzud* disasters.

The estimated annual animal losses range from 90 to 3600 US dollar.

Herders' income not evenly distributed throughout year depending seasonal variation of anima products.

33% of surveyed households are living with monthly income less than US$30 and 37% with annual income less than US$500.

89% of herders are able to have health service when they are sick. 65% of those who was not able to have health service because of no money.

18% surveyed households could not send children to school during the last 5 years.

Certain negative consequences such as mental stress (66%), destroyed health (26%), be disabled (1.3%), running up a huge debt (18%), school children dropouts (17%), shortage of food (10%), became an alcoholic, family break-up, involving in robbery and crime, even suidcide have been followed by the *dzud* of 1999-2000.

3.4 Conclusions

The market economy newly introduced in Mongolia in the last decade also affects the herders' livelihoods. Mongolia has been exercising a central market–capital city Ulaanbaatar-oriented transition, while the herders (one-third of the population) are living sparsely distributed over a vast territory. Weak developed infrastructure (road, communication, electricity, etc.) increases costs for social services and access to market, while increased needs caused by the climatic hazards to migrate with the animals far away from the settled area seeking better pasture, tends to increase herders' remoteness. Thus, all these complex development factors are serious and are threatening the sustainability of the entire country.

4. Impacts and Vulnerability

4.1 Activities Conducted

The climate change impact assessment included snow cover, water resources, permafrost, grasslands and the livestock sector.

The major activities conducted to investigate the impact of climate change in each sector were

- assess current impacts of climate change;
- select appropriate methodologies;
- develop new methodologies when required;
- select the climate change scenario; and
- assess future impacts of climate change

4.2 Description of Scientific Methods and Data

4.2.1 Data

The main source of climatological data was the Clicom data base, which operates in the Institute of Meteorology and Hydrology. This data base provides monthly as well as daily observed data of air temperature in °C (average, maximum, and minimum); precipitation in mm; wind velocity in m/s; sunshine duration in hours; humidity in mm; and soil moisture in mm, for the period 1960-2003. Data that were not available in the Clicom data base, like data for the snow cover, water resources and animals, were collected from other related sources.

Also we used different scale weather maps, geo-stationary and NOAA satellite cloud, dust and vegetation index imagery, 1:1,000, 000 scale thematic maps of natural zones, and pasture vegetation. Attributes of these thematic maps were verified, edited and re-classified.

4.2.2 Methodologies

Linear regression methods have been used to analyze trends of the observed changes. The study sites and methodologies used for impact assessment varied, depending on the sector. Therefore, a description of the methodologies will be discussed under each sector separately.

4.2.2.1 Climate change scenario

For the future impact assessment we used two types of scenarios:

Sensitivity analysis: Hypothetical (i.e., usually put in the framework of the sensitivity analysis by applying an ensemble of potential climates), or uniform changes in temperature (ΔT) and precipitation (%P) are used to test the sensitivity of various sectors to climate change. Uniform scenario means annual changes in temperature and precipitation and in their combinations, with the expectation that they cover a range of plausible future climates. In our study, these changes have been taken as +1,2,3°C and 5°C increase in temperature and 10 and 20 per cent in precipitation.

This scenario is good in that it is able to generate a family of tables that will provide an insight into the sensitivity of the given sectors to climate variations. The sensitivity analysis was used in the water resources, pasture, and animal husbandry sectors only.

Special Report on Emissions Scenarios (SRES): We also used the SRES, of the IPCC scenario runs, performed with three coupled Atmosphere-Ocean General Circulation Models (AOGCM)s, such as the HadCM3, ECHAM3, and CSIRO Mk2 in water resources, permafrost, natural zones and pastures. Only the

HadCM3 was used in the study of snow cover and livestock. For all the models, we analyzed the response to the middle forcing scenarios A2 and B2. Future impacts of climate change were presented for three 30-year time slices, centered on the 2020s, 2050s, and 2080s, each relative to the current condition.

4.3 Results

Climate change represents an important additional stress to the natural environment that is already affected by pollution, increasing resource demands and unsustainable management practices. The climate change studies conducted in Mongolia concluded that global warming would have a significant impact on natural zones, water resources, snow cover, and permafrost.

4.3.1 Water resources

4.3.1.1 Introduction

The surface water of Mongolia exists in more than 3,800 rivers, 3,500 lakes, about 7,000 springs, and 190 glaciers. The water resources in rivers and lakes are 22.0 cubic km, while glaciers contain 63.0 cubic km water (*Surface Water of Mongolia*, 1999). Depending on the continental climate and local topography such as high mountains, forest-steppe, steppe and the Gobi Desert, surface water resources are unequally distributed over the country.

The rivers in Mongolia originate from the three large mountain ranges: the Mongol-Altai, the Khangai-Khuvsgul and the Khentei (Figure 4.1). The rivers are divided into three main basins, depending on their drainage system: the AOB, the POB, and the IDB of Central Asia. The AOB is the largest basin: its drainage area covers about 20 per cent of Mongolia's territory. About 50 per cent of surface water resources originate from this basin. All rivers flowing from the south-eastern slope of the Khuvsgul mountains, from the northern slope of the Khangai mountains, and from the western slope of the Khentei mountain system belong to the AOB. The POB is the smallest with respect to the drainage area and the water resources originating from it. Rivers in this basin contribute to 11 per cent of Mongolia's surface water resources. Although the rivers originate from high mountains, a large part of the catchment area of this basin is in the so-called `Mongolian Great Steppe'. The IDB of Central Asia has the largest drainage area, accounting for 68 per cent of the total territory of the country. The rivers flowing from the Mongol Altai mountains, the southern slope of the Khangai mountains, and the rivers flowing from other small mountain ranges such as the Bulnai and Kharhiraa ranges, contribute to this basin.

Figure 4.1: River basins (● selected hydrological stations for current study)

There are four main seasonal water regimes observed in the rivers of Mongolia. These are:

- Winter low-flow period, which lasts approximately from December to April;
- Spring-runoff period due to snow melting, which lasts approximately from April to June;
- Summer-runoff period due to rainfall, which lasts approximately from June to September; and
- 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. Regime 2 and 3 are usually combined in the rivers flowing from the Mongol-Altai mountains, which is not usually the case in the rivers flowing from the Khangai mountains.

These regimes are mostly derived by the climate conditions of the given season, such as temperature, precipitation, and humidity. Thus, the different water regimes have been studied separately, taking into account that seasonal changes may show the impacts of climate change.

4.3.1.2 Data and methodology

Twenty gauging sites (Figure 4.1) of different scales and climatological characteristics were selected from the national monitoring network according to basin size, varying climatic and basin characteristics, as well as availability and homogeneity of time series.

Systematic observations at these selected 20 sites over the past 30-55 years were used for our present study. The longest time series is for the Tuul river, starting in 1944, and the shortest is for the Khalkhgol river, starting in 1971. The period of observation coincides roughly with the reference years of the World Meteorological Organization's base years 1961-1990, for climate change studies. These rivers are significant because they are not affected by local anthropogenic factors; Mongolia is a sparsely populated with only two and a half million inhabitants over a 1.5 million km^2 territory.

Information collected at each study site included monthly mean and daily maximum river discharge, the timing of first ice, freeze-up, break-up, ice cover duration, water clear of ice, and annual maximum ice thickness. All these data were assembled for observation years in spreadsheet, and trends were estimated by linear regression. Ice thickness is measured manually on the tenth, twentieth, and last day of the month. The dates of first ice and water clearing of ice, freeze-up, break-up and occurrence of other forms of ice were recorded at the same sites where river water discharge was measured.

Air temperatue trends were analysed from the nearest meteological stations to the river gauging stations.

The Basin Conceptual Model (BCM) was used for the assessment of water resource changes under climate change. The BCM is a monthly balance model, which uses multiannual monthly mean values of precipitation, temperature, potential evapotranspiration, and runoff. It uses previous month storage to compute infiltration, evapotranspiration, and runoff. It contains six parameters, with two of the parameters being the upper and lower temperature bounds on the freezing and melting process.

The Thornthwaite temperature-based method was used for estimating evapotranspiration of the selected river basins. This method uses the mean temperature and the daily sunshine duration to compute the monthly evapotranspiration.

Model calibration and validation: A split sample test was used to evaluate the hydrologic model. In this test, the historic record is broken into two segments, one used for calibration and the other for validation. Since the ranges of climatological and hydrological data for the selected rivers were different, the last 24 years were selected for model verification and testing. In particular, the first 10 years (1972-81) were used for calibration and the remaining 14 years (1982-96) were used for validation. The estimation of river runoff is done for each hydrological year. The hydrologic year begins in October, when snow accumulation is assumed to be zero. The estimated condition of soil moisture and snow pack at the end of each year is then taken as the initial condition of the calculation in the next year.

The correlation coefficient and the average monthly error are used to describe model performance.

4.3.1.3 Current impact

Changes in river water runoff: According to observed data, there are two cycles of water availability in the rivers flowing from the Khangai and Khentii mountains, where rainfall plays a major role in water supply. The first cycle started from the end of the 1930s (in some rivers from the early 1940s) and finished in the early 1980s. Thus, one full cycle showing alternating high and low water availability lasted for about 40 years. A second cycle began in the early 1980s and reached its maximum in the mid 1990s. As an example, the annual mean run-off in the Selenge and Tuul rivers are shown in Figure 4.2.

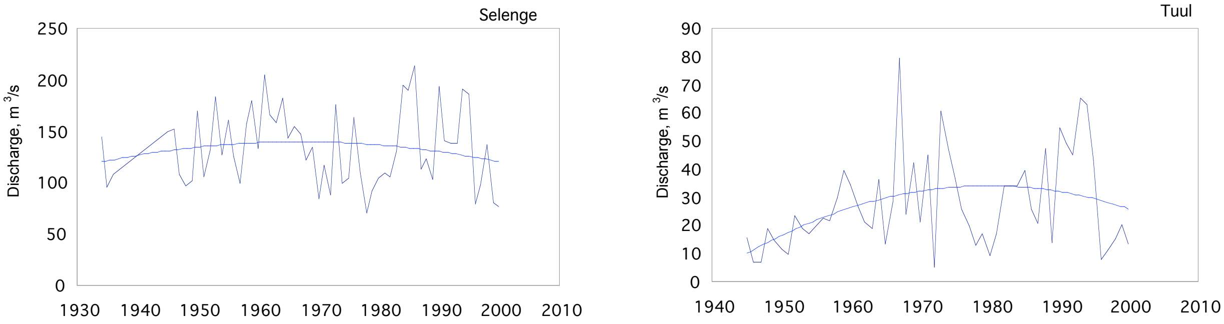


Figure 4.2: Trends of annual mean river run-off of the Selenge and Tuul rivers

However, the water cycle observed in the river flows from the Mongol Altai mountains, where glaciers and ice rivers contribute 50-90 percent of annual river flows, is somewhat different to those rivers fed by rainwater. The period started in the early 1960s and lasted till the 2000s. The duration also seems to be 40 years but this trend is opposite to that observed in rivers flowing from the Khangai Khentii mountains (Figure 4.3). Clear trends in increasing river flows have not been observed.

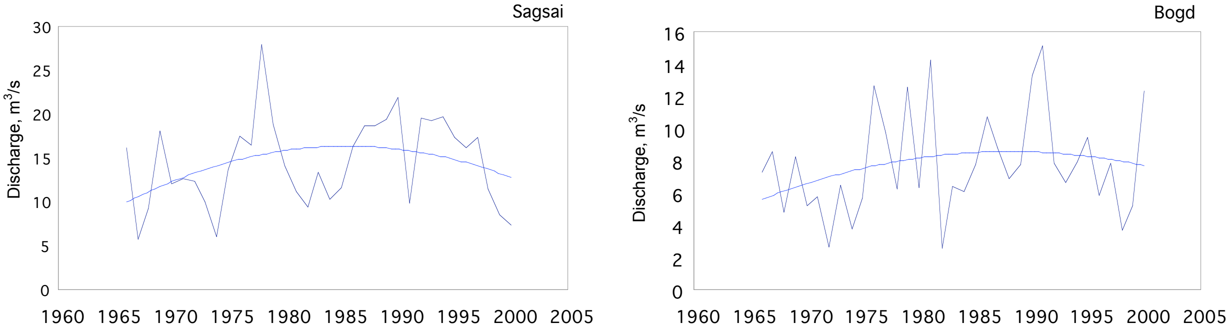


Figure 4.3: Trends of annual mean river run-off of the rivers flowing from the Khangai, Khentii, mountains

The area of glaciers had decreased by 6 per cent in 1985 from that observed in the 1950s (*Surface Water of Mongolia*, 1999). Thus, the high water availability observed in the rivers fed by ice melt compared to those fed by rainfall can be explained by the melting of glaciers and ice rivers due to the warming observed in Mongolia since 1960.

The major conclusion from the above results is that the river water cycle lasts about 40 years but that the cycles for different regions may not coincide depending on the source of water formation. It is difficult to say whether surface water resources are decreasing or increasing over the past 60 years.

Freeze-up and break-up dates in rivers: Freeze-up and break-up dates have changed from three days to one month, more specifically 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; but only 2-5 days in the rivers flowing from the Khan Khukhii mountains.

Changes in ice phenology dates correspond to an increase in air temperatures of autumn and spring months, when river ice processes take place.

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; and 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. The largest change in ice break-up has occurred in the Mongol Altai mountains and in the Khanuin river flows from the northern slope of the Khangain mountains.

Shifts in break-up dates are longer than in freeze-up dates.

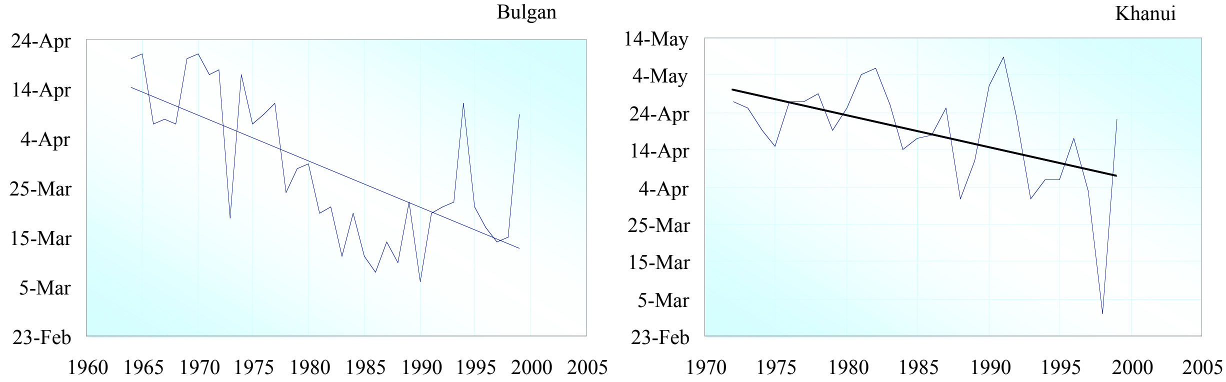


Figure 4.4: Trends in ice break-up dates in the Bulgan River (Linear regression: slope=-0.93day/year; R2=0.45) that flows from the southern slope of the Mongol-Altain mountans and Khanui river (Linear regression: slope=-0.85day/year; R2=0.25) that flows from the northern slope of the Khangain mountains

Autumn temperatures do not correlate well with dates of freeze-up at most of the sites, nor do spring temperatures correlate well with break-up dates. At higher altitudes, river ice break-up dates correlate with the sum of winter negative temperatures. But in most of the cases, the break-up date correlates relatively well with dates when air temperatures rise above 0ºC in spring. Figure 4.4 illustrates the relationship between river ice break-up dates and dates when the air temperature crosses 0ºC in spring at the Choibalsan station of the Kherlen and Muren stations of the Delgermuren river. Also, a good correlation was found between the freeze-up dates and the dates when the air temperature falls below 0ºC in autumn.

Changes in dates of freeze-up and break-up were similar for lakes and rivers. These changes in river and lake ice dates reflect clear trends in the regional climate.

Changes in the timing of the break-up were greater than changes in the freeze-up, perhaps because greater warming has occurred in winter than in other seasons. 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: Usually, 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 and begin growing out across the river. Further, it grows slowly and reaches its maximum in March. During the ice cover growth, frazil, anchor ice and hanging dams are common.

The climate in Mongolia is strongly continental, with large fluctuations between day and night temperatures. Thus, 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 (Figure 4.5). The decrease was 40-100 cm in rivers flowing from the Mongol 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 had 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. For example: the number of days in the delayed start of the freeze-up and earlier break-up was longer in the western region (in the Mongol Altain mountain rivers) than in the central (Khangai and Khuvsgul mountain rivers) and eastern regions (lower catchment of the Knentii mountain rivers).

Changes in the spring high water period due to melting of snow: In spring, river water levels increase due to melting of winter snow cover, glaciers and ice rivers, usually in April-May. Spring high water flows contribute 10-35 per cent to annual water resources from rivers.

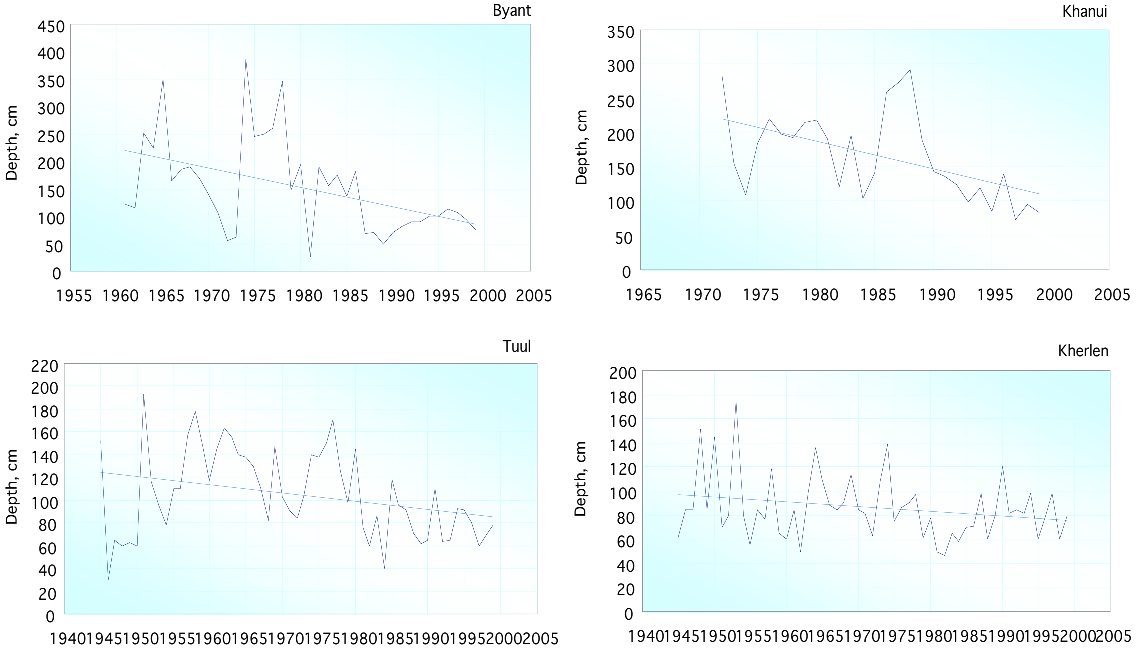


Figure 4.5: Time series of annual maximum ice thickness in four Mongolia Rivers (Buyant (Linear regression: slope= -3.64 cm/year; R^2=0.22, significance level: 99%), Khanui (Linear regression: slope= -4.08 cm/year; R^2=0.28; significance level: 99%), Tuul (Linear regression: slope= -0.71 cm/year; R^2=0.12, significance level: 90%), and Kherlen (Linear regression: slope= -0.16 cm/year; R^2=0.11, significance level: 90%). The sites were in the lower catchment of Buyant and Kherlen and the middle catchment of the Khanuin and Tuul Rivers. The River Buyant flows from the Mongol-Altai mountains and the River Tuul flows from the western slope of the Knentii mountain.

Increased air temperatures in winter and earlier snowmelt has 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 five 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.

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

As mentioned earlier, summer rainfall distribution has changed, also changing the summer high water period. In particular, the summer high water/flood starting date has been delayed by 2-10 days. However, this trend in most rivers was statistically not significant. The peak or maximum discharge of summer flood at rivers has changed too. Peak discharge has increased by 30-50 m^3/s in the rivers in the IDB and decreased by 50-150 m^3/s in the rivers in AOB.

4.3.1.4 Future impacts

Uniform changes in temperature (ΔT) and precipitation (%P) are used to test the sensitivity of water resources to climate change. With the set of hypothetical scenarios we have generated, a series of results was produced that gave insight into the sensitivity of the basin flows to climate variations (Table 4.1).

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

Table 4.1: River run off sensitivity to changed temperature and precipitation.

As can be seen from Table 4.1, if the annual precipitation drops by 10 per cent, while the temperature remains constant, the average river flow reduces by 7.5 per cent, 12.4 per cent and 20.3 per cent in the IDB , the AOB and the POB , respectively. If, besides the precipitation drop, average temperature increases of 1°C, 2°C, 3°C, and 5°C are taken into account, an additional flow reduction is expected. In other words, it appears that for each °C temperature increase, there is at least 2 per cent decrease of annual flow.

As intuitively expected, river runoff is much more sensitive to the precipitation changes than to the temperature changes, i.e., the impact of precipitation changes is substantially greater than the impacts of temperature fluctuations.

According to the SRES results, the runoff in the river in the POB is projected to decrease greater than the rivers in the other two basins (Table 4.2).

	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

Table 4.2: Prejected river runoff changes

4.3.2 Snow cover

4.3.2.1 Introduction

Clear skies in winter due to high anticyclone dominance over Mongolia results in less snowfall. Snow contributes less than 20 per cent 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 and wind. Sometimes, late first snowfall persists as snow cover in mountainous regions. Studying snow cover is important because snow cover in winter has both a positive and negative impact on animal husbandry. Long-lasting thick snow cover impacts adversely to animal raising, limiting the pasture size. On the other hand, no snow cover means no water for animals because in winter all surface water is covered by thick ice.

The date of snow cover formation (when over 50 per cent of an area is covered by snow), or the date when snow cover is cleared (when over 50 per cent of snow cover melts away), snow depth, and density are most important issues for pastoral animal husbandry. These parameters differ depending on geographical and climate conditions. As given in the *Agro-meteorological Reference Book of Mongolia* (1989) the duration of stable snow cover is 120-150 days in mountainous regions, 70-120 days in the eastern steppe and 30-60 days in the Gobi Desert region.

4.3.2.2 Data and methodologies

Data for snow cover was collected from 40 meteo-stations. Observed data for snow such as the date of snow cover formation , snow depth, duration and last snow cover were available from 1971-2001. All these data were collected from paper archives and digitized and prepared on an Excel spreadsheet for various analyses.

Linear regression methods have been used to analyze the current trends. We have developed a number of methodologies to study the future impacts of climate change on snow cover. The most applicable method was one based on autumn and spring threshold temperature that indicates snow cover formation and snow cover disappearance. After testing a number of threshold temperatures, it was found that -10^0C in autumn and spring adequately shows the changes of snow covered area in winter. The following equation was obtained:

$$\text{spring: } S=(k-a/b-a)*d+15; \text{ autumn } S=(b-k/b-a)*d+15$$

In the above equation, S is the date when daily air temperature is below and above -10^0C; a indicates the mean temperature of the months when air temperature is below -10^0C; b is the mean temperature of the months when air temperature is above -10^{0}C; k- is the threshold of air temperature which is -10^{0}C; and d indicates the number of days in a month.

The applicability of the equation was validated by comparing observed and calculated snow cover duration for the 1971-2002 period and quite a good correlation was found (R=0.82). Therefore, this equation was used to study the changes in dates of snow cover formation and cover and snow cover duration.

4.3.2.3 Current impacts

Snow cover forms in mid October in the forest-steppe and 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) stays for several days (usually for 1-2 days), covering large areas. We call this the last snow cover. Sometimes, the last snow cover occurs even in June. For example, snowfall occurred on 16 June 1971 in Tariat soum of Arkhangai aimag, on 4 June 1990, and on 25 June 1991 in Khatgal soum of Khuvsgul aimag, and on 5 June 1991 in Galuut soum of Bayankhongor aimag. The starting and ending date of snow cover, and the number of days with snow cover in different ecological zones are given in Table 4.3. These dates are averaged from 1970-2001 data.

	Day, Month				Days
Natural zones	Date of first snow-fall	Date of snow cover formation	Date of snow cover clear up	Formation of last snow cover	Duration of snow cover
Forest-steppe	16 Oct	19 Nov	13 Mar	27 Apr	115
Steppe	22 Oct	28 Nov	6 Mar	15 Apr	100
Altai mountains	14 Nov	14 Nov	24 Jan	I26?? Apr	70
Desert steppe	9 Nov	18 Nov	2 Feb	2 Apr	65

Table 4. 3: Starting and ending date of snow cover and number of days with snow cover (1970-2001)

As shown in Table 4.3, the formation date of stable snow cover is similar in all regions, but the clear-up date is almost one month earlier in the Altai mountains and the Gobi regions than it is in the forest-steppe and steppe regions.

Average depth of snow varies from 0.5 to 25 cm. In regions where snow cover stands for 50 and more days, maximum depth is reached in February and March. In regions where snow cover stands less than 50 days, the maximum depth of snow depends on the intensity and duration of higher snowfall during the season.

The 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 stable snow cover formation date occurs earlier in the forest-steppe and the eastern part of the country and later in other parts. The snow cover formation date has become 10 days earlier in western Mongolia, and 3-5 days earlier in central and eastern Mongolia. Most trends are not statistically significant. Trends of 10 or more days towards an earlier disappearance of snow cover are significant at a level of 90 per cent at some stations. As an example, snow cover disappearance date records at Baruunturuun, Suhbaatar, Hujirt and Khalkhgol are shown in Figure 4.6.

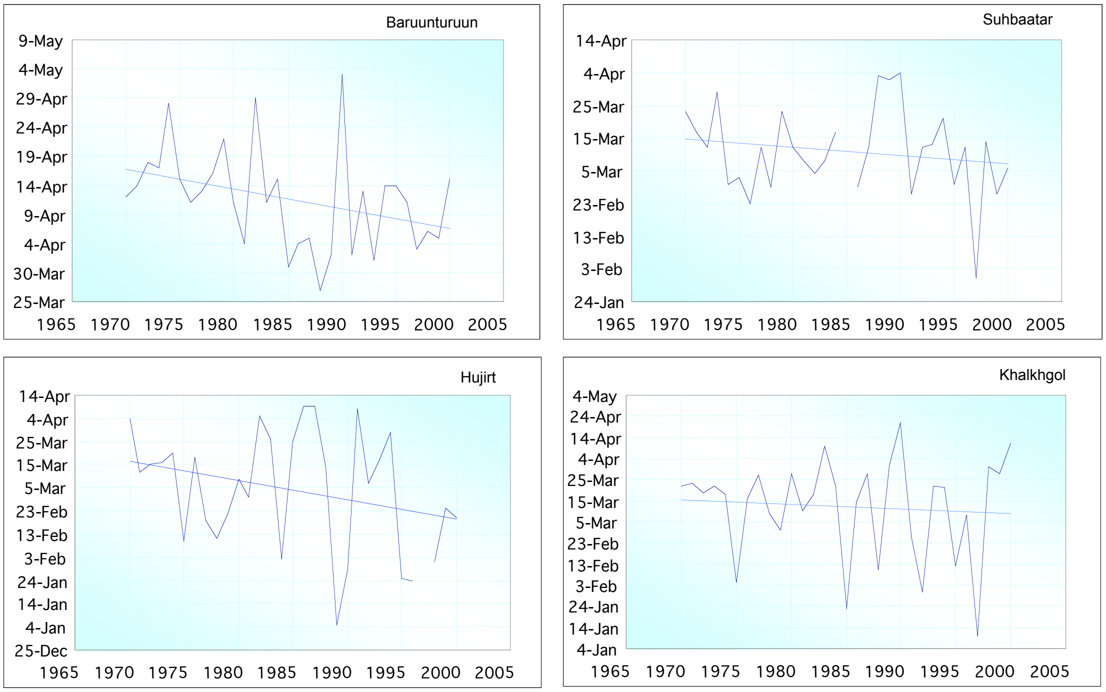


Figure 4.6: Snow cover disappearance date records at Baruunturuun, Suhbaatar, Hujirt and Khalkhgol

4.3.2.4 Future impacts

Snow cover duration: Currently, the area where snow cover stands for 100-120 days accounts for 30 per cent out of the total area that is covered by snow, and 37.5 and 32.2 per cent where snow cover stands for 120-140 days, and longer than 140 days respectively. According the HadCM3 scenario, snow cover duration longer than 140 days is projected to decrease almost two times by 2050 and nearly three times by 2080, while snow cover duration of 121-140 days would increase from the current 37.5 to 50 per cent by 2050, and 57 per cent by 2080 (Table 4.4).

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

Table 4.4: Projected changes in snow cover duration (%)

Date of snow cover formation and disappearance: Snow cover formation tends to be delayed and in most of the area, the snow cover will form in the last week of November (Figure 4.7). The snow cover disappearance date in spring is projected to begin earlier by 20 days (Figure 4.8).

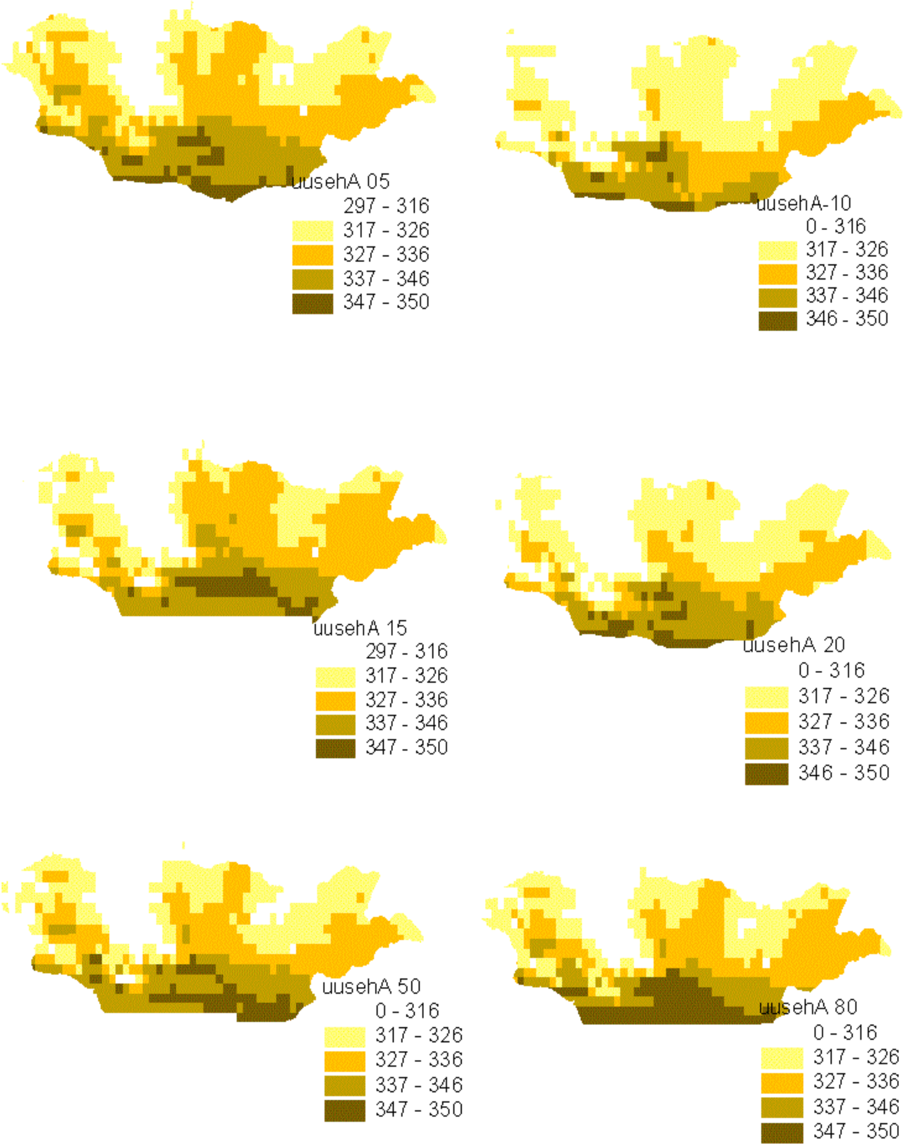


Figure 4.7: Projected changes in snow cover formation date, HadCM, A2

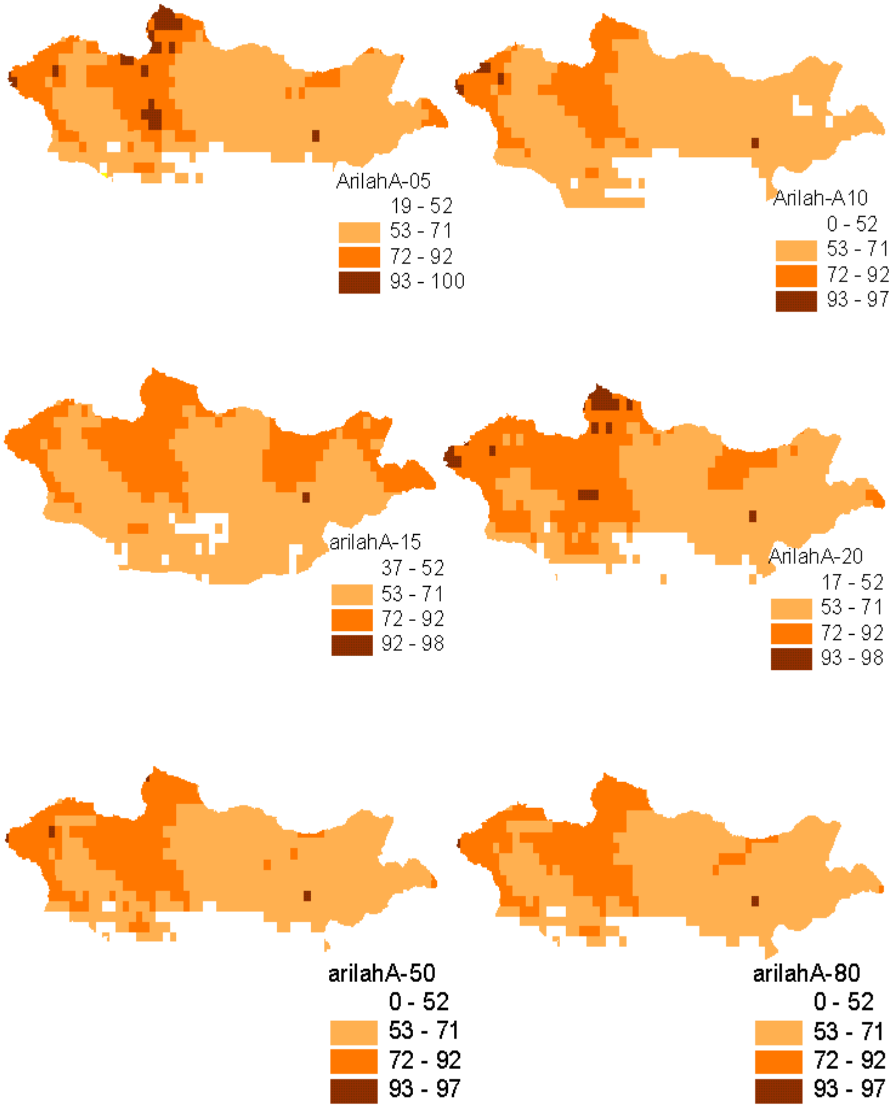


Figure 4.8: Projected changes in snow cover disappearance date, HadCM, A2

4.3.3 Permafrost

4.3.3.1 Introduction

The permafrost distribution covers about 63 per cent of the total territory of Mongolia. The Mongolian permafrost is classified into seven categories: *continuous, discontinuous, widespread, rarespread, sporadic, and seasonal*.

The continuous permafrost occupies 1,41,000 square km, or 9.4 per cent of the Mongolian territory and is distributed in the Hangai, Hentein, Huvsgul, and Mongol-Altain mountain regions. The depth of permafrost is 100-200 m in lake and river flood-planes and 300-500 m at the 300-400 m absolute altitude. The temperature varies from –1.5ºC to –3.5ºC.

The discontinuous permafrost occupies 27,000 square km, or 1.8 per cent of the country's territory. This category of permafrost is distributed in the Mongol-Altain region and in the western slope of the

Huvsgul mountains. The area of widespread permafrost is 1,52,630 square km, or 10.2 per cent and the lowest boundary starts at 1460-1800 m absolute altitude; the depth is 50-100 m and the temperature is from –1.0 ºC to 1.5ºC. The sporadic permafrost is distributed in central Mongolian steppe, the Orhon-Selenge river valley, lake basins and in the forest-steppe of western Mongolia. The depth is 5 m and temperature ranges between -0.1 ºC and 0.5 ºC and occurs in the wet loam and loamy soil. The *pereletka* is distributed in the Dariganga plains and Hyangany mountains. The seasonal freezing ground is distributed in the southern steppe and the Gobi Desert with a depth of 1.7-3.5m.

4.3.3.2 Data and methodologies

There is no widespread systematic observation network on permafrost. Therefore, for the study on the past and present impact of climate change on permafrost, we used observed data for the last 10 years, as well data that were collected from field studies conducted for the last 30-40 years. Observed data include permafrost temperature and depth at sites located in the Khuvsgul, Khangai and Khentii mountains representing continuous, discontinuous and widespread permafrost. The permafrost distribution map was used to assess future impacts of climate change (Figure 4.9).

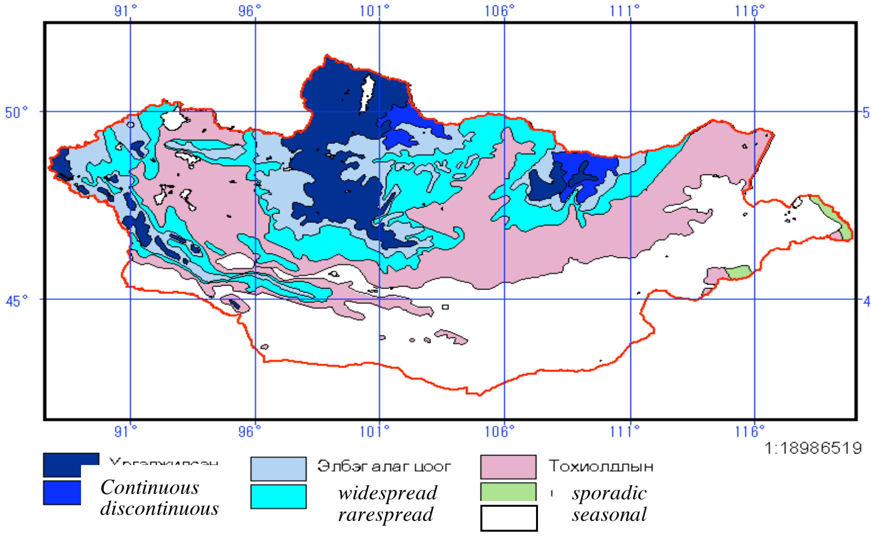


Figure 4.9: Permafrost distribution map

Three kinds of permafrost indexes were used to project the changes in permafrost distribution under future changed climate. One of these permafrost indexes is based on the following simple equation:

$$F_{air} = \frac{\sqrt{T^-_{air}}}{\sqrt{T^-_{air}} + \sqrt{T^+_{air}}}$$

Where: F_{air} indicates permafrost index; and $\sqrt{T^-_{air}}$ and $\sqrt{T^+_{air}}$ indicate the sums of negative and positive temperatures of a year. F_{air} >0.5 means the area has permafrost. This index shows permafrost and non-permafrost area only and does not show different categories of permafrost.

The second permafrost index that was developed under this study was based on the distribution of the sum of temperatures below zero, as shown in the equation below:

$$F_{T^-_{air}} = \sum T^-_{air}$$

Where $F_{T^-_{air}}$ is the permafrost index; and T^-_{air} is the sum of negative temperatures of a year.

The third index is expressed as a ratio of mean temperature of the coldest and warmest months of a year:

$$F_{Jun/Jul} = \frac{T_{coldest}}{T_{warmest}}$$

Where $F_{Jun/Jul}$ is the ratio of mean temperature of the coldest and warmest months; $T_{coldest}$ is the mean temperature of January; and $T_{warmest}$ indicates the mean temperature of June.

All permafrost indexes have been calculated at 899 grid cells sized 0.5^0x0.5^0 to match the resolution of the climate change scenarios in order to assess the climate change effects.

4.3.3.3 Current impacts

Mongolia has experienced certain changes in the frozen ground. Beginning from the 1970s, the annual mean temperature of permafrost has increased on an average from 0.05^0C to 0.15^0C in the Selenge river basin; from 0.05^0C to 0.10^0C in the Knentiin mountainous area; and from 0.10^0C to 0.15^0C Khunsgul and Khangai mountainous area.

Permafrost phenomena such as melting mounds, thermokarst, and solifluction also occur more frequently. Extensive thermokarsting has been discovered in the continuous and discontinuous permafrost zone of the Khangai-Khuvsgul mountains. The average rate of thermokarst varies from 5-10 cm/year, with the maximum rate of 20-40 cm/year.

Extensive solifluction has also been observed in the continuous permafrost zone of the Khuvsgul and Khangain mountains, at a minimum rate of 2 cm per year. The thickness of seasonally frozen ground has decreased by 10-20 cm in the Dornod for the last 30 years.

There are also clear changes in surface soil freeze in autumn and spring thaw. The date of the freeze in autumn was delayed by 2-6 days when the date of the thaw in spring advanced by 2-6 days. Longer shifts in timing have occurred in the forest-steppe and shorter shifts in the Gobi Desert.

4.3.3.4 Future impact

The permafrost distribution map was created according to the classification of temperature calculated by the three permafrost indexes. The applicability of the permafrost index to present current permafrost distribution was validated by comparing the percentage of different classes of permafrost in the map with the percentage of different classes of permafrost in the created map by permafrost indexes (Table 4.5).

Permafrost map		*Permafrost map created by* F_{air}		*Permafrost map created by* $F_{T^-_{air}}$		*Permafrost map created by* $F_{Jun/Jul}$	
Permafrost categories	*%*	*Temperature classification /^{0}C/*	*%*	*Temperature classification /^{0}C/*	*%*	*Temperature classification /^{0}C/*	*%*
Continuous	*9.4*	F_{air} >0.5	34.4	<-3000	25	*< -2.3*	*14*
Discontinuous	*1.8*					*-2.3–-1.4*	*26.2*
Widespread	*10.2*						
Rarespread	*12.2*						
Sporadic	*29.4*			-3000-2600	13.7	*-1.4–-1.1*	*24.3*
Seasonal	*37*	F_{air} *<0.5*	*64.6*	-2600 <	61.3	*-1.1 <*	*35.5*

Table 4.5: The performance of permafrost indexes showing the current permafrost distribution

As can be seen from the above table even though $F_{Jun/Jul}$ shows only four categories of permafrost (1) continuous; (2) merged class of discontinuous-widespread-rare spread; (3) sporadic; and (4) seasonal, the percentage of presenting the categories is very close to the current permafrost distribution map compared to other two indexes. Hence, we used this index to assess the future impacts of climate change on permafrost.

For the projection of permafrost distribution under changed climate conditions in the future, we used three AOGCM models, such as the HadCM3, ECHAM3, and CSIRO Mk2 models, with the middle forcing scenarios A2 and B2. Future impacts of climate change were presented for three 30-year time slices, centered on the 2020s, 2050s, and 2080s, each relative to the current condition. The results are given in Tables 4.6-4.8.

Permafrost classes	Temperature classification /^{0}C/	Current	A2			B2		
			2020	2050	2080	2020	2050	2080
Continuous	>-2.3	14.0	4	1	0	3	1	0
Discontinuous-widespread-rarespread	-2.3 -1.4	26.2	24	18	7	22	20	15
Sporadic	-1.4 -1.1	24.3	22	15	13	18	15	14
Seasonal	-1.1<	35.5	50	67	81	57	64	71

Table 4.6: Permafrost projections under HadCM3 A2 and B2 scenarios in Mongolia relative to current conditions

Permafrost classes	Temperature classification /^{0}C/	Current	A2			B2		
			2020	2050	2080	2020	2050	2080
Continuous	>-2.3	14.0	4	1	0	2	1	0
Discontinuous-widespread-rarespread	-2.3 -1.4	26.2	23	19	6	23	19	16
Sporadic	-1.4 -1.1	24.3	20	14	12	17	14	12
Seasonal	-1.1<	35.5	52	67	82	58	66	73

Table 4.7: Permafrost projections under CSIRO A2 and B2 scenarios in Mongolia relative to current conditions

Permafrost classes	Temperature classification /^{0}C/	Current	A2			B2		
			2020	2050	2080	2020	2050	2080
Continuous	>-2.3	14.0	1	0	0	1	0	0
Discontinuous-widespread-rarespread	-2.3 -1.4	26.2	20	10	0	17	8	3
Sporadic	-1.4 -1.1	24.3	12	11	3	12	11	13
Seasonal	-1.1<	35.5	66	80	97	70	81	85

Table 4.8: Permafrost projections under ECHAM A2 and B2 scenarios in Mongolia relative to current conditions

According to the results of scenarios, the continuous permafrost area will be limited by 1-4.4 per cent by 2020, depending on climate change models and will disappear by 2050-80. Seasonal frozen area, or the area where permafrost does not exit, will be increased almost two times by 2020, and three times by 2080.

4.3.4. Pasture

4.3.4.1 Introduction

More than 80 per cent of Mongolia's total land area or 130, 541.3 thousand ha are used for agriculture, and 127,307.0 thousand ha (97.5 per cent) are used for pasture. Pasture growth begins in late April and biomass peak is usually reached in August. If standing pasture at this height of the season is set to a 100 per cent, it will be 70-80 per cent in late autumn, 50-60 per cent in winter and 30-40 per cent spring. At the same time, the quality of the vegetation decreases by a factor of 2-3 and protein content by a factor of 3-4. Mongolian livestock obtains over 90 per cent of its annual feed intake from the annual pastures. In winter, the grass dries off, and its quality deteriorates. During this period, the animals take only 40-60 per cent of their daily feed requirements. Pasture yields are strongly affected by climate and weather conditions. They thus strongly vary from year to year, vary with altitude, and decrease from north to south. Pasture availability (in summer), as standing hay, is 0.5-0.8 tons in mountain pastures, 0.3-0.4 tons in steppe pastures, and 0.1-0.3 tons in Gobi Desert pastures. Currently, fodder production is estimated at about one-third of that in 1986.

4.3.4.2 Data and methodology

Data of climatological and pasture plants, including plant phenology dates and biomass of 64 stations, was analysed. Observation for pasture plants was carried out in a fenced area of 25 m x 25 m. Pasture biomass is measured every 10 days: on the fourth, fourteenth, and twenty-fourth of a month. Phenological dates of eight dominant plants, such as *Agropyron sp.*, *Cleistogenes sp.*, *Festuca sp.*, *Leymus chinensis*, *Stipa sp.*, *Carex sp.*, *Allium polyrhrizum* and *Artemisia frigida*, as well as rangeland biomass data were analysed and their trends defined. A time series longer than 15 years was selected for the analysis.

The necessary data of soil characteristics include texture class of soils, percent of sand, silt, and clay, pH, bulk density in t/m^3, rooting depth in cm, and C and N in g/m^2 in soil organic matter in the top soil of 20 cm. A current natural zone map was used for future impacts of climate change on the ecosystem zone. The spectral bands of NOAA/AVHRR data and the NDVI are used to analyse the land cover changes in Mongolia.

The CENTURY4.0 model was applied to study the impact of climate change on rangeland production. It was originally developed to simulate soil organic matter dynamics in the natural grasslands of the North American Great Plains. This model (Parton et al., 1988,1993,1994; and Metherell et al., 1994) is a general computer model of the plant-soil ecosystem, which simulates the dynamics of carbon (C), nitrogen (N), phosphorus (P) and sulfur (S), of different types of terrestrial ecosystems at monthly time step. The model can simulate the dynamics of grassland systems, arable cropping systems, forest systems, and savanna systems. In the grassland/crop systems and the forest systems, different plant production sub-models are linked to a common soil organic matter sub-model. The model runs on a monthly time step and the major input variables for the model include monthly average maximum and minimum air temperature and monthly precipitation, plant chemical characteristics (e.g., lignin content, plant N content) and soil properties (e.g., soil pH, texture, organic C and N levels, and bulk density).

In the plant production module, state variables are distinguished for live shoots and roots, and dead plant material. Potential production of a crop, under optimum conditions of temperature, moisture and nutrient supply, is primarily determined by the ambient level of photo synthetically active radiation, that determines maximum gross assimilation rate, the efficiency of conversion of carbohydrates into structural plant constituents, and the maintenance respiration rate.

The growth rate of most plant species responds to root temperature according to the sigmoid curve, up to an optimum temperature, then plateaus, covering a range of temperatures over which there is relatively little effect on growth, and a rapid decline above the optimum. Plant growth rates depend on the combined temperature response of photosynthesis and respiration. The model output variables included soil C and N, aboveground plant production and evapotranspiration.

The most widely used and essential measure of ecosystem functioning is NPP, and any change in the NPP of an ecosystem indicates a change in the health of the ecosystem. Taking into account that vegetation is a key factor in determining the exchange of heat and moisture between the earth's surface and atmosphere, we have made an effort to analyze the effects of climate change on ecosystem zones in Mongolia using the NPP and Aridity Index.

For this purpose, we used the CENTURY model and determined the current NPP and Aridity Index that corresponds to each natural zone. The country was divided into 899 grid cells sized 0.5^0x0.5^0 to match the resolution of the climate change scenarios to assess the climate change effects.

The applicability of the NPP and Aridity Index to present current natural zones was validated by comparing the percentage of different ecological zones in the current natural zone map, with the percentage of different ecological zones in the created maps.

Natural Zone Map		Created by NPP		Created by Aridity Index	
Ecosystem zones	%	NPP C g/m^2	%	Aridity Index	%
High mountains and Taiga	8.4	>296	10.8	>0.9	10.1
Mountain forest-steppe	23.3	251-295	23	0.51-0.9	30.2
Steppe	25.9	131-250	25.5	0.31-0.5	22.9
Desert-steppe	21.9	61-130	28.0	0.14-0.3	26.7
Desert	15.3	61-105	12.2	<0.14	10.1

Table 4.9: Model performance results for deriving natural zones by NPP and Aridity Index

As can be seen from Table 4.9, both the NPP and Aridity indexes could not present the high mountain and taiga zones separately but show the other ecosystems quite well.

4.3.4.3 Current impacts

It is difficult to quantify the changes in ecosystems that may have occurred as a result of the last 60 years of climate change in Mongolia. This is because the Mongolian ecosystem is very complex and there is no exact methodology to assess its diversity. On the other hand, due to its continental climate, vegetation re-growth and drying up is extremely variable, depending not only on the climate of a particular year but also the climate variation of the season.

One of the key issues of the global climate change is a land use/cover change. There are many different and complex factors in Mongolia, which have made an impact on land cover change and usage. However, Mongolia might be the only country in the temperate East Asia region, where natural driven factors are major impacts on land cover change, since about 80 per cent of the land is natural grassland. The land cover has changed significantly over just the last decade (Table 6.10 and Figure 4.9, 4.10).

Land classes	Area in km^2		Change (%)
	1992	2002	
Water body	17470	11131	-36
Sand, barren land	52593	76700	46
Desert	522938	525259	0
Desert–steppe	155126	253936	64
Dry steppe	334360	240397	-28
Grassland, steppe	251261	250672	0
Forested area	223904	205534	-8
Permanent snow, ice	296	204	-31
Total (sq. km)	1557948	1557948	

Table 4.10. Land cover changes between 1992-2002.

The plant productivity of the Mongolian arid and semi arid rangeland has high variability, following the distribution of precipitation. The mean of peak standing biomass varies from 100-1,000 kg ha-1, decreasing from the north to the south of the country. Plant composition also varies in different ecosystems. Mongolian steppe grassland appears to be more dominated by the cool season C3 species, rather than the warm season C4 species. Out of the common species found in the Mongolian Plateau, the species *Cleistogenes squarrosa*, is characterized by the C4 photosynthetic pathway. C4 grasses tend to be distributed in warm and dry locations than C3 grasses (Tieszen et al., 1999).

The average peak standing biomass is 590 kg/ha in the forest-steppe, 300 kg/ha in the steppe, 220 kg/ha in the desert-steppe and 170 kg/ha in the Altai mountains and the desert.

Our study results show that the peak of pasture biomass has declined by 20 to 30 per cent during the past 40 years (Table 4.11). Pasture plant monitoring observation started from 1964 within the national network of meteorological observation. As mentioned before pasture plant observations were carried out in the fenced fields, thus this reduction could be considered as the result of climate change only.

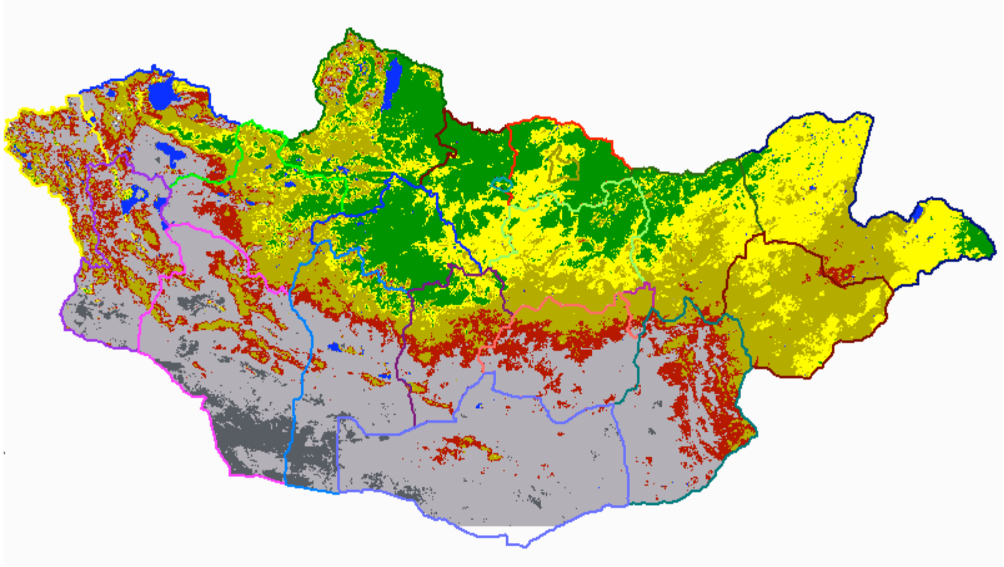


Figure 4.10: Land cover map, 1992

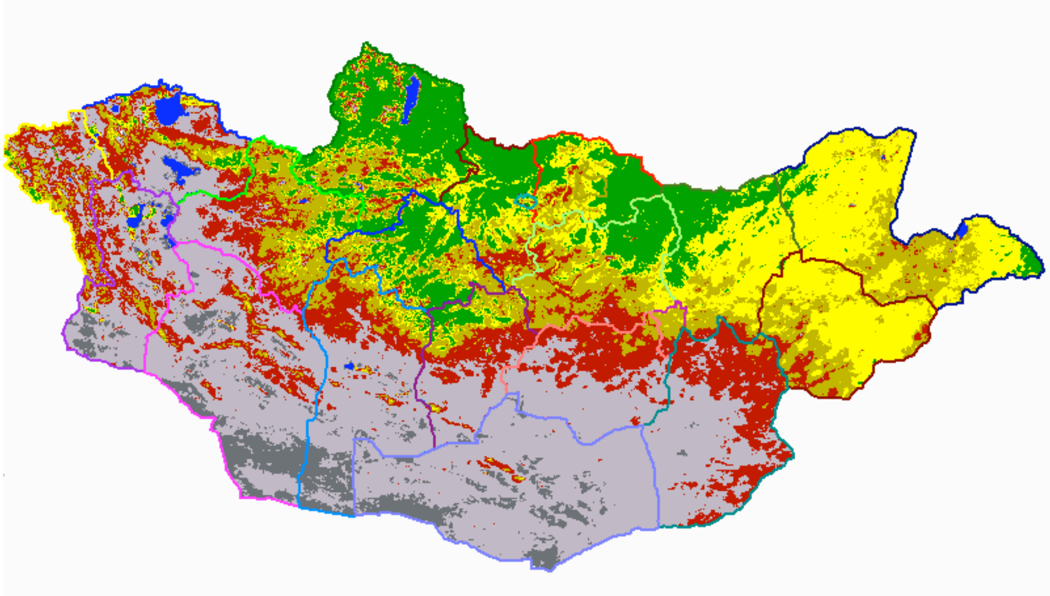


Figure 4.11: Land cover map,2002

Ecosystem	No. of stations	time series	4 Jun	14 Jun	24 Jun	4 Jul	14 Jul	24 Jul	4 Aug	14 Aug	24 Aug	Peak
forest-steppe	18	16-31	0.01	-0.01	0.01	-0.05	-0.03	-0.03	-0.06	-0.05	-0.07	-0.06
steppe	13	19-34	-	-	-0.04	-0.07	-0.06	-0.07	-0.07	-0.07	-0.05	-0.05
Altai mountains	5	17-24	-	0.00	-0.01	-0.02	-0.02	-0.01	-0.02	-0.01	-0.01	-0.02
desert steppe	18	17-29	-0.01	-0.02	-0.04	-0.01	-0.01	-0.01	0.00	-0.02	-0.01	-0.03
desert	2	18-21	-	-	-	-0.01	-0.03	-0.04	-0.05	-0.06	-0.05	-0.07

Table 4.11: Pasture biomass changes, 100 kg/ha/1 year (1960-2000)

This result was validated by the normalized difference vegetation index (NDVI) trends. The analysis of the NDVI trends of the third decades of July for the period of 1982-2002 at each pixel of 8x8 km resolution data shows a clear decline of the NDVI in 69 per cent of the country's territory for the last 20 years.

In general, pasture plant onset is observed relatively late in the southern part of the country because of moisture deficit and in the northern part because of low temperature. Phenological stages after emergency occur at different times, depending on plant characteristics and geographical and climatological conditions of location. Generally, heading of most plants is observed during late June; flowering, in mid July; and seeding in August. For *Carex sp.,* phenological stages occur early as flower buds in the beginning of June and as flowers at the end of June. Normally, plant senescence occurs in September. Shifts in temperature and precipitation in temperate rangelands may result in altered growing seasons and boundary shifts between grasslands, forests and shrub lands.

Our study shows certain changes in plant phenology. The Table 4.12 displays the average dates of phenological stages, such as heading, flowering, seeding and senesence of several dominant plant genes such as *Agropyron sp., Artemisia frigida, Carex sp., Festuca sp., Leymus chinensis,* and *Stipa sp.*

Species	Ecosys-tem	N of stations	time series	Average date of phenology					trend, day/1 year	
				Emergency	Heading					Emergency
Agropyron sp.	the forest steppe	9	16-30	5/9	6/20	7/16	8/16	9/11	-0.57	0.43
Artemisia frigida		8	12-29	5/4	7/2	7/22	8/20	9/11	-0.55	-1.10
Carex sp.		6	16-32	5/5	5/29	6/12	7/15	9/1	-0.49	0.45
Festuca sp.		9	15-30	5/10	6/17	7/18	8/15	9/9	-0.32	-0.32
Leymus chinensis		5	19-30	5/10	6/20	7/16	8/16	9/15	-0.55	0.17
Stipa sp.		17	15-32	5/9	7/4	7/28	8/21	9/11	-0.49	-0.12
Agropyron sp.	the steppe	5	20-30	5/10	6/24	7/18	8/18	9/12	-0.16	0.09
Artemisia frigida		5	18-34	5/7	7/8	8/3	8/28	9/17	-0.10	-0.46
Carex sp.		1	29	4/27	5/18	5/31	7/22	9/9	-1.12	0.70
Cleistogenes sp.		5	18-25	5/13	7/29	8/17	9/6	9/18	-0.14	-0.34
Leymus chinensis		7	23-34	5/7	6/27	7/21	8/20	9/18	-0.13	-0.16
Stipa sp.		14	14-34	5/8	7/7	8/3	8/26	9/15	-0.46	-0.04
Agropyron sp.	the Altai mountains	2	23-30	5/12	6/19	7/15	8/14	9/8	-0.54	0.11
Artemisia frigida		1	21	5/11	7/5	8/1	8/26	9/16	0.60	-0.28
Carex sp.		2	13-18	5/15	6/17	7/7	8/12	9/10	0.07	-1.11
Cleistogenes sp.		1	27	5/16	6/26	7/30	8/25	9/13	0.65	-0.31
Stipa sp.		5	18-29	5/15	6/18	7/12	8/10	8/31	0.00	-0.75
Agropyron sp.	the desert steppe	1	21	5/18	6/24	7/27	8/30	9/19	-2.19	-0.51
Allium polyrrhizum		12	14-32	5/15	7/25	8/12	8/30	9/15	-0.52	-0.09
Artemisia frigida		6	18-26	5/10	7/16	8/12	9/8	9/15	0.15	0.11
Carex sp.		1	18	4/29	6/2	6/16	8/22	9/23	-1.15	-1.11
Cleistogenes sp.		11	16-30	5/24	7/14	8/17	9/8	9/16	-0.01	0.14
Leymus chinensis		2	17-18	5/7	6/9	7/14	8/20	9/10	-0.13	1.59
Stipa sp.		14	19-32	5/11	6/19	7/13	8/5	9/6	0.07	-0.11
Agropyron sp.	the desert	1	15	5/2	6/19	7/17	8/5	9/12	-0.38	1.73
Allium polyrrhizum		1	21	4/26	7/25	8/10	8/29	9/26	1.32	0.23
Carex sp.		1	16	5/3	6/9	7/16	8/26	9/15	0.59	0.35
Stipa sp.		2	22-24	5/3	6/11	6/21	7/17	9/9	-0.03	0.30

Table 4.12: Average dates of phenological stages and their trends

According to trend analysis of phenological data, pasture plants emergency tends to begin earlier in the forest-steppe and the steppe. In particular, the *Agropyron sp.* emergency date has begun to occur earlier by three days in the steppe and 10 days in the Altai mountains and the desert for last 20 years. In the Altai mountains, the desert-steppe and the desert, some plants (like the *Artemisia frigida, Stipa sp.*) have had a delayed trend. In relatively arid areas such as the Altai mountains and the Gobi Desert, the growing season is determined by soil moisture rather than temperature. Generally, pasture plant growth senescence occurs earlier in the forest-steppe, the steppe and the Altai mountains, and later in the desert-steppe and the desert. In the Altai mountains, plant senescence now occurs earlier for the reason that the plants dried up and could not re-grow because of the severe drought that has occurred consecutively in the last three years. Senesence dates of *Agropyron sp.*, and *Leymus chinensis* were found to have had a delayed trend. For other development stages there is no general and clear trend for different ecosystems.

As displayed in the table, some plants have started to grow earlier and dried up later in time. Such plant responses were different in various ecosystems. For example, *Artemisia frigida* has started to grow earlier in the forest-steppe, but grows later in the desert. These changes in phenology, pasture biomass, and carrying capacity could be a warning for Mongolia's fragile ecosystem. As mentioned earlier, complete changes of the entire ecosystem could not be proved because of the complexity of the ecosystem, limited available data and time series.

All these results are derived from observation and monitoring data (20-60 years) analysis. Therefore, these results could be examples of changes in Mongolia's entire ecosystem. The composition and geographic distribution of many ecosystems could shift, as individual species respond to changes in climate and it is likely to be reduced in biological diversity.

The results of the field survey that conducted in 2002-2004 show clear and certain changes in plant growth and phenology, particularly, that vegetation cover became sparse, the number of species decreased, and that the phenology rhythm has changed in the desert steppe, the mountain-steppe and the meadow pasture. But it is still not clear whether these are climate induced changes, or just specific cases of very dry and hot weather

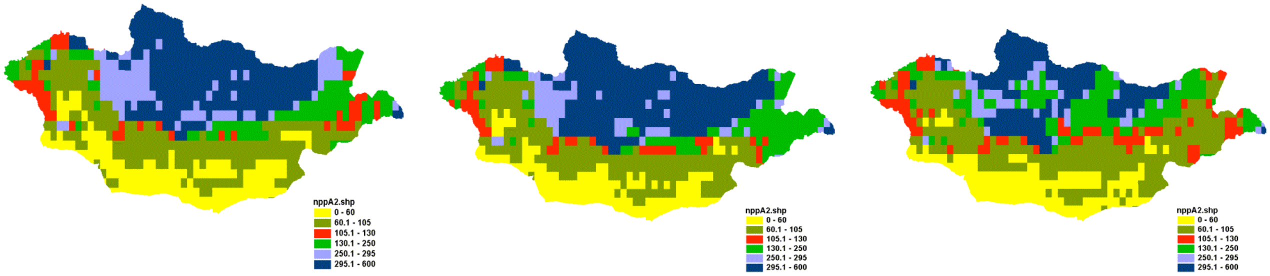
The results from the field survey in the desert show that dominant plants such as *Stipa* sp., *Artemisia frigida*, *Agropyron cristatum*, and *Allium* sp. are major contributors for plant growth in the dry steppe and desert steppe regions. Plants are now having delayed (by 1-2 months) plant growth compared to 30-40 years ago, probably due to decreased precipitation in the spring.

In individual plants, it was found that the number of leaves and shoots was often limited by the negative effect of environmental stress, even though the plants were able to grow more often. Due to decreased spring precipitation, the number of leaves of individuals has reduced. For example: in the desert-steppe 30-40 years ago, *Stipa glareosa* had 24-32 shoots with a height of 12-15 cm, but field research in 2002 showed that the same species had only 15-18 shoots of 4-6 cm height. Similarly, the species *Allium polyrrhizum* used to have 36-40 shoots of 10-12 cm height, while nowadays there are 23-28 shoots of 5-7 cm in an individual plant. This indicates that vegetation has become sparse and biomass has reduced.

Late re-growth has also been observed in September and October in Tuv and Arkhangai *aimags*. This is an abnormal case in the vegetation growth cycle in Mongolia. However, it could be kept in mind that the re-growth of plants in late autumn did not happen even when there was enough rain. Thus, this may be explained as increased warming in autumn rather than late rain. It is also noticed that the re-growth of plants were observed in late autumn in the desert-steppe.

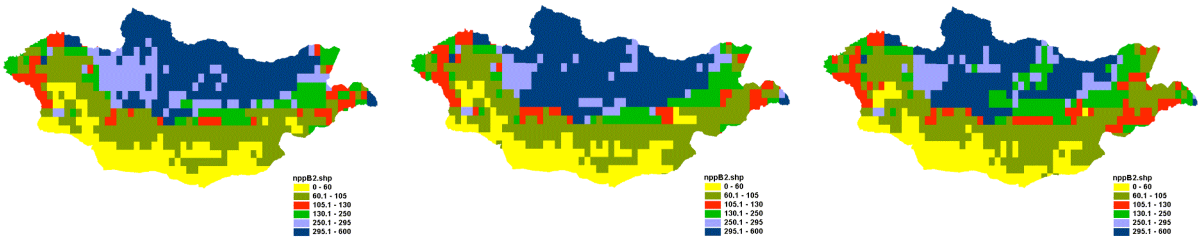
4.3.4.4 Future impacts

Ecosystem zones: As projected by both the NPP and Aridity Index, the boundary of current natural zones is expected to shift to the north of the country due to increased dryness and air temperature. The results of the climate change models, the HadCM3, ECHAM3, and CSIRO Mk2 middle forcing scenarios A2 and B2, are almost the same. The area of mountain taiga is projected to increase in 2020 and 2050 but will be reduced by 2080 and may replaced partly by steppe. The area of forest-steppe will be reduced, while the boundary of the steppe zone is likely to be shifted to the north, stretched by the desert-steppe. This feature is more likely in 2080. The desert area also appears to be increasingly shifting to the north due to combined impacts of increased temperature and reduced precipitation. As an example HadMC3 results defined by NPP are illustrated in Figures 4.11 and 4.12.



2020 2050 2080

Figure 4.12: Projected ecosystem zone changes by HadCM3, A2



2020 2050 2080

Figure 4.13: Projected ecosystem zone changes by HadCM3, B2

Pasture: The impact of future climate change on pasture has been assessed by both uniform changes in climate (sensitivity analysis) and HadCM3, ECHAM3, and CSIRO Mk2 middle forcing scenarios A2 and B2.

According to the sensitivity analysis, a plant aboveground biomass decreases with increased temperature. The rate of plant biomass changes in each 10 per cent of precipitation change are much greater than the rate of changes in each °C temperature increase, i.e., aboveground biomass is more sensitive to changes in precipitation than temperature (Table 4.13). Aboveground biomass in the forest-steppe will still decrease when the air temperature increases by 3°C and above even due to increased precipitation by 20 per cent.

		Temperature changes			
		T+0	T+1	T+3	T+5
Precipitation changes, %	Forest steppe				
	P+0%	**0.0**	**-6.3**	**-23.9**	**-44.1**
	P-10%	**-11.9**	-18.1	-35.5	-53.9
	P+10%	**12.1**	5.3	-12.7	-33.8
	P+20%	**22.9**	16.5	-2.3	-24.8
	Steppe				
	P+0%	**0.0**	**-5.5**	**-20.8**	**-37.7**
	P-10%	**-12.7**	-18.4	-32.0	-47.8
	P+10%	**12.3**	6.9	-9.4	-27.5
	P+20%	**24.1**	18.8	2.1	-17.1
	Altai mountain				
	P+0%	**0.0**	**-4.0**	**-11.4**	**-19.9**
	P-10%	**-15.8**	-19.4	-25.6	-33.4
	P+10%	**17.7**	13.6	5.1	-4.0
	P+20	**34.9**	30.7	21.8	11.5
	Gobi desert				
	P+0%	**0.0**	**-1.6**	**-7.4**	**-14.9**
	P-10%	**-21.3**	-18.8	-23.9	-30.5
	P+10%	**20.2**	16.8	9.6	1.4
	P+20%	**39.0**	35.1	26.5	17.5

Table 4.13: Aboveground biomass change, (in percentage)

The sensitivity of NPP and C: N to temperature and precipitation changes has the same pattern as plant aboveground biomass. Soil organic carbon and soil organic nitrogen have been decreasing with increased temperature and precipitation and have been increasing when precipitation decreased.

The HadCM3 and CSIRO Mk2 models suggest that pasture productivity in the forest-steppe and steppe should decrease by 2020-80, while ECHAM3 projects a slight increase of pasture productivity in 2020 (Table 4.14-4.16). Pasture productivity will increase in all natural zones in the future, particularly by ECHAM.

Ecosystem zones	A2			B2		
	2020	2050	2080	2020	2050	2080
Aboveground biomass						
Forest steppe	-3.8	-6.0	-37.2	-10.4	-11.9	-27.8
Steppe	-2.9	-5.0	-19.9	-0.6	-0.6	-7.1
High mountains	20.2	24.9	25.3	2.5	26.2	27.9
Desert steppe	16.9	40.6	46.8	18.9	43.7	52.1
C:N						
Forest steppe	-1.2	-1.4	-10.4	-2.8	-3.8	-7.1
Steppe	-1.7	-0.7	-7.2	-1.9	-1.7	-3.9
High mountains	-1.2	-1.4	-2.8	-2.1	-1.7	-2.2
Desert steppe	-1.0	-0.7	-2.0	-0.9	-0.4	-0.7

Table 4.14: Projected changes in aboveground biomass and C:N by HadCM3

Ecosystem zones	A2			B2		
	2020	2050	2080	2020	2050	2080
Aboveground biomass						
Forest steppe	8.5	-7.2	-22.3	7.9	-10.1	-14.0
Steppe	11.8	3.8	-11.0	14.0	-0.4	-5.5
High mountains	90.8	77.6	74.0	104.4	71.4	74.9
Desert steppe	50.6	57.0	52.1	60.8	51.1	31.7
C:N						
Forest steppe	0.6	-3.1	-9.1	1.5	-4.5	-5.0
Steppe	0.8	-1.4	-5.7	1.4	-2.6	-3.1
High mountains	4.0	2.4	-0.5	5.6	1.5	1.1
Desert steppe	0.5	-0.4	-2.2	1.1	-1.0	-1.5

Table 4.15: Projected changes in aboveground biomass and C:N by ECHAM

Ecosystem zones	A2			B2		
	2020	2050	2080	2020	2050	2080
Aboveground biomass						
Forest steppe	-4.6	-6.8	-30.8	-7.6	-12.7	-16.9
Steppe	-4.2	-1.6	-21.9	-7.3	-11.4	-15.2
High mountains	11.3	34.0	34.8	11.0	8.5	62.7
Desert steppe	11.1	36.9	53.0	27.9	25.9	57.6
C:N						
Forest steppe	0.6	-3.1	-9.1	1.5	-4.5	-5.0
Steppe	0.8	-1.4	-5.7	1.4	-2.6	-3.1
High mountains	4.0	2.4	-0.5	5.6	1.5	1.1
Desert steppe	0.5	-0.4	-2.2	1.1	-1.0	-1.5

Table 4.16: Projected changes in aboveground biomass and C:N by CSERO Mk2

C:N is going to be reduced significantly in all natural zones by HadCM3 in 2020-80. The CSIRO Mk2 and ECHAM3 suggest a slight increase in C:N by 2020 and predict that it will decrease further between 2050-80 in all natural zones.

4.3.5. Livestock

4.3.5.1 Introduction

Mongolia is one of few countries in the world that has pastoral livestock industry. Animal husbandry plays a special role in the country's economy and agricultural sector. Climate variability and extreme climatic conditions affect livestock growth, animal production, and the economic efficiency of animal husbandry.

The livestock sector provides a livelihood to almost half of the Mongolian population. Mongolia's livestock are raised in open pasture year-round. Traditionally, herders move seasonally (four times: winter-spring-summer-fall) with their livestock on the pasture and raise five types of animals, namely, sheep, goats, cattle (including yaks), horses and camels. Sheep and goats are the most numerous among livestock numbers of a herder's household. Animals are the major source of life for herders. Horses, camels, and sometimes, yaks are used for transport, dried dung is used as an energy source for cooking and heating, and cash is generated from animal production for medical and veterinary services, education of children, clothing, and purchasing of assets. The native breeds of animals have small body sizes and a low productivity, so their performance is substantially below that of exotic breeds.

Sheep. Sheep constitute over 50 per cent of the total livestock, distributed evenly in all ecological zones. This means that sheep breeding is suitable in all ecological zones of Mongolia. The Mongolian sheep has adapted to the climatic conditions due to their qualities such as squared and small body size, fat tail, robust, good development of muscles and bones, and straight legs. Mongolian sheep are kept mainly for mutton, which is tasty and of high quality. The average slaughter weight is 23.5 kg and the slaughter yield is 48.1per cent. Rams produce 1.52 kg, ewes 1.23 kg and yearlings 1.0 kg of wool per head, with a clean wool yield of 60.9 per cent. The wool is very suitable for making felt and felt goods. Ewes are milked in June and July for 30-45 days and give 29.7 kg of milk with 6.35 per cent fat content.

Goats. Goats are well adapted to diverse environmental conditions and relatively prolific. Because of their pointed muzzle and thin and mobile lips, they are able to pluck out sparse and short grass on hill slopes among stones. Native Mongolian goats are very important for the national economy because together with the much valued cashmere fibre, they also produce meat, milk, and skin. Goats, like sheep, are milked in the summer time only. The total dry matter of the milk is 15.44 per cent, total protein 3.8 per cent, fat 5.81 per cent, sugar 4.78 per cent and minerals 0.89per cent. About 3.0 thousand tons of cashmere with a diameter of 14-16 μm, are prepared in Mongolia annually, as an important export contingent.

Cattle. The Mongolian cattle have smaller body size, short and wide body, and short legs compared to other breeds. Mongolian cattle have low milk yield varying from 750-800 kg for 180 days lactation and the average fat content is 4.36 per cent. About 66.9-113.6 thousand tons of beef are produced annually, of which 12.9-14.0 thousand tons are exported.

Horses. Horses are distributed in all the ecological zones, the majority of which is located in the steppe region. Mongolian horses have smaller body size, deep square chest and well-developed bones and muscles. They also use less forage and have higher adaptability in unpleasant environment relative to other breeds. Mongolian horses are bred for riding, draught and racing. They are used as a producer of meat and milk: 34.5 thousand tons meat and 8.0 million litres milk are produced annually in Mongolia and 2.7 thousand tons of horse meat are exported.

Camels. A majority of the camels are in the Gobi region with only 6.2 per cent in the high mountains and forest-steppe regions. The camels are well adapted to the climatic conditions, making fat reserves in their two humps during the forage abundant period and using it efficiently even during the harsh climatic conditions. There are few two-humped camels in the world and they live in the Mongolian Gobi region.

4.3.5.2 Data and methodology

The observation data for animal parameters are limited in time and space. There are only three climate-animal observation sites in three different natural zones to collect data on the live weight of ewe, goat and cattle, timing of sheep wool and cow hair cutting, cashmere combing, and wool and cashmere productivity. Observation length is about 20 years.

Field surveys have also been conducted to study animal behavior and correlate it to various environmental factors such as temperature, wind and snow. The goal of field survey was to verify the study results based on observations.

The locally developed models EKZNJTZ and EKU1KJTZ, that simulate ewe weight changes in summer-autumn and winter-spring, respectively, have been used in the analysis. The models predict ewe weight changes, taking into account the pasture resources and their dynamics, both in terms of quantity and quality, and weather conditions (i.e., temperature, wind speed, snow cover, etc.). Time series from 1961 to 1990 of meteorological data, such as daily maximum and minimum temperature, daily mean wind speed, daily and monthly precipitation, thickness and density of snow cover on the pasture and peak standing biomass and total aboveground nitrogen as estimated by the CENTURY model served as input data to the model.

The model has been developed by the Tuvaansuren. The model estimates such parameters as the daily grazing time of the ewes in winter and spring seasons, amount of daily intake and water, basic metabolism, pasturing, growth and development of fetuses, milk-yield, the possible impact of external factors, energy expenditure for keeping the body temperature constant in cold weather conditions and energy intake during grazing. The model has two parts. The output of the model is the ewes' weight change. The first part of the model predicts ewe weight change for the period from 1 November to 30 April. The second part predicts ewe weight change for the period from 1 May to 31 October. The main difference between the two parts is the calculated time step i.e., ewe weight change is calculated by the day-time step in winter and spring, and by an hourly step in summer and autumn.

The daily energy balance, W_e, in $\text{kcal} \cdot \text{d}^{-1}$, of ewes is calculated as:

$$W_e^i = W_p^i - (W_o^i + W_m^i + W_n^i + W_c^i + W_t^i + W_f^i + W_l^i)$$

where,

W_p - energy intake
W_o - energy requirement for basic metabolism
W_m - energy requirement for grazing
W_n - energy requirement for warming ingested material
W_c - energy requirement for digestion
W_t - energy requirement for maintaining body temperature
W_f - energy requirement for foetus growth
W_l - energy requirement for milk production

The rate of change in live-weight is subsequently calculated by the dividing the energy balance (net energy intake) by the energy requirement for live-weight gain:

$dM_j = We_j / Cp_j$ where, Cp_j- energy requirement for live-weight gain (kcal/kg).

Then sheep weight on day j follows from:

$$Mo_j = Mo_{j-1} + dM_j$$

The model has been calibrated at five sites, representative for different natural zones, such as forest-steppe, Gobi Desert, steppe, and high mountains. The correlation coefficient between calculated and actual ewe weights at the selected sites was 0.92. The average relative error was less than 5 per cent, ranging between 0.2-10.1per cent in each site.

4.3.5.3 Current impacts

Many environmental factors affect animals in complex ways. Animal live-weight is a major expression of this combined effect because many features such as growth and development, fertility and birth, productivity, resilience and adaptive capacity depend on change of animal's weight. In other words, animal live-weight is dynamic depending on pasture and climatic conditions each year because animals graze the year round on native pastures. Thus, animal weight change serves as an integrated indicator of environmental factors and its changing trend is a critical part of climate and ecosystem change study.

One of the specific characteristics of the Mongolian nomadic livestock husbandry is that the animals take the necessary energy and nutrients for growth in summer and autumn. This means that animals start to gain weight in early summer when availability of high quality grass is high and attain their maximum weight at the end of autumn. Winter weather has a number of negative consequences on for animal production in Mongolia, such as low temperatures, strong winds, snow cover, restricting accessibility of the grass, snow and dust storms. In the winter-spring period the animals lose weight. However, the adapted Mongolian animals survive, spending the energy from the weight gained in summer-autumn

The average weight of the Mongolian ewe in the forest steppe region is 45.95 kg. The maximum ewe weight in the autumn is 53.2 kg, varying between 48.1 – 56.8 kg and the minimum weight in spring was 35.1 kg, varying between 29.5-39.5 kg. Therefore, ewes lose about 34 per cent of their autumn weight in spring while gaining their spring weight by 51.6 per cent in late autumn.

During the past 22 years, ewe, goat and cattle weight have decreased by 3.63 kg, 2.0 kg and 13.8 kg in 2001, compared to levels in 1980 (Figure 4.13). The weight loss was observed not only at the annual base but also in different seasons. Sheep weight declined by 4.6 kg and 8.5 kg in autumn and spring respectively for study period of the past 22 years (Figure 4.14). This decrease in animal weight has biological and economic consequences. It leads to not enough weight gain and thus, the inability to build up the necessary strength in autumn, to cope with forage shortage and harsh climate of winter and spring. In other words, calories/energy resources, gained during summer and fall, were found to be decreasing.

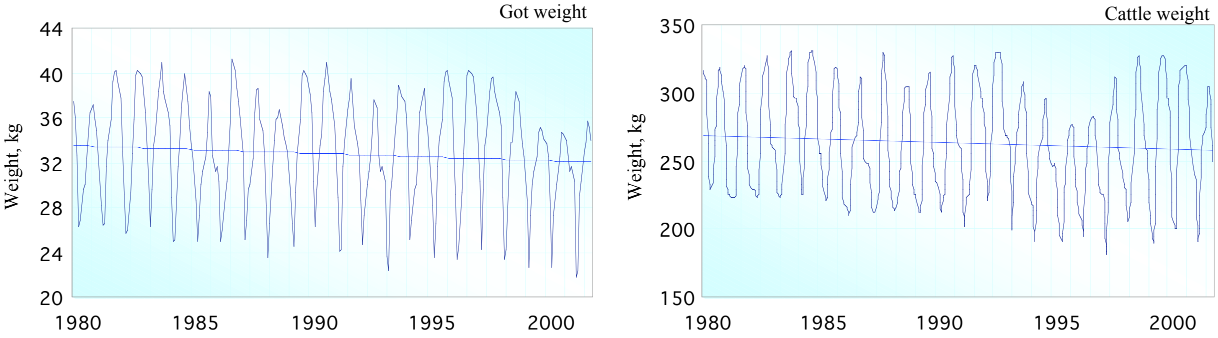


Figure 4.14: Observed changes in goat and cattle weight (1980-2001)

In addition to decreasing animal weight, wool and cashmere productivity has also been decreasing. Wool output decreased by 90 g or 4.3 g annually. Also, cashmere output decreased by 4.1 g or 0.2 g annually, which means a loss of about 20 tons of cashmere from 11 million goats. Sheep and cow hair cutting times have been shifted ahead by about a week.

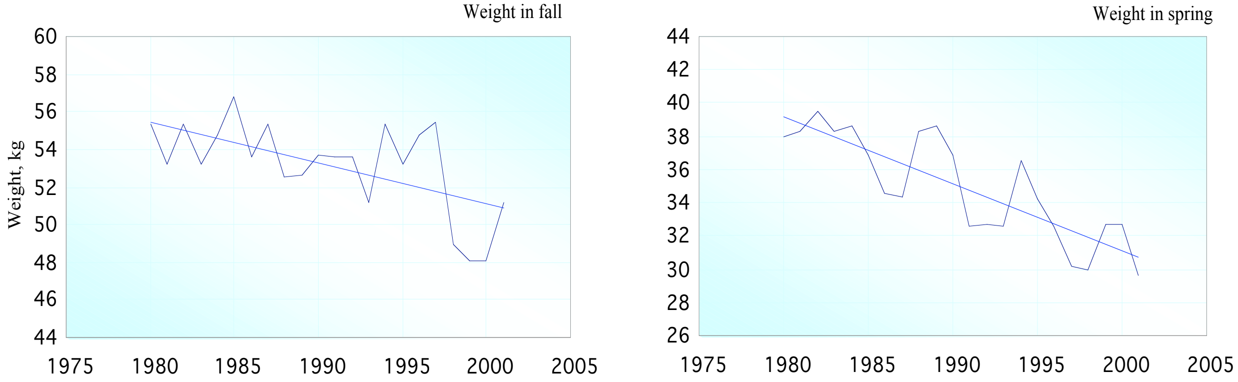


Figure 4.15: Ewe weight gain changes in Fall and Spring for the 1980-2001 period

One of the reason of decreased animal weight is decreased grazing time. A climatic factor that is associated with animal grazing in summer is high temperature. Since two-thirds of the year is cold in Mongolia, summer high air temperature makes it difficult for animals to graze on pasture. The threshold temperature established by the observation, above which animals cannot graze is 16-19^{0}C in the high mountains, 20-22^{0}C in the steppe and 26^{0}C in the GobiDesert. Since animals cannot graze on pastures when the air temperature is very hot, their daily intake reduces, and ultimately leads to insufficient weight and strength to overcome the harsh winter.

The relationship between daily weight change, reduced grazing time and daily intake were calculated using the same model. Daily weight gain was estimated for the last 20 years. According to this estimation, animal weight gain in June and July had decreased during the last decade compared to the previous decade. The June-July grazing period shortened by 0.8 hours due to hot climatic conditions during last two decades; and it became shorter by 0.2 hours during the last decade relative to the previous decade. Also, a number of days with more than three hours shorter grazing time have increased by about seven days during the past 20 years (Figure 4.15).

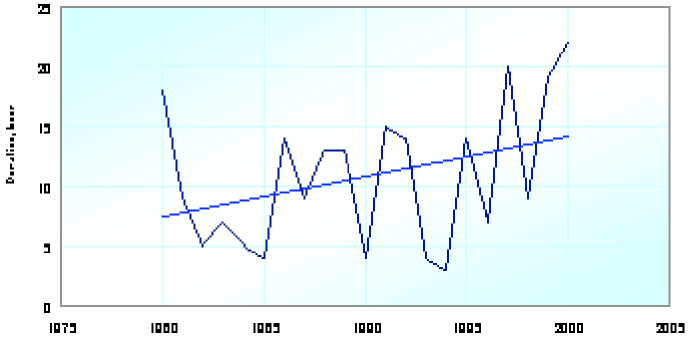


Figure 4.16: Changes of shortened grazing time (more than three hours)

A study of climate conditions for grazing is critical because we have little probability to make immediate changes to the pastoral livestock industry, and also climate change effect on pastoral system is primarily negative.

4.3.5.4 Future impacts

The sensitivity of ewe weight to the changed climate has been done for uniform changes of temperature and pasture biomass. Eight sites that represent three different pasture ecosystems have been studied.

The result shows that ewe weight is projected to decrease in the steppe and high mountain region at increased temperatures and that even pasture biomass will increase. In the steppe ewe weight is projected to decrease by 1.8-7.2 kg at increased temperatures of 1^0C-5^0C when pasture biomass remains unchanged. There is some small increase that could be expected in the Gobi Desert at increased pasture biomass when temperature increases by 1-2^0C (Table 4.17). Thus, temperature rise has a dominant role in ewe weight gain.

Natural region	Changes of air temperature, C^0	Pasture biomass changes ,%						
		-30%	**-20%**	**-10%**	**0**	**10%**	**20%**	**30%**
Partially wooded steppe	**0**	**-2.9**	**-2.8**	**-2.7**	**0.0**	**0.3**	**0.5**	**0.8**
	1	-4.7	-4.6	-4.5	**-1.8**	-1.5	-1.3	-1.0
	2	-7.1	-7.0	-6.9	**-4.2**	-4.0	-3.7	-3.5
	3	-9.2	-9.1	-9.0	**-6.4**	-6.2	-6.0	-5.7
	4	-9.4	-8.7	-7.3	**-6.8**	-6.5	-6.6	-6.2
	5	-9.8	-9.2	-8.6	**-7.2**	-6.9	-6.8	-6.4
High mountain	**0**	**-3.0**	**-2.9**	**-2.8**	**0.0**	**0.2**	**0.5**	**0.7**
	1	-5.0	-4.8	-4.7	**-2.0**	-1.8	-1.5	-1.3
	2	-7.2	-7.1	-6.9	**-4.3**	-4.1	-3.9	-3.6
	3	-8.1	-8.0	-7.8	**-5.3**	-5.1	-4.9	-4.6
	4	-8.8	-8.2	-7.9	**-5.7**	-5.2	-5.1	-4.8
	5	-9.5	-8.7	-8.1	**-6.6**	-6.2	-6.0	-5.6
Gobi and Desert	**0**	**-2.6**	**-2.5**	**-2.4**	**0.0**	**0.3**	**0.5**	**0.7**
	1	-2.6	-2.5	-2.4	**0.0**	0.3	0.5	0.7
	2	-2.7	-2.6	-2.5	**-0.1**	0.2	0.4	0.6
	3	-3.0	-2.8	-2.7	**-0.3**	-0.1	0.1	0.4
	4	-3.1	-3.1	-3.0	**-0.4**	-0.2	-0.1	0.2
	5	-4.0	-3.7	-3.1	**-0.8**	-0.5	-0.1	0.0

Table 4.17: Ewe weight changes with changed temperature and pasture biomass.

Projected changes in grazing time in summer by three models HadCM3, ECHAM, and CSERO Mk2 are very similar. Areas with favorable climate conditions in summer allowing animals to graze without any difficulties will decrease by almost two times by 2020, 4-5 times by 2050 and much more by 2080. Also, the areas where summer climate conditions make it difficult for animals to graze are projected to decrease. The areas where summer climate conditions prevent animals from grazing are projected to increase from the current 40 per cent to about 70 per cent by 2050, and 80 per cent by 2080 (Figure 4.16). But normal climate conditions in winter for animal grazing will be more favorable due to warming. The ECHAM model suggests that the area with favorable climate conditions for animal grazing in winter will increase two times by 2050 and three times by 2080 (Figure 4.17).

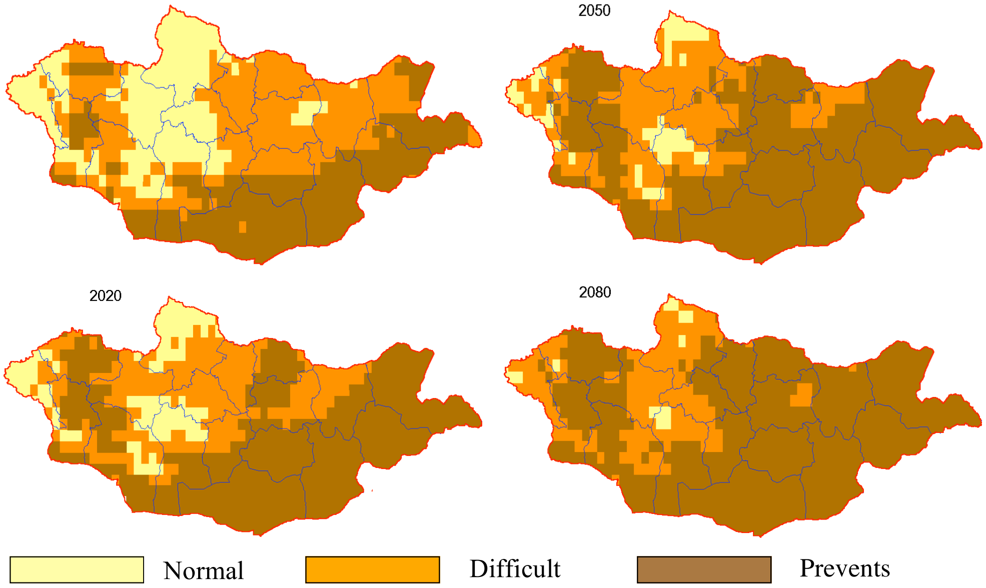


Figure 4.17: Projected changes in summer grazing condition, /HADCM3, A2/

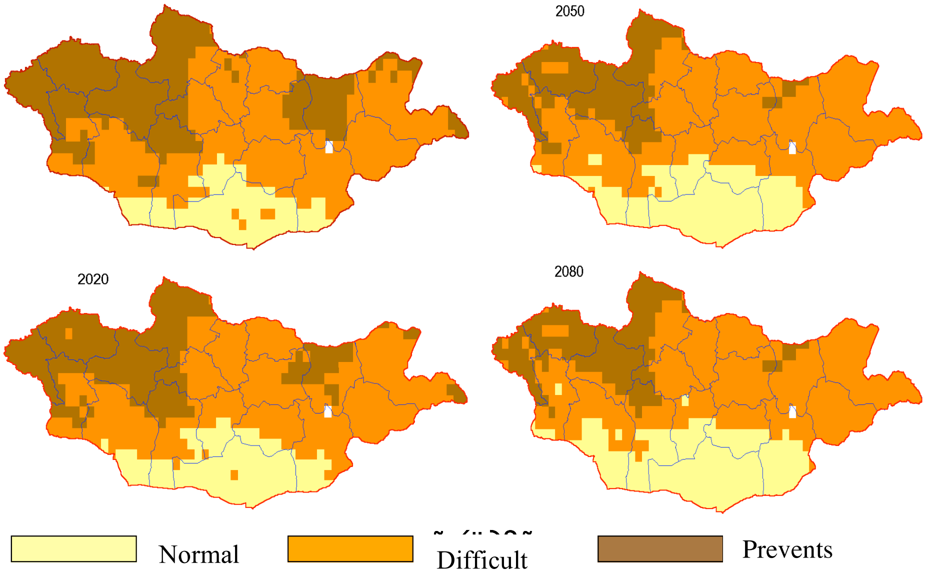


Figure 4.18: Projected changes in winter grazing condition, /HADCM3, A2/

More seriously, due to the decreased yield and quality of pasture, and shortened grazing time, summer-autumn live-weight of animals will decrease greatly in the forest-steppe and steppe regions (Table 4.18).

Natural zone	A2			B2		
	2020	2050	2080	2020	2050	2080
Forest-steppe	-10.68	-34.40	-57.75	-26.97	-38.33	-53.99
Steppe	-12.85	-31.67	-39.50	-15.86	-24.10	-34.37
High mountain	-2.92	-3.05	-9.03	-2.76	-3.64	-3.77
Desert-steppe	2.02	3.87	-0.18	2.18	0.96	-0.36

Table 4.18: Estimated changes of ewe weight gain in summer-autumn by HadCM3

Even though the climate condition in winter is projected to be improved, animal weight is projected to decrease.

4.4 Vulnerability

Mongolian native breeds of animals are characterized by an excellent adaptation to the local harsh environmental conditions, and resistance to unfavourable weather and various kinds of diseases. Nevertheless, about 2.4 per cent of the total population dies each year because of severe climatic conditions in winter and spring. However, natural disasters like the summer drought, harsh winter (*dzud*), spring and autumn frost, and strong dust storms, blizzard and cold rain, and heavy snowfall all often cause a mass death of animals and weakening of livelihood of herding families. In this respect, the pastoralists are vulnerable to a myriad of such climate-induced events. Among all of these natural disasters, *dzud* is the most risky because the damage due to it are incomparably higher than others causes. Therefore, vulnerability of livestock to climate changes focused on climate extremes of drought and *dzud*.

4.4.1 Data and methodologies

To define spatial distribution of drought frequency over Mongolia the observed data collected in the Institute of Hydrology and Meteorology were used, which includes the qualitative score of summer conditions like, good summer, droughty and drought that occurred between 1973-2000. These data have been analysed and classified according to the drought rate.

Indexing of extremes (drought and *dzud*) have been developed to prescribe the rate of vulnerability and used to assess the current and future vulnerability. These indexes provide the level of *dzud* as well relative vulnerability. Also this indexing gives the possibility to separate the climate impacts from non climatic ones. Because summer index to assess drought and winter index to assess the *dzud* developed using only temperature and precipitation.

A simple drought/summer index has been developed to assess the drought under climate change. Drought is expressed by the equation below, assuming that drought condition will occur if the given summer month temperature is higher than the long-term average, while precipitation is lower than the long-term average. Thus, drought is assessed by the degree of S_{summer} above zero degrees anomaly.

$$S_{\text{summer}} = \sum_{i=1}^{n}\sum_{j=1}^{4}\left(\frac{T-\overline{T}}{\sigma_T}\right)_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{4}\left(\frac{P-\overline{P}}{\sigma_P}\right)_{ij}$$

Where:

T and P are *j* summer monthly mean temperature and precipitation at *i* meteo-station;

$\overline{T} and \overline{P}$ are long term average temperature and precipitation at the same meteo-station; and

$\sigma_t and \sigma_p$ are standard deviations of temperature and precipitation.

The drought indexes have been calculated at 64 stations that are evenly distributed over the country. The drought classification is as follows: S_i =2.0-3.0 drought, $S_i \geq 3.0$ severe drought. The changing pattern of drought indexes were almost the same at all stations.

Similarly, a simple winter index has been developed to assess the changes in winter condition. The winter severity is expressed by equation below, assuming that a winter is severe if the winter month temperature is lower than the long-term average, while winter precipitation is higher than the long-term average. Thus, severity is assessed by the degree of S_{winter} below zero degrees anomaly.

$$S_{\text{winter}} = \sum_{i=1}^{n}\sum_{j=1}^{4}\left(\frac{T-\overline{T}}{\sigma_T}\right)_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{4}\left(\frac{P-\overline{P}}{\sigma_P}\right)_{ij} \qquad (2)$$

Where:

T *and* P are winter j monthly mean temperature and precipitation at i meteo-station;

$\overline{T} and \overline{P}$ are long term average temperature and precipitation at the same meteo-station; and $\sigma_t and \sigma_p$ are standard deviations of temperature and precipitation.

4.4.2 Drought occurrence

In Mongolia, drought has not been recognized as a natural hazard. This may be because Mongolia is considered as a cold country and there is no record of serious damage during the warm season as during summer and autumn.

An analysis of the drought indexes shows clear increasing conditions of drought occurrence, i.e., drought has increased significantly at the level of 95per cent in Mongolia for the last 60 years. In particular, the drought condition has increased rapidly in the last decade (Figure 4.18). The drought indexes have increased in the past, especially in the last decade, so it is clear that the drought scale has also increased in Mongolia. The worst droughts Mongolia experienced in the consecutive summers of 1999, 2000, 2001, and 2002 affected 50-70per cent of the territory. Such long-lasting and severe droughts have not been observed in Mongolia in the last 60 years.

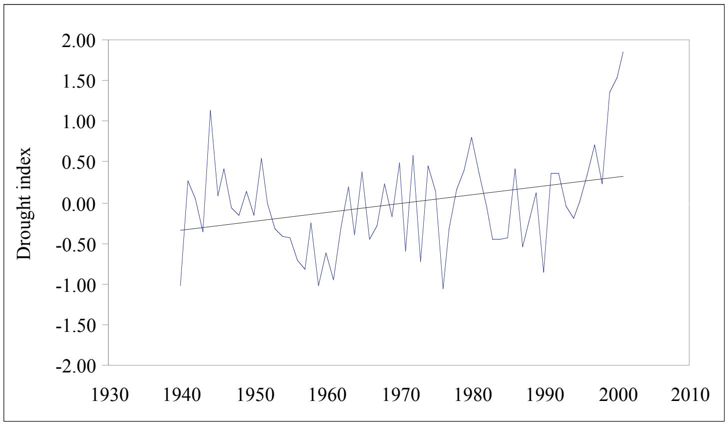


Figure 4.19: Trend in drought index for 1940-2002

Almost two-thirds of Mongolia's land belongs to the semi-arid and arid environment and is characterized by extreme variability and unreliability of rainfall both between different years and between different seasons and places in the same year. Consequently, areas that are characterized by the scarcity of vegetation and water are considered drought areas. Assuming that larger areas affected with drought have more adverse consequences, we have studied the relationship between calculated drought indexes and the observed percentage of area covered by a drought for the last 60 years (Figure 4.19). The study result clearly shows that the higher the index, the bigger the drought scale.

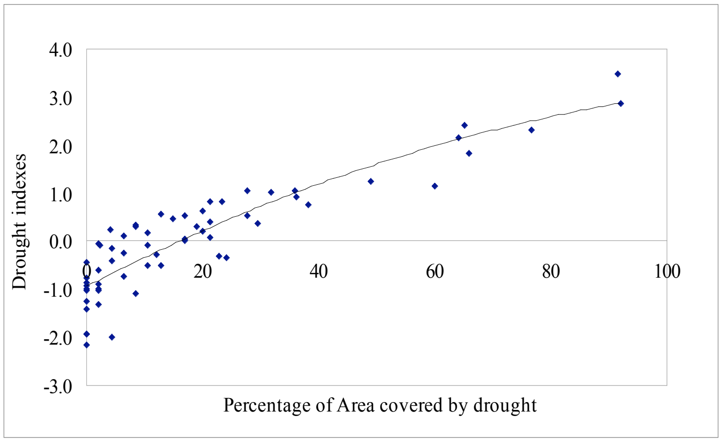


Figure 4.20: Relationship between drought index and area covered by a drought

4.4.2.1 Impact of drought on livestock husbandry

In Mongolia, the growing season is very short, and extends from May to September. Pasture productivity varies in wide range depending on summer conditions. A dry summer or drought decreases rangeland productivity by 12-48 per cent in the high mountains and by 28-60.3 per cent in the desert-steppe. The animals in Mongolia take the necessary energy and nutrients for growth in summer and autumn. Animals start to gain weight in early summer when high quality grass is available and attain their maximum weight at the end of autumn. If there is a dry summer, or prolonged drought, animals cannot gain sufficient strength and energy to overcome winter. Thus, drought is one of the key determinants of the vulnerability of livestock to climate change.

Herders used to relax in the summer months after the long and severely cold winter, whether the summer conditions were good or bad. On the other hand, animals do not die even during very severe drought conditions. Thus, drought in Mongolia was not regarded as a natural disaster, unlike in many African and South Asian countries. However, drought results in *(a)* the decrease of pasture plants; *(b)* the decrease of palatable species in pasture plant; *(c)* reduced water availability; and *(d)* the absence of grass on pasture (Table 4.19). Also, drought prevents herders from preparing hay and other supplementary feed for animals and dairy products for themselves. Most importantly, animals are unable to build up the necessary strength (i.e., calories/fat) during the drought period in summer to enable them to cope with the harsh winter and spring windstorms and therefore, they die in large numbers.

	State	Impact	Consequences
Animal husbandry	Animals have to rebuild their strength and gain sufficient weight to overcome the approaching winter	no sufficient vegetation on pasture drying of water sources increased HWD and hot days	animals cannot build the necessary energy, nutrients and fat animals cannot graze on pasture because of hot weather and decreased daily intake decreased animal weight
Grazing and feed	Fodder for the long-lasting winter (7-8 months) has to be prepared and saved during the summer season	reduced hay-making area grazing areas that are normally preserved for winter/spring are used during the summer, thus there is no pasture in winter	no fodder can be prepared and reserved for winter. reduced food reserves for livestock reduced winter pasture
Livelihood	Mongolian herders conserve their dairy products (milk, dried curd, clotted cream, butter and others) for winter in the summer months.	reduced livestock productivity, especially milk	herders face malnutrition since local people depend heavily on milk and meat products for their major dietary requirements during summer and most seriously in winter. reduces food reserves reduces cash that could be gained from the sale of dairy products
Environmental degradation	Increased overgrowth in numbers of voles (*Microtus brandtii*) and grasshoppers Increased evidence of forest and steppe fire	Destroys pasture	No grass grows on affected areas No hay grows on affected areas

Table 4.19: Some impacts and consequences of drought

There appeared to be a direct relationship between drought indexes and sheep (r=0.56) and goat (r=0.71) weight (Figure 4.20). Thus, we could infer that this statistical relationship demonstrates the negative impact of drought on animal bio-capacity.

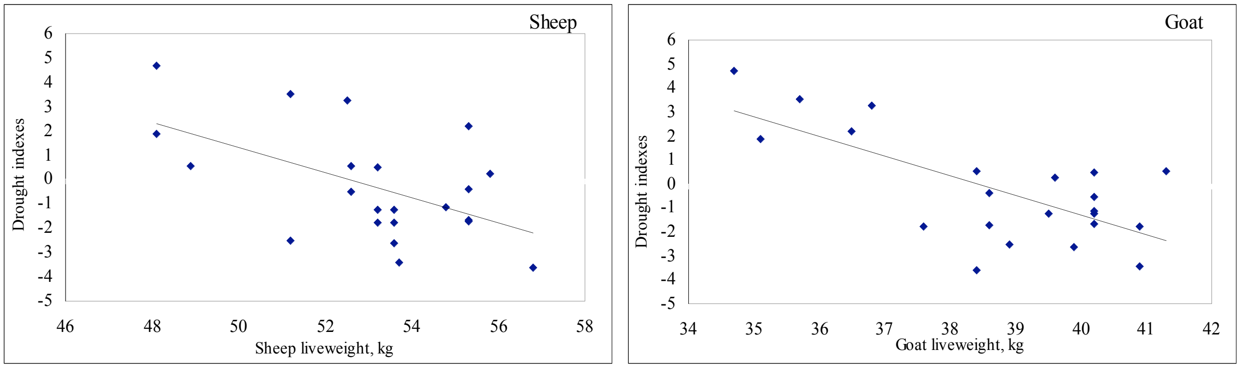


Figure 4.21: Relationship between drought indexes and summer-autumn live-weights of sheep and goat

As given before the autumn maximum weight has decreased by an average of 4 kg for the period 1980-2001 as a result of decreased summer peak standing biomass and increased drought conditions due to climate change. On the basis of our analysis, we came into conclusion that pre-summer condition is one of the major determining factors to animal mortality in winter. If there is prolonged drought, animals cannot gain sufficient strength and energy to overcome the severe winter, even if there is no *dzud* condition.

4.4.3 Dzud

Dzud is purely a Mongolian term. The *dzud* is a very complex and long-lasting phenomenon that is mainly caused by natural elements such as sudden spurts of heavy snowfall, long-lasting or frequent snowfall, extremely low temperatures, or drifting windstorms that reduce or prevent animals from looking for fodder. Reduced or no access to grazing negatively impacts the food security of livestock and human populations in winter. In other words, the term *dzud* can be described as `livestock famine', and the widespread death of animals because of hunger, freezing and exhaustion. *Dzud* also represents a high risk to humans in the affected areas. The larger the scale and the longer the duration of *dzud*, the higher the mortality of the livestock. There are several forms of *dzud*, depending on the characteristics, contributing factors and causes: *Tsagaan* (white); *khar* (black); *tumer* (iron); *khuiten* (cold); and *khavsarcan* (combined) (Table 4.20).

Dzud Form	*Description*	*Climatic criteria*
Tsagaan	Describes the phenomenon that results from high snowfall that prevents livestock from reaching the grass covered by it. Herders used to get out from the *dzud* area if the area was small. It is very serous disaster if it covers a large area. This is the most common and disastrous form of *dzud*.	Long duration: High amount of snowfall at the beginning of winter Short duration: High snowfall at the end of winter
Khar (black)	Occurs when the lack of snow in grazing areas leaves livestock without any unfrozen water supplies where wells are not accessible. Both humans and animals suffer from lack of water to drink. This form usually happens in the GobiDesert region	Very little or no snowfall in winter No winter forage on pasture because of drought in summer No winter forage on pasture due to overgrowth in number of voles (*Microtus brandtii*) and grasshoppers and increased evidence of forest and steppe fire
Tumur (ice)	Happens when an impenetrable ice cover forms on the surface due to snow melting that prevents livestock from grazing.	Short rapid warming in severe winter conditions i.e., 3-7 ºC higher than the monthly mean temperature
Khuiten (cold)	Occurs when air temperature continuously drops for several consecutive days. Extreme cold temperature and strong freezing wind prevents animals from grazing and they expend most of their energy in maintaining their body heat.	When air temperature falls by 5-10ºC lower than the monthly mean temperature
Khavsarsan (combined)	A combination of at least two of the above phenomena occur at the same time	
Tuuvaryin	Describes the phenomenon of overgrazing, or the rapid depletion of pastureland resources due to crowding and/or migrating of livestock in a certain territory.	Happens if the white, black, ice, and cold *dzud* covers a large area and in this sense increases the scale of the *dzud*.

Table 4.20: The forms of and their description

A *dzud* lasts from one to several months. Mongolian herders are experienced coping with *dzud* when it occurred in a small area and lasted for a short duration, since they conduct nomadic livestock husbandry. However, the occurrence of *dzud* in a larger area and of a longer duration makes it difficult for herders to cope with.

According to the observed data, the frequency of *dzud* that covered more than 25 per cent of the country's territory has increased twice in 1980-90 and tripled in 1990-2000 compared to the 1960s.

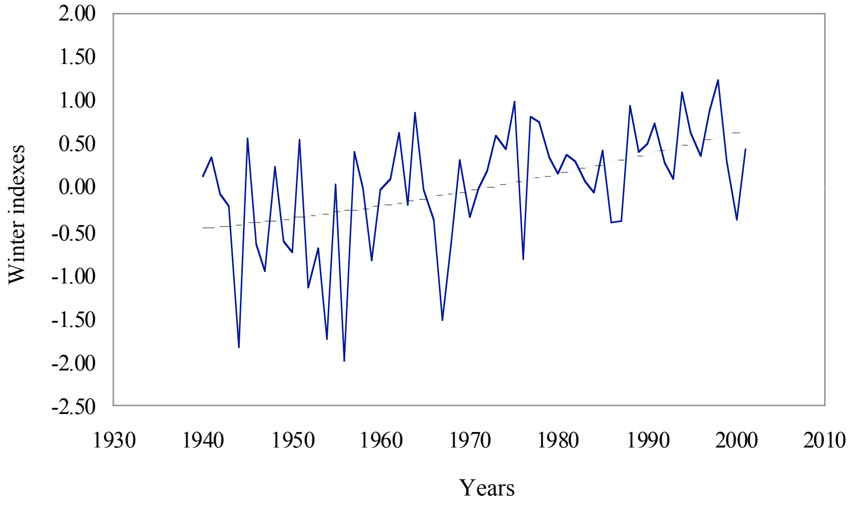


Figure 4.22: Trends in winter indexes

The winter indexes have been calculated at the same 64 stations where drought indexes have been calculated. Analysis of the winter indexes shows a slight decrease in severe winter occurrence. The normalized value of the winter indexes for the country is shown in Figure 4.21.

As can be seen from this figure climatic condition of winter in Mongolia are getting milder. As mentioned before the winter temperature has increased by 3.6^{0}C for the last 60 years, which is twice higher than any other seasons. Thus, winter is getting warmer. One could argue that herders would benefit from a milder winter. Unfortunately, study results show that increased temperature in winter resulted in a number of unusual or unseasonal weather phenomenon. For example, usually there are no windstorms during winter in Mongolia but recently, windstorms occurred in December and January. Windstorms during winter, or during the coldest time of the year, are characterized by strong drifting winds over a large area and are very dangerous because animals run long distance and do not remain standing in the drifting wind, thus, many die due to exhaustion. On the other hand, a short (3-7 days) rapid rise of air temperature causes rapid melting of snow cover but the melted water turns into ice sheets over a large area after the air temperature drops to a monthly mean level. This ice sheet greatly prevents the grazing of animals. Animals also have temperature stress from temperature fluctuation of short periods, together with many other negative environmental consequences. All these cause to increase the dzud occurrence, its scale and damage.

Livestock losses occur every year during the winter period, however, abnormally high livestock deaths occur in the case of a *dzud*. Livestock production is the major source of income of pastoral households. Livestock is the basis of the entire rural economy. Apart from providing the major nutritional sources, livestock are widely bartered in exchange for all manner of non-animal products. Hence, financial capability of households directly depends on livestock population they keep. In the event of a *dzud*, large numbers of herders lose a high percentage of their livestock. The loss of larger animals means that there will be no food and no cash. Considering this, the number of animals lost can be a measure of the severity of *dzud.* The relationship between winter indexes and number of animals killed during winter clearly shows that the harsher the winter, the higher the mortality of livestock (Figure 4.22).

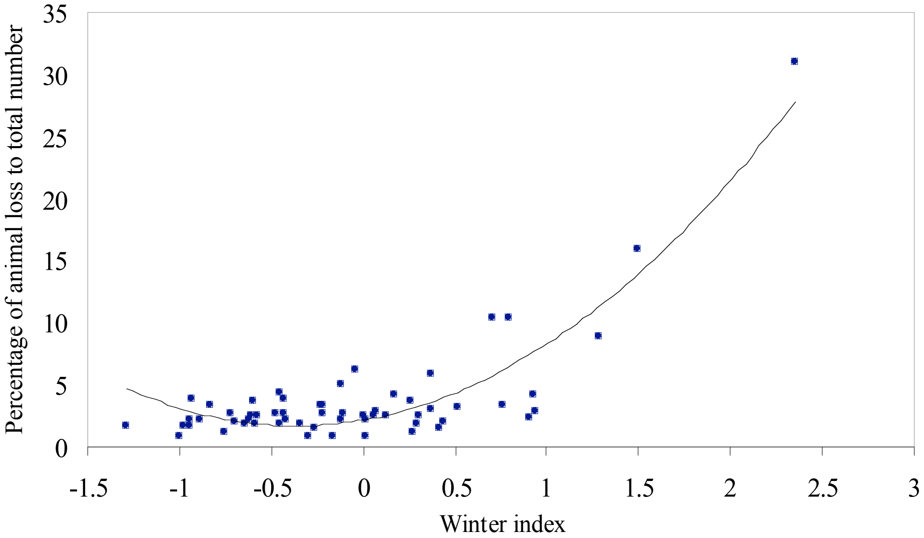


Figure 4.23: Relationship between livestock death and winter indexes

In addition to the severely cold weather, the mass death of livestock significantly affects the herders' daily lives. A large number of people lose their means of transportation, preventing them from moving from the affected area. Those who can move out of their normal grazing areas, place additional burden on areas not directly affected by the *dzud* and increased scale of *dzud*. They also face insufficient supply of heating materials (dung) when *dzud* lasts longer, causing negative impact on the herders' health. Usually, mortality of the aged and loss of newborn children increase during a *dzud*. The massive death of livestock not only affects the herders' livelihood but also causes severe socio-economic damage to the whole country. Gross agricultural output in 2003 decreased by 40 per cent, compared to that in 1999 and its contribution to the national GDP decreased from 38 per cent to 20 per cent (*Mongolian Statistical Year Book*, 2003). The livestock sector has become more destitute.

Climatic conditions during winter certainly play major role for *dzud* to occur. Winter weather has a number of negative consequences for animals in Mongolia. In the winter, the animals lose weight and reach their minimum weight in spring. But March-April is usually the most difficult period for the livestock. The grass has not yet grown and it is still cold, dry, and extremely windy with frequent dust storms and occasional snowfalls. This period is also the time when animals bear their young. In their malnourished condition, many female animals and their young are expected to perish. The rate of livestock mortality increases in spring due to the unavailability of adequate hay and fodder for the already weakened animals, i.e., animals die at an increased rate due to continued lack of food throughout the spring. Hence, livestock loss usually occurs at the end of winter and at the beginning of spring, when pastoral resources are at their lowest. Thus, after a long-lasting winter, spring pasture plant growth is very important because the animals are in greatest need of fresh forage/plants to rebuild their lost strength during winter and produce milk for the newborn animals. According to the observation the spring is getting warmer and dryer. Accordingly, April peak standing biomass has decreased by 10-20 per cent in the steppe and forest-steppe, and May peak standing biomass has decreased by about 30 per cent in both the steppe and forest-steppe. It could thus be said that natural resources to support recovery are also decreasing. Hence, resource degradation appears to be contributing to the increased vulnerability of livestock.

A three-year field survey was carried out over Mongolia, as well as a case study, in order to verify our research and to describe major risks perceived by pastoralist and how they cope with problems caused by dzud. More than 700 herders' households were interviewed. The herders complained not only of the decline in pasture plant species and animal weight but also with decreased production of meat, milk, wool, and cashmere. Respondents were seriously affected due to the severity of *dzud* and drought: 66 per cent of respondents were mentally shocked, 16 per cent became ill, 18 per cent are in debt, 17 per cent could not send the children to school, and 10per cent have declared that they do not get sufficient food to eat and often feel hungry.

4.4.4 Vulnerability mapping

For the mapping of the spatial distribution of livestock vulnerability to climate extremes, we have selected the Drought frequency map, White and Black Dzud frequency maps. Each map has been reclassified according to the classification of frequency (Table 4.21).

No.	Vulnerability intervals	Vulnerability	Drought frequency	White Dzud frequency	Black Dzud frequency
1	2	Slight	1 – 20%	No zud	No zud
2	4	Moderate	1 – 20%	1 – 10%	1-10%
3	6	High	21 – 40%	11 – 20%	11 – 20%
4	8	Very high	41 – 60%	21 – 40%	21 – 40%
5	10	Severe	61 – 70%	41 – 70%	41 – 60%

Table 4.21: Reclassification of maps

Using the GIS techniques we have analysed the above maps as separate and overlaid in different ways according to the intensity and damage caused by *dzud* and drought. Combinations of the layers are drought –white *dzud*, drought –black *dzud*, and white and black *dzud* and some other combinations. The Black and White *dzud* frequency overlay map is shown in Figure 4.23. As can be seen from this map almost 60 per cent of the country's territory belongs in a highly severe *dzud*-prone area.

Ninety per cent of the county is a highly vulnerable and natural disaster-prone area when *dzud* is combined with drought (Figure 4.24). The western edge of the Khangai mountains, the Altai mountain regions including the Great Lakes basin and the Gobi Desert have been particularly identified as very vulnerable areas. The Altai-Khangai mountain region, including the Great Lakes basin fall within the Altai-Sayan Eco-region, which is one of the world's most outstanding Global 200 Eco-regions. Thus, the increased tendency of drought and *dzud* conditions due to climate changes would affect not only the livestock sector but also some of Mongolia's unique ecosystems and biodiversity.

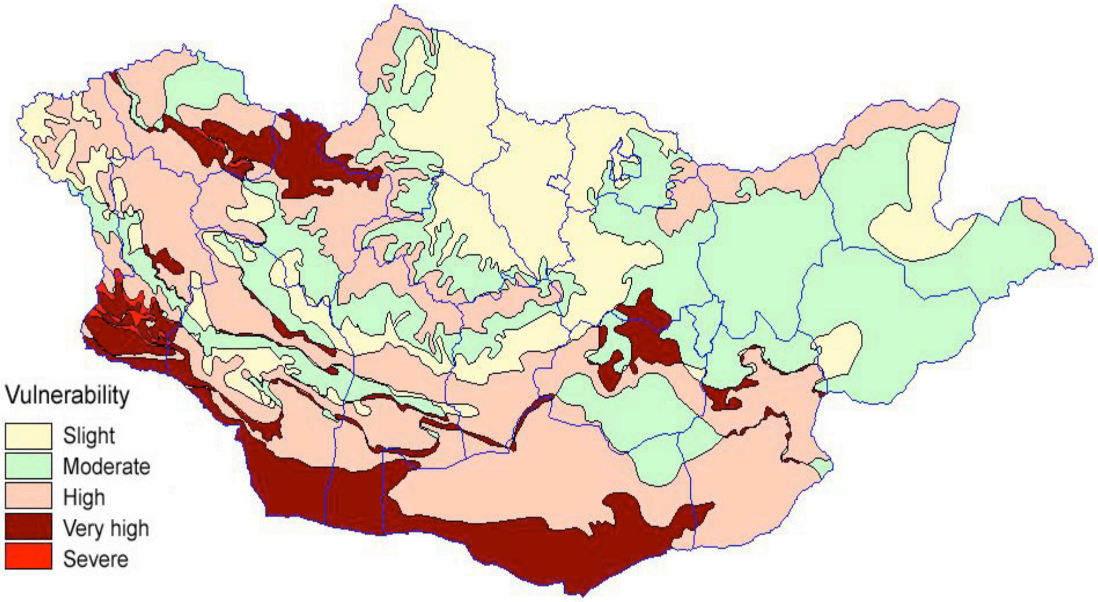


Figure 4.24: Black and white dzud *frequency overlay map*

During the disastrous period of 1999-2003, the regions that lost more than half of their animals (from 800, 000 to 1, 400,000 animals) fall in the severely vulnerable area to drought and *dzud* (Figures 4.25-4.26).

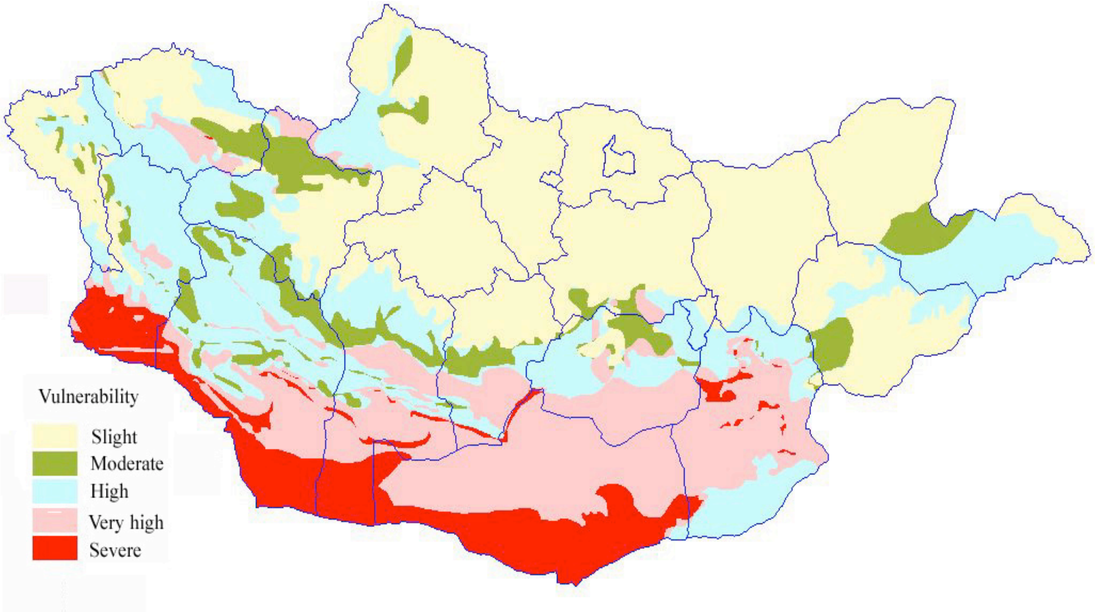


Figure 4.25: White and black dzud *and drought frequency overlay map*

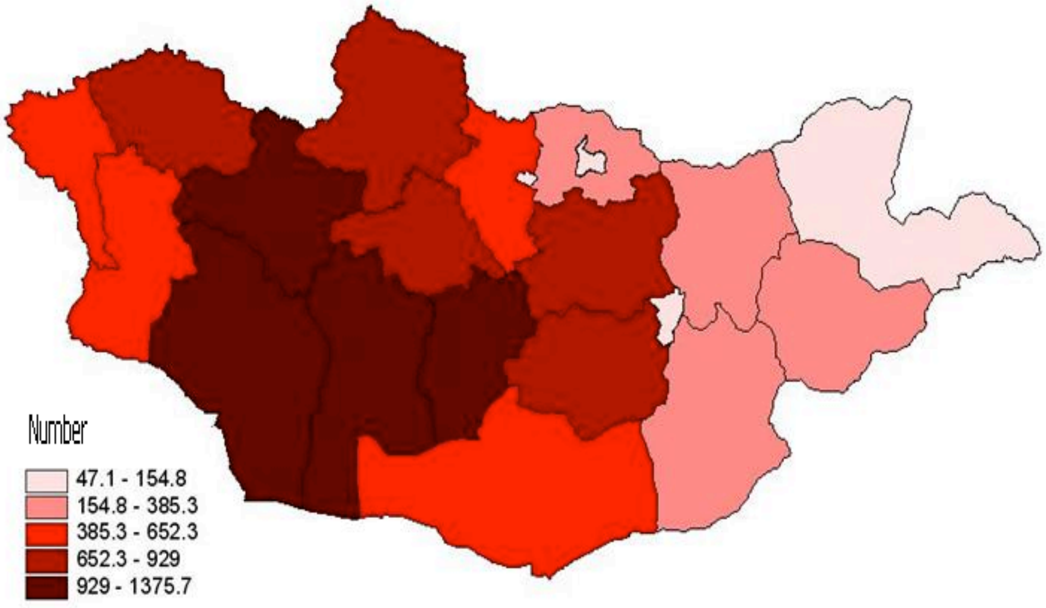


Figure 4.26: Number of livestock killed during 1999-2000 period.

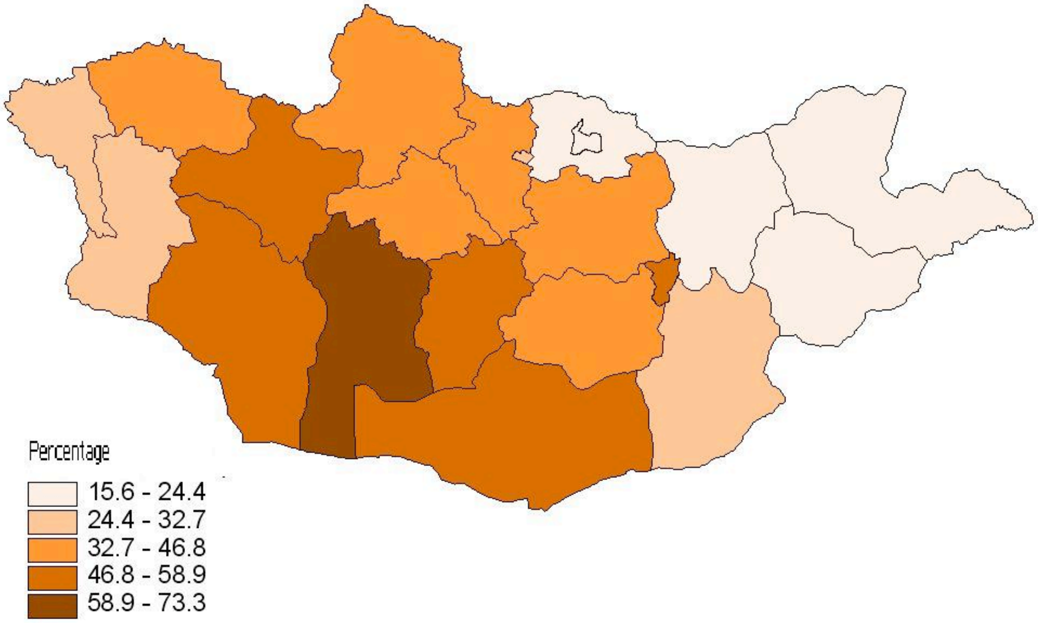


Figure 4.27: Percentage of livestock killed during 1999-2000 period to the number was in 1999.

The projected drought index trends estimated by the HadCM3 scenario are high enough to double the severity of these extremes by 2080. In case any adaptation measures are not taken, the animal mortality will reach about 12 per cent by 2020, 18-20 per cent by 2050, and 40-60 per cent by 2080.

6.5 Conclusions

More than 60 per cent of Mongolia's land has been identified as sensitive/vulnerable area to climate-driven extremes.

Fluctuating rainfall and the occurrence of drought are common features in Mongolia. Drought is intricately related to the lives of the Mongolian pastoralists for centuries, and it had really projected itself to famine and destitution. Lack of rainfall has consequences on pasture and livestock productivity, and can be used for predicting the effects on human populations depending on the livestock sector. The incidence of drought is expected to increase in future. Considering the fact that the pre-summer condition is the major determining factor for the impending winter, increased drought will make the livestock more vulnerable to winter conditions due to their poor nutrition and the insufficient reserve forage. During the cold part of the year, the increased snowfall and its untimely melting due to increased winter temperature and shortened cold wave duration also results in high negative impacts. Such changes will have impacts on plants and animals and most seriously on the herders' way of life and livelihoods, changing the harmony of pastoralists that have lived there for centuries.

Even though winter temperature have increased, it has resulted in the occurrence of a number of abnormal, unusual/unseasonable weather phenomenon such as windstorms in winter, short (3-7 days) rapid rise of air temperature that cause formation of impenetrable ice-cover on the land surface, which prevents animals from grazing. All this brings additional stress to increased and repeated *dzud*. There is also a strong relationship between drought/*dzud* and animal deaths. The death rates of domestic animals are also expected to increase in the drought and *dzud*-prone area. Therefore, the livestock sector remains vulnerable to climate variability in future changed climate conditions.

On the other hand, there are also severe organizational constraints. Herders have been affected by a reduction of different services in rural areas because many of the underlying technical and scientific issues in livestock sector were not adequately addressed before privatization programmes were undertaken.

The market economy newly introduced in Mongolia in the last decade also affects the herders' livelihoods. Mongolia has been exercising a central market–capital city Ulaanbaatar-oriented transition, while the herders (one-third of the population) are living sparsely distributed over a vast territory. Weak developed infrastructure (road, communication, electricity, etc.) increases costs for social services and access to market, while increased needs caused by the climatic hazards to migrate with the animals far away from the settled area seeking better pasture, tends to increase herders' remoteness. Thus, all these complex development factors are serious and are threatening the sustainability of the entire country.

Apart from providing the major nutritional sources, livestock are widely bartered in exchange for all manner of non-animal products. Hence, the financial capability of households directly depends on the livestock population they keep. During a serious *dzud*, large numbers of herders lose a high percentage of their livestock. In general, those with larger flocks have lost more than those with smaller flocks. But the most vulnerable group is the households with animals less than 200 because this group can lose all their animals, or their herd size would be reduced to a size that is too small to maintain and that cannot generate an adequate income for the family.

5. Adaptations

5.1 Activities Conducted

The pastoral livestock sector directly engages half of the Mongolian population and provides food and fibre to the other half. Livestock and livestock processed exports amount to about one- third of foreign exchange earnings. Mongolia's development is highly dependent on pastoralism. This sector already suffers from climate variability, particularly due to severe winters and summer droughts. Given the overriding importance of the sector to the national economy, its vulnerability remains a key threat to the country's potential for sustainable development. Therefore, the study undertaken under AIACC aimed to formulate adaptation measures that focus on those issues of national concern. It also aimed at evaluating concrete and practical adaptations that could possibly decrease the livestock sector's vulnerability to climate change. This section discusses some selected adaptation measures, addressing questions like:

- what are adaptation measures?
- how are adaptation measures assessed and prioritized?
- what criteria are used to evaluate adaptation options?
- to what risks, threats, or impacts is adaptation directed?
- when and where does adaptation take place?
- who is responsible for adaptation?
- who should pay for the costs of adaptation?

Activities conducted in adaptation assessment include a review of adaptation options that have been identified in previous studies related to climate change such as the US Country Study Programme, National Action Programme on Climate Change and Initial National Communication, review of national as well as sector policy and legislative documents on livestock sector, current (AIACC) impact and vulnerability assessment of livestock sector to climate change and interviews and discussions with local officials and herders.

5.2 Description of Scientific Methods and Data

Different methods were used to identify adaptation options. These include, computer modeling (EKZNJTZ and EKU1KJTZ), household survey, focus group discussion, multi-stakeholder workshop, GIS analysis and adaptation screening matrix.

The long list of adaptation options has been prepared on the basis of expert judgments. Assessing the preference among these options in different sectors is a complicated task for policy/decision makers, since there are multiple problems and objectives to be solved and met. Therefore, a simple approach, or the Screening Matrix of adaptation was used to examine the priority of measures. Adaptation options are qualitatively ranked as high, medium and low against the criteria to indicate the preference. The EKZNJTZ and EKU1KJTZ model was also used to analyze some adaptation measures like modifying grazing schedules and increasing pasture biomass

The Mongolian pastoral livestock production system has three primary components:

- natural resources, which is characterized by the physical and biological environment, or primary resources and climatic conditions;
- livestock, including the bio-capacity of processing and converting feeds to products (i.e., milk, meat, fibre) at a rate sufficient to meet animal needs and provide a surplus for human needs; and
- Herders, who take management over livestock production.

It can generally be said that the pastoral livestock industry depends on the availability of natural resources that is mainly governed by climate, and animals' bio-capacity to cope with the environment and human element that supports and depends on livestock. Therefore, the identification of adaptation options is focused first,on what should be done for conservation of the natural resources against the changing climate; second, what should be done for strengthening animal bio-capacity to cope with adverse impacts of climate change; and third, what should be done by the herders to ensure better management to enhance the livelihood of rural community.

As mentioned earlier, impacts of climate change on pasture productivity are gradual but long term, and often associated with increasing intensity of extreme events, particularly droughts and dzud. Therefore, adaptation measures relate to two types of impacts of climate change: (i) gradual long-term changes (degradation of quantity and quality of pasture) that focus on changing the trends; and (ii) changes in the frequency and intensity of extreme events (drought and dzud), which mainly focus on increasing the efficiency and effectiveness of current measures.

5.3 Results

In the first step, an expert team has prepared a long list of adaptation options on the base of identified adaptation options in previously conducted climate change studies. This includes the adaptation option that has been suggested by local officials as well as herders during a field survey conducted during 2002-2004 and the impact and vulnerability assessment results. The emphasis was on the agricultural sector and its related policies. The adaptation options also tried to ensure that their implementation would not be harmful to the environment. As many other developing countries, Mongolia is more concerned with immediate and pressing domestic issues such as economic development, public health, and education; addressing poverty is also one of the concerns that is being given particular attention, especially during the recent past.

Thus, in order to select the adaptation options that can be integrated into the country's overall sustainable development programme, all adaptation options in the list were prioritized using a simple approach the Screening Matrix and screened with the following three criteria:

- Does the option meet the objectives of both adaptation to climate change and development of the sector?
- Does the option meet the government policy (action plans and programmes in agriculture)?
- Does the option have any adverse impacts to the environment

After the selection of adaptation options using the above three criteria, the options were also assessed against six additional criteria to compare the proposed options in terms of which measures are expected to contribute more or less to the reduction of the livestock sector's vulnerability:

- Is this option a high priority? Priority of the option considers the priority of particular measures among the adaptation measures and refers to how the suggested adaptation options are being practiced in the country with, or without consideration of climate change.
- Is the option in the target of opportunity? Opportunity considers the relative importance of climate change in comparison to other exogenous developments and to possible positive or negative side-effects of the proposed options.
- How effective is the option? Effectiveness to reduce the negative impacts through the reduction of key impacts such as loss of pasture quantity and quality, animal weight decrease, lack of water supply, and vulnerability to drought, dzud and other extremes. This considers the expected climate changes as being superimposed on alternative development options and a comparison among options is made of the changes between conditions with and without climate change scenarios, even if climate does not change
- Does the option have benefits? Benefits expected from the implementation of adaptation options consider not only economic measures but also the conservation of the pasture and its ecosystem.
- How expensive the option to implement considers the feasibility for implementation. Costs of measures considered all costs involved, including investments, and operation and maintenance costs.
- Is there any barrier for implementation? Barriers for implementation consider technical, social, financial and institutional aspects. Social aspects include whether the adaptation measure

interferes with the interest of local people. Institutional aspects relate to all management and legal issues involved in the planning, implementation and maintenance.

These criteria are more desirable to indicate the conditions of adaptation options in not only mitigating impacts of climate change but also the overall potential for sustainable development.

Adaptation options are qualitatively ranked as high (H), medium (M) and low (L) against the criteria to indicate the preference. An adaptation measure was identified as high priority as long as it was effective, technically feasible, socially acceptable, financially recoverably and could be implemented under the existing or an improved institutional and legal framework in Mongolia.

The identified adaptation options have been discussed in three level multi-stakeholder workshops in order to select the potential adaptation options with wider involvement of different stakeholders.

Local workshops. Much of the actual implementation will be carried out at the level of the household or communities level. On the one hand, these levels possess substantial accumulated indigenous knowledge and experience on how to best to manage the problems faced. On the other hand, the local community or herders are the potential beneficiaries of successful implementation of adaptation measures. Besides, the local authority is the most responsible organization to manage the implementation of the potential adaptation measures in the livestock sector. Therefore, to arrive at a sound understanding of the people's potential and ensure their commitments in implementation, three workshops were held at a local community, including different pasture ecosystems, namely: Gobi-steppe region, Steppe region, High mountain and Forest region. More than 200 participants attended the workshops, including local governors, and animal experts such as veterinarians, environmentalist, climatologists and herders.

Almost all the adaptation options that were prepared by the expert team have been accepted by the local experts, as well as the herders. The adaptation option to ownership of the pasture and water supply points was not accepted by more than 98 per cent of participants. It was found that financial and material shortage, inadequate information and remoteness from market were also among the major constraints. Therefore, the participants emphasized the importance of education and training, financial and management support in the implementation of adaptation measures. Most importantly, the participants stressed the need for interaction between scientific and local indigenous knowledge to cope with climate variability and to move from study, assessment, and discussion to actual implementation of adaptation measures.

Workshop with scientists. The implementation of many adaptation options requires the support and interaction of scientific and advanced knowledge. Therefore, the results from local workshops regarding the selected adaptation options were discussed with leading scientists of animal husbandry and pasture management, through lectures with students of state as well as private agricultural universities. The focus of these discussions was on the following issues:

- What is the role of scientists in the implementation of adaptation measures?
- What should be done to introduce new varieties of pasture plants that are resistant to drought to facilitate adaptations to improve pasture quality, and develop cultivated or irrigated pasture?
- What should be done to improve the productivity of animals?
- How should know-how be transferred on mechanic and automatic equipment or appliances to facilitate the manual labor of herders?
- What is the scientific, technical, and financial capacity of the institutions to support the implementation of adaptation measures?
- What should be done to improve the capacity of institutions and how should the barriers be overcome?

One of the serious concerns that was raised at these local workshops was the shortage in educated personnel to take care of rural education, grazing management and social and economic issues. The local communities suggested during the workshops that students should go back to their home province after graduation and take the responsibility of reforms in the pastoral system along with globalization. Therefore, participants also paid some attention in what should be done.

The recommended adaptation measures based on the discussions with the above two levels are classified into five main groups as follows: (a) conservation of the natural resources; (b) strengthening animal bio-capacity; (c) proper management to enhance the livelihood of rural community; (d) food security and supply; and (e) climate extreme forecasting and monitoring (Table 5.1).

Vulnerability	**Mass death of livestock, increased poverty in rural area and overall decline in national economy of Mongolia**							
Climate drivers	**Drought, harsh winter (locally known as *dzud*) extremely low temperature, high snowfall, snowstorms**							
		Evaluation criteria						
Adaptation objective	Adaptation measures	current capacity	opportunity	effectiveness	benefits	cost	barrier	Expected results
Improved integrated pasture management	Improve grazing management	M	H	H	H	L	S&m	increased conservation of nature and ecosystem
	Introduce cultivated pasture	L	M	H	H	H	F	reduced dependency on climate, increased opportunity to develop intensive livestock industry
	Improve pasture yield	L	M	M	H	H	T&F	Increased feed, reduced vulnerability to drought and *dzud*.
	Improve pasture water supply	L	H	H	H	H	T&F	better use of pasture and stock survival, ecosystem conservation and rural development.
	Legislate possession of pasture	M	M	M	M	L	S&m	effective development of cultivated pasture
	Introduce taxation of pasture	L	M	M	M	L	S	increased conservation of nature and ecosystem
	Livestock population control according to the pasture capacity	M	M	M	M	H	S	increased conservation of nature and ecosystem
Increased strengthening animal bio-capacity	Improve shelter for animals	M	H	H	M	M	F	reduced vulnerability to climate extremes not only dzud but also snow and wind surges and others
	Increased supplementary feed	M	H	H	H	M	N&F	reduced vulnerability to and minimize loss of animals during drought/*dzud*,
	Improve per animal productivity	L	H	H	H	H	T&F	increased income and livelihood
	Introduce genetic engineering	L	H	H	H	M	T&F	increased productivity and breeds
	Improve veterinary services	M	H	H	H	H	T&F	decreased disease
	Introduce high productive cross breeds	L	H	H	H	H	T&F	increased animal quality and income, reduced vulnerability
Enhanced livelihood of rural community	Promote collective communities	M	H	M	H	M	S&m	increased capacity to cope with climate driving disasters and increased livelihood

	Develop/transfer new technologies	M	H	H	H	H	T&F	increased opportunity to develop intensive livestock industry
	Expand access to credit and generate alternative income	L	H	M	H	H	m	increased financial capacity
	Expand the supply of renewable energy applications to herders	M	H	H	H	M	T&F	increased livelihood
	Promote and support the establishment of different kind of enterprises	L	M	M	H	H	T&F	the base to develop intensive livestock industry
	Establish insurance system of animals	L	M	M	M	H	T&F	reduced vulnerability to climate extremes and decreased poverty
	Establish risk fund	L	H	M	H	H	F&m	reduced vulnerability to climate extremes and decreased poverty
	Prepare educated herders	L	M	M	H	M	S	increased opportunity to develop intensive livestock industry
	Training of young herders	H	H	M	H	M	L	increased capacity
Increased food security and supply	Expand dairy and meat farms close to big cities to meet the demand of milk and other dairy products	M	H	H	H	H	T&F	increased opportunity to develop intensive livestock industry
	Promote and expand other food supply farms / egg, vegetables /	M	H	H	H	H	T&F	
Climate Change study	Establish climate change monitoring stations	H	H	H	H	H	T&F	increased scientific knowledge in climate change studies
	Improve forecasting system of extreme events	H	H	H	H	H	T&F	
Note: H-high, M-medium, L-low, F-financial, T-technical, S-social, m-management,								

Table 5.1: Adaptation Measures

Workshop with policy and decision makers. Successful implementation of adaptation measures directly and indirectly depends on actions and decisions of leading, as well as planning organizations. Thus, the adaptation measures were presented to policy makers including those from the Ministry for Nature and Environment, Ministry of Food and Agriculture, Agency of Civil Defense, Ministry of Building and City Infrastructure, Institute of Meteorology and Hydrology and Institute of Geography. The focus of the meetings with policy makers was to draw their attention to the impacts of climate change, and urge their action in implementation of adaptation measures and integration of adaptation measure in development plan.

Livestock depends to a great extent on the availability of pasture resources. The demands of the animal to survive and be productive must continually be balanced with the availability of feed and water. Therefore, its vulnerability depends on sustainable pasture management. The latter is aimed at increasing livestock productivity as well as the high-level maintenance of pastures.

Adaptation measures to reduce the impacts of long-term changes on livestock sector will mainly focus on improved pasture yield, including the *revival of traditional pasture management*, which involves the use of one pasture only for the length of one season; *restoration of degraded pasture*, including reforestation of flood plains and increased vegetation cover; *expansion/rehabilitation of pasture water supply, development of irrigated pasture, modifying the schedule of grazing*; and others. It is also important that the livestock do not exceed the carrying capacity of the pasture. Even though the feasibility of these adaptation measures is promising, it will require adequate training, time, management, and financing.

Revival of traditional pasture management: On the basis of the adaptation assessment, maps of the traditional seasonal camping area (Figure 5.1); and ecological zones of pasture (Figure 5.2) with its moving technologies and ecological pasture for livestock herding have been prepared and documented as a reference to improved grazing management.

The Mongolian pasture has been divided/classified into five major ecological zones for livestock herding (Figure 5.2) according to the climate condition, grassland type and landscape:

1. Altain mountain ecological zones that represent a combination of the high mountain vertical belt and dry steppe landscape.
2. Khangai-Khentein mountain ecological zones that represent a combination of the high mountain belt and river valley dry steppe landscape.
3. Central ecological zones that represent the forest-steppe and steppe landscape.
4. North Gobian ecological zones that represent the steppe and desert-steppe landscape.
5. South Gobian ecological zones that represent the desert-steppe.

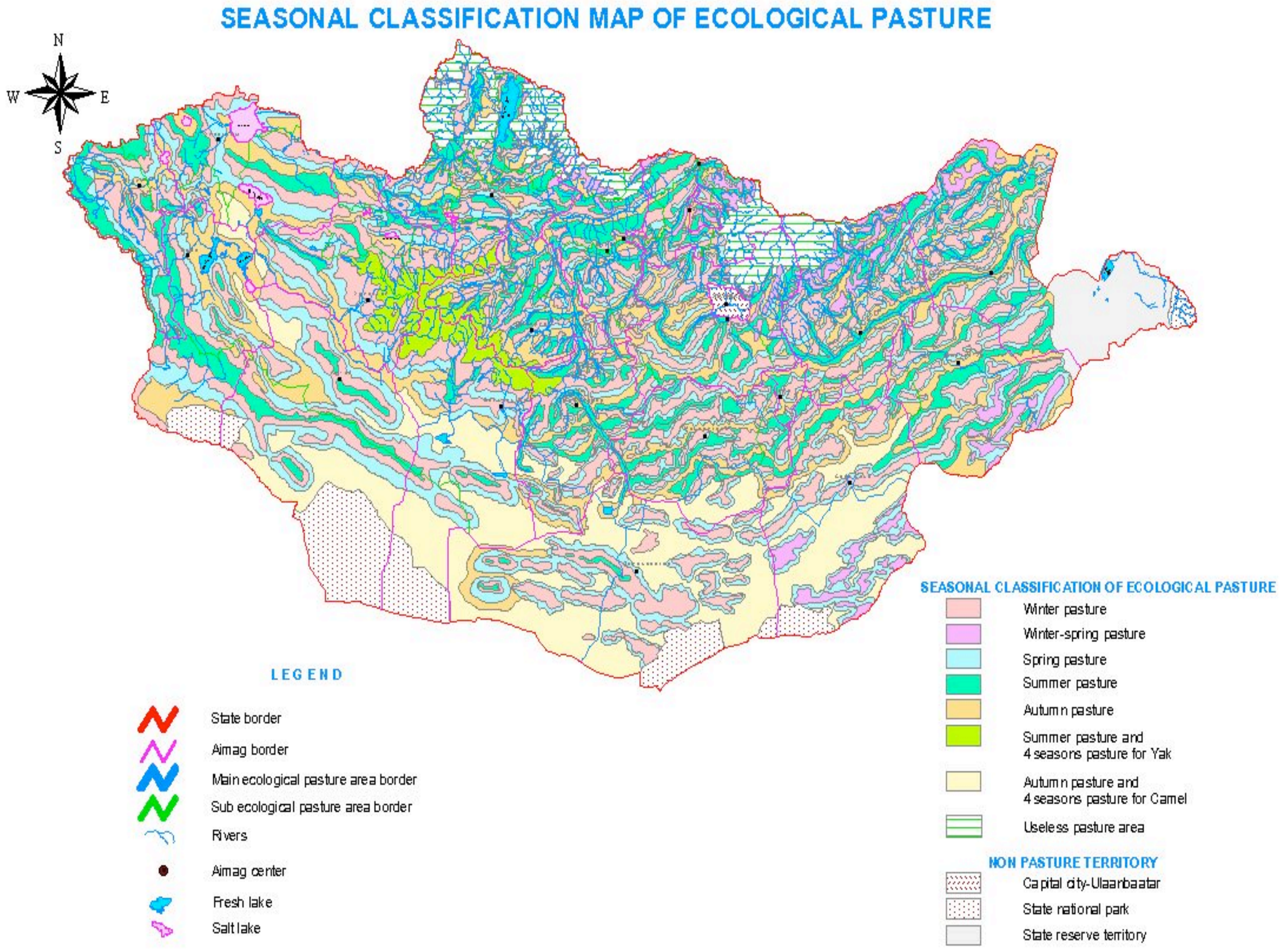


Figure 5.1: Map of seasonal classification of pasture

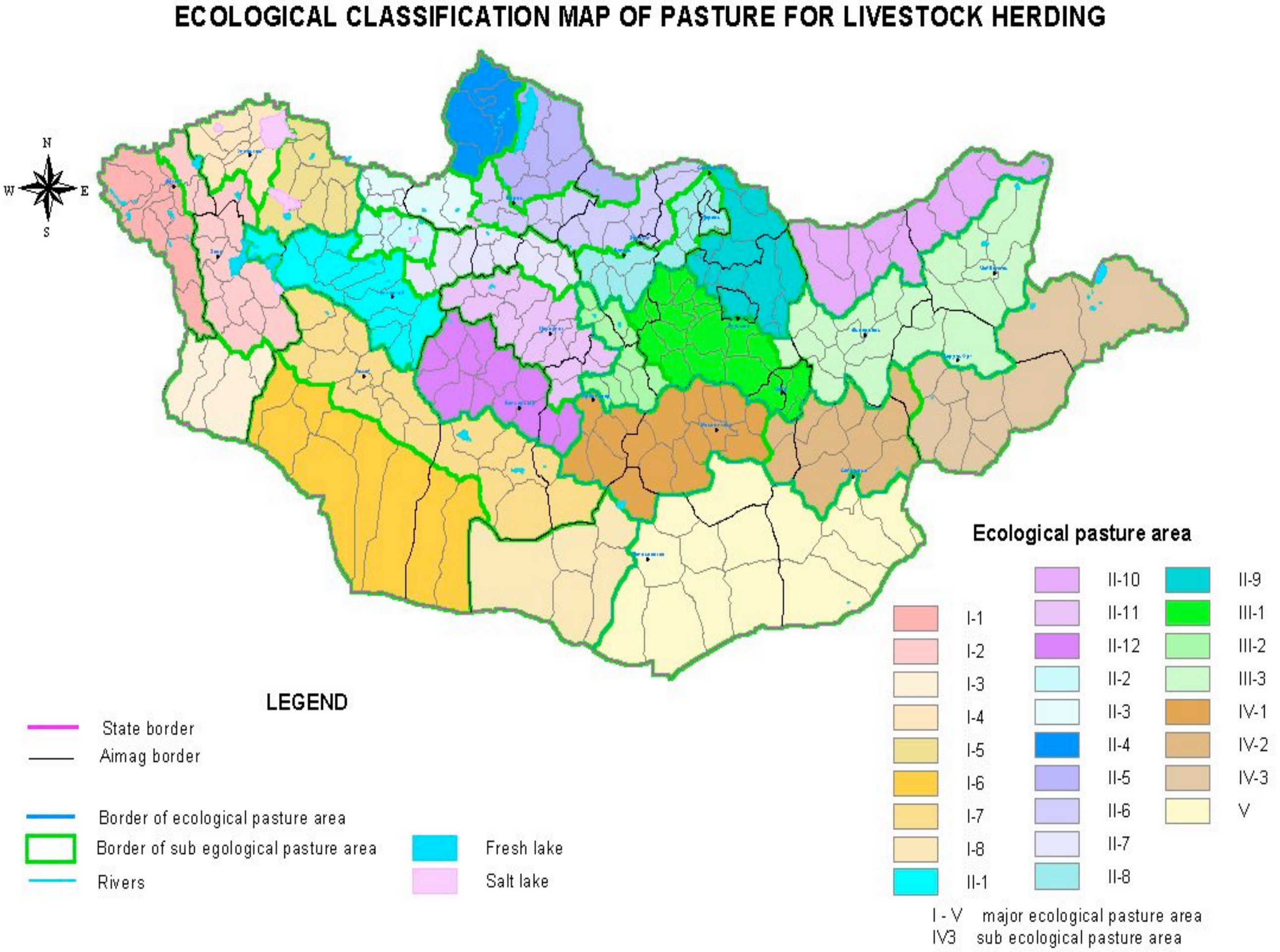
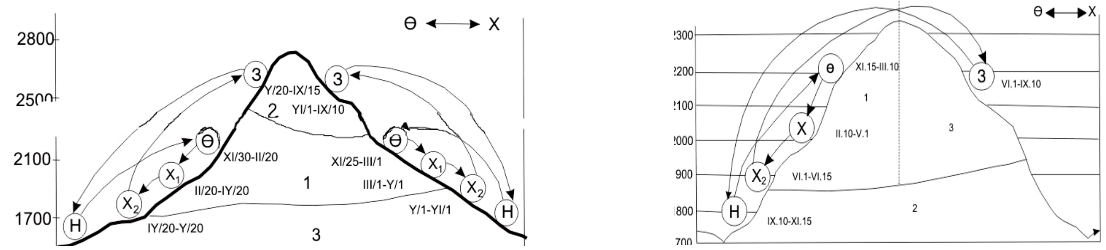


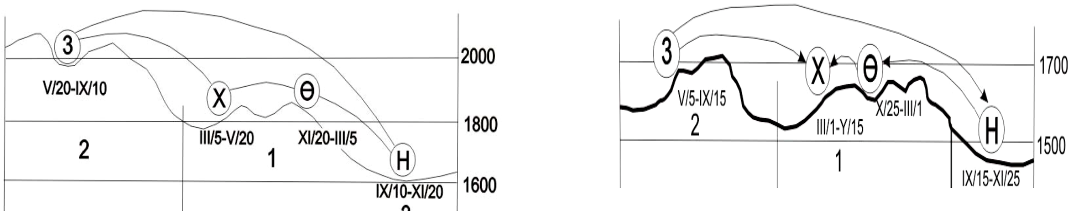
Figure 5.2: Map of ecological classification of pasture for livestock herding

The traditional seasonal pasture grazing technologies (Figure 5.3) with sufficient reserves for emergency cases and grazing with due consideration of growth phases of vegetation and recovery after previous grazing, and taking livestock to more distant fattening pastures (otor) clearly demonstrated its resilience and sustainability. The traditional vertical movement cycle practice within ecological zones for livestock herding is usually determined according to the access to forage, water, and, in some cases, availability of shelter for livestock.



High mountain

Mountain and forest steppe



Forest steppe and steppe

steppe and desert steppe

Q - winter camp, X - spring camp, Ç - summer camp, H - autumn camp, ⟶ movement way

Figure 5.3: Traditional seasonal movement in different region

Modification of grazing schedule from mid-day hours to early morning or late evening hours to allow livestock to spend extended time on the pasture to compensate for the reduced grazing time due to summer high temperature stress could be one of the adaptation options to climate change. As simulation results show in the future warm climate condition, the grazing time should be extended by at least six hours by 2020, and even longer by 2050 and 2080 (Table 5.2 and 5.3). To extend the grazing time by 6-8 hours is practically impossible. The demands of the animal to survive and be productive must continually be balanced with the availability of feed and water. Thus, modification of the grazing schedule should be combined with other relevant measures.

Ecosystem zone	Grazing time					
	0	2	4	6	8	10
HADCM3						
2020						
Forest steppe	-1.71	-1.06	-0.36	0.24		
Steppe	-2.19	-1.18	-0.30	0.43		
High mountain	-0.20	0.34	0.71	1.12		
Gobi desert	0.43	0.52	0.62	1.05		
2050						
Forest steppe	-5.50	-3.68	-2.25	-1.16	-0.33	
Steppe	-5.27	-3.53	-2.48	-1.21	-0.26	
High mountain	-1.17	-0.63	-0.19	0.20	0.58	
Gobi desert	0.25	0.55	0.69	0.80	0.92	
2080						
Forest steppe	-8.11	-6.22	-4.39	-2.56	-1.65	-0.50
Steppe	-6.38	-4.61	-2.99	-1.54	-0.56	0.06
High mountain	-1.60	-0.99	-0.54	0.03	0.32	0.69
Gobi desert	-0.14	0.00	0.17	0.28	0.42	0.61
ECHAM						
2020						
Forest steppe	-1.64	-1.16	-0.48	0.08		
Steppe	-1.90	-1.29	-0.68	-0.12		
High mountain	-0.57	-0.12	-0.07	0.24		
Gobi desert	0.54	0.67	0.89	1.26		
2050						
Forest steppe	-4.89	-3.11	-1.92	-1.02	-0.31	
Steppe	-5.36	-3.61	-2.48	-1.21	-0.30	
High mountain	-2.98	-1.56	-0.48	-0.09	0.24	
Gobi desert	-0.56	-0.11	0.26	0.65	0.88	
2080						
Forest steppe	-7.51	-5.33	-4.39	-2.56	-1.65	-0.23
Steppe	-8.39	-6.45	-3.66	-1.54	-0.56	-0.24
High mountain	-2.69	-0.99	-0.54	0.03	0.12	0.44
Gobi desert	-1.44	0.00	0.17	0.28	0.42	0.54
CSIRO						
2020						
Forest steppe	-1.63	-1.02	-0.24	-0.04		
Steppe	-1.89	-1.21	-0.31	-0.06		
High mountain	-0.63	-0.24	-0.07	0.54		
Gobi desert	-0.81	-0.49	-0.14	0.33		
2050						
Forest steppe	-4.21	-3.21	-2.08	-1.03	-0.19	
Steppe	-3.98	-2.56	-1.69	-0.98	0.02	
High mountain	-2.67	-2.07	-1.36	-0.48	-0.04	
Gobi desert	-2.48	-1.95	-1.36	-0.62	0.02	
2080						
Forest steppe	-7.21	-5.87	-3.74	-2.14	-1.11	-0.41
Steppe	-6.38	-4.06	-2.84	-1.94	-0.92	-0.09
High mountain	-3.99	-3.05	-2.14	-1.21	-0.36	0.02
Gobi desert	-3.64	-3.11	-2.31	-1.24	-0.48	-0.08

Table 5.2: Projected modification of grazing time to reduce a loss of weight gain in summer

Ecosystem zone	Grazing time			
	0	1	2	3
HADCM3				
2020				
Forest steppe	-0.29	-0.21	-0.06	0.08
Steppe	-0.30	-0.20	-0.02	0.10
High mountain	0.01	0.15	0.21	0.29
Gobi desert	0.11	0.15	0.26	0.31
2050				
Forest steppe	-0.80	-0.61	-0.37	-0.16
Steppe	-0.49	-0.32	-0.05	0.03
High mountain	-0.59	-0.37	-0.23	-0.09
Gobi desert	0.02	0.05	0.09	0.14
2080				
Forest steppe	-2.44	-2.05	-1.21	-0.71
Steppe	-1.99	-1.68	-1.48	-0.63
High mountain	-2.25	-1.92	-1.64	-1.01
Gobi desert	-1.45	-1.25	-1.03	-0.41
ECHAM				
2020				
Forest steppe	-0.26	-0.24	-0.11	-0.08
Steppe	-0.32	-0.26	-0.09	-0.04
High mountain	-0.24	-0.11	0.01	0.06
Gobi desert	0.01	0.08	0.12	0.19
2050				
Forest steppe	-0.59	-0.41	-0.34	-0.12
Steppe	-0.77	-0.48	-0.12	-0.14
High mountain	-0.43	-0.33	-0.15	0.03
Gobi desert	-0.16	-0.01	0.06	0.11
2080				
Forest steppe	-2.04	-1.68	-1.42	-0.56
Steppe	-2.23	-1.86	-1.33	-0.91
High mountain	-1.82	-1.84	-1.09	-0.45
Gobi desert	-1.33	-1.05	-0.44	-0.24
CSIRO				
2020				
Forest steppe	-0.16	-0.06	0.01	0.06
Steppe	-0.22	-0.17	-0.06	0.05
High mountain	-0.26	-0.19	-0.08	0.04
Gobi desert	-0.11	-0.04	0.02	0.12
2050				
Forest steppe	-0.44	-0.32	-0.26	-0.03
Steppe	-0.48	-0.36	-0.12	-0.04
High mountain	-0.43	-0.48	-0.15	-0.04
Gobi desert	-0.23	-0.12	-0.02	0.08
2080				
Forest steppe	-1.77	-1.42	-1.11	-0.26
Steppe	-1.82	-1.60	-1.18	-0.63
High mountain	-0.96	-0.74	-0.43	-0.22
Gobi desert	-0.78	-0.62	-0.31	-0.11

Table 5.3: Projected modification of grazing time to reduce a loss of weight gain in winter

Adaptation measures for *increased livestock productivity* would be to increase livestock weight or livestock bio-capacity by utilizing different kinds of supplementary feed, not only in winter but also in summer to increase daily feed intake due to decreased grazing time. Simulation results show 1.9-3.3 kg/day supplemental feed will be required to feed a sheep in the summer of 2020 in order to compensate the projected weight decrease by this time (Table 5.4).

Natural zones	Time period		
	2020	2050	2080
Forest-steppe	3.0	3.4	3.6
Steppe	3.3	4.2	4.6
High mountain	1.9	2.3	2.8
GobiDesert	-	-	2.1

Table 5.4: Estimated supplemental feed required to compensate the projected decrease of animal weight

Adaptation measures to reduce the vulnerability to summer drought and winter *dzud* includes an increased feed reserve for livestock and pasture reserve for harsh winter. The latter means allocating plots of pasture that are not used in summer. Fattening of animals during the warm season also greatly improves the adaptive capacity of animals during winters. The reservation of sufficient amounts of supplemental feed is most essential to be used to rebuild the strength of animals during drought and *dzud* conditions i.e., the primary objective in supplementary feeding is to minimize the loss of animals. The feed reserve can be improved by increasing hay-making, sown fodder, feed manufacturing and increasing indigenous (plant and non-plant) feed preparation.

Establishment of *cultivated pasture* will reduce the livestock dependency on nature and climate. A successful implementation of this measure would greatly reduce not only the expected impact of climate change but also the vulnerability to drought and harsh winters (*dzud)*. Possession of land is not the most important driving force of a society engaged in pastoral livestock production; rather, having access to pasture and to water and shelter resources necessary to permit optimal livestock production has been the focus of Mongolian pastoralism. Privatization of pasture is not conducive to maintaining the traditional or even current pastoral livestock system in Mongolia. However, ownership/possession of land often increases investment, since the land would be managed as a capital in which investments must be made to promote sustainability and prevent land degradation. Therefore, cultivated pasture development would be feasible in case where the land tenure is legally certified. On the other hand, the measure is costly because it will require sufficient irrigation, good seeds, and application of fertilizers.

There are strong arguments in favour of increasing security of tenure over pastureland in Mongolia's extensive livestock sector, in order to promote sustainable land management and reduce conflicts over pasture. However, herders were willing to have small pasture areas near the winter/spring camps for emergency use. Policy/decision makers as well as herder still need to find an appropriate approach to applying solutions to this issue.

Increased vegetation cover of pasture by different varieties of perennials that are tolerant to drought is also a good adaptation option to increase pasture yield and restoration of degraded pasture. The feasibility of this measure depends on seed availability for such varieties of perennial pastures. the willingness of herders to bear the responsibility is also important.

Expansion and rehabilitation of pasture water supply is another promising measure for improved pasture utilization, and stock survival, as well as ecosystem conservation and rural development. However, implementation of this measure would require high investment.

Current demonstrations of community-based adaptation, where the community decides on how to share the limited common resource shows this is a promising adaptation measure. Further strengthening of the collective actions among herders with involvement of livestock experts and feed preparatory groups in the community will certainly help to find the solution and implementation mechanisms/tools to encourage herders in adapting to climate change. The community's decision making is based on knowledge of livestock behavior and its needs. This includes knowledge of the set of physical and biological resources available to satisfy needs of the livestock in the environment, which is very important in not only the conservation of natural pasture but also to enhance an adaptive capacity.

Expand access to credit. Herders need flexible access to credit for financing (to purchase feed for animals, equipment for improvement of pasture, adopting new technologies and for investment in high quality animals, etc.). Increased access to credit would greatly help increasing their adaptive capacity and successful adaptation to climate change.

Research, training, strengthening and building upon existing capacity might be the most important measure in strengthening the adaptive capacity and ensuring the community livelihoods. It is also important that more feasible and workable instruments are devised to influence local habits and traditions for the successful implementation of adaptations. This can be reached by educating herdsmen and increasing their awareness with respect to environmental degradation and climate change. Research and training must be maintained and expanded at the herders' level.

Improvement of the *forecasting* and *warning systems* are also essential, although implementation could be deterred by institutional and communication infrastructure. Increased disaster forecasting especially drought and *dzud* would, however, help in preparing to meet potential dangers

Barriers: There are certainly many barriers for the implementation of adaptation measures, including financial, technical and human resources, and institutional capacity, legislative framework, and public support. The most widely recognized barriers are considered below.

- *Institutional*: Problems in Mongolia seem more or less recognized on sectoral levels, and they are being addressed to a certain extent. However, there is no coordination of sectoral actions and the responsibilities are not clearly distinguished between sectors.
- *Financial:* Due to the economic difficulties in Mongolia, as the county is undergoing a transition period, the government fails to resolve financing issues. Lack of financial resources for initial investments would limit the implementation of the measures.
- *Technical:* Lack of appropriate technologies and know-how is the most urgent technical problem.
- *Legislative:* Adequate policies and strategies should be established both at the national and the local level. At the moment, the legal, regulatory and standardization framework for pasture use are inadequate to effectively implement some of the adaptation measures.

Who is responsible for adaptation: The identified measures would involve a range of possible actors. Long-term concerns with respect to sustainable use of pasture resources is generally the responsibility of the national government, since the pasture is state owned. Hence, the implementation of adaptation measures should first be on national planning organizations. But successful adaptation requires coordination between central and local levels of management. Adaptation to long-term changes will especially require a combination of measures at the local level as well. Participation of national and local governments, scientists, and herders is equally important in the implementation of any of the adaptation measures.

Who should pay for the costs of adaptation: Implementation of most of the adaptation measures requires heavy investments. Mongolia has many other socio-economic problems and financial constraints. Therefore, it is important that at the national planning level, the available funds are more clearly prioritized and allocated according to the objective of the economic and technical criteria.

There are many regional and global programmes related to the implementation of the UNFCCC targets. The Global Environment Facility (GEF) provides financial support to cover the incremental cost in developing countries and those with economies in transition to protect and manage the global environment, including climate change. Therefore, the other way to find financing in implementation of adaptation measures could be to develop adaptation projects under the GEF funding through its implementing agencies like UNDP, UNEP and the World Bank. Also, Mongolia should participate in regional, sub-regional and bilateral co-operations and initiatives on climate change-related issues, so that it can gather more experience and knowledge on adaptations to climate change.

5.4 Conclusions

Mongolian pastoral livestock sector is highly sensitive to climate change impacts. Considering the livestock-based subsistence economy, and that almost half of the population is engaged in that sector, adaptations to climate change impacts are vital in achieving sustainable development. The key risks from climate change to livestock are increased incidence of drought and *dzud* (harsh winter).

Several adaptation measures have been recommended on the base of findings from this study. The selected adaptation measures include: *(a)* conservation of the natural resources; *(b)* strengthening animal bio-capacity; *(c)* management to enhance the livelihood of rural community; *(d)* food security and supply; and *(e)* climate extreme forecasting and monitoring. The interaction between forage condition and feed availability and timing of feed availability and animal body condition is basic to all pastoral livestock production. Adaptations for the purpose of improving the economic sustainability of livestock production and the ecological sustainability of natural resources used in livestock production is focused on improving feed availability to livestock during annual production cycles. Reduction of vulnerability of livestock to impacts of climate change through the suggested adaptation measures requires actions in a coordinated way and incorporation in long-term planning.

Many of the actions to remove or palliate barriers require administrative decisions or actions. This includes the definition and granting of grazing rights, probably emphasizing winter camps and hay lands in the first instance; a structure for the organization of the herding population so that they can participate in the regulation of local land use, as well as pasture management, development, and maintenance, all of which must have users' participation; and monitoring of pasture condition and regulation of its use. This will also require the participation of herders' associations as well as the establishment of guidelines on the use of grazing land.

The suggested adaptations are useful in coping with climate change. However, it may make sense to start with existing adaptations that people have already made to deal with climate-related phenomena.

6. Capacity Building Outcomes and Remaining Needs

The project is designed to enhance capacity building in the country, especially involving young scientists in global change research.

Data collection and management is improved: Key and activity data gaps reduced. The climate-animal observation site to represent Desert-steppe zone was established and installed in Umno-Gobi aimag. Networked data base of the climate change studies results have been established and this networked database is based on Windows Server 2000 as operating system. The new feature of the system is Terminal Services adds terminal support to the Windows 2000 Server. This database is linked to the web-site.

National information exchange network established: There have been organised three regional workshops. During these workshops national climate change related information exchange network established. Directors of the Centre for meteorology, hydrology and environment monitoring are the focal person of this network. Annual and final output of the project were published as a book and disseminated. But this network is still informal.

A multi-disciplinary team of scientists has worked: A multi-disciplinary team of scientists from Ministry of Nature and Environment, Institute of Meteorology and Hydrology, Institute of Botany from Mongolian Academy of Sciences; Computer Information Center, National Agency for Meteorology, Hydrology and Environment Monitoring; Institute of Geography, Institute of Agriculture, Institute of Livestock and others have worked in this collaborative project. In total 48 experts (including contractors and graduate students) have involved in implementation of the project. National experts on climate change study have been increased 4 times i.e. about 80 per cent of the team member was those who had not been involved in previous climate change studies.

Permanent climate-animal observation site established: Established and equipped climate-animal observation site in Umno-Gobi aimag to represent Desert-steppe zone and provided training.

12 members of the project team have participated in training other workshops organized by AIACC.

Lessons learnt: The research under Assessments of Impacts and Adaptations to Climate Change (AIACC) has provided much useful information about the impact, vulnerability and adaptation to climate change for the livestock sector of Mongolia. The project has not only enabled greatly to be integrated the results from the field survey as well as the socio-economic case study with climate change research but also highly engaged the participation of communities at grassroots.

We also make quite a progress in developing of new approach in impact and vulnerability assessment.

Major and very important needs we have to contact are

- Develop adaptation action programme on the base of our study.
- Develop pilot programme on integrated pasture management on the base of results case study and demonstrate
- Conduct more training and capacity building at the grassroots.

7. National Communications, Science-Policy Linkages and Stakeholder Engagement

The ministry most closely involved in climate change and environmental problem is the Ministry of Nature and Environment (MNE). The National Agency for Meteorology, Hydrology and Environment Monitoring (NAMHEM), which is directly under the responsibility of the MNE, is responsible for coordinating the work under the NCCSAP. The Agency has been designated by the government as the lead agency for climate change issues in the country. The Institute of Meteorology and Hydrology (IMH) which is directly under the responsibility of the NAMHEM, conducts climate change research, which includes departments dealing with agricultural climate and water resources management and others. The final, annual, and semi-annual reports and all other outcomes of the project have been submitted to the MNE, HAMHEM and IMH. This project was administrated by IMH and Dr. Bayasgalan, deputy director of the Environmental Impacts Assessment, MNE, has been designated the director of the project by the minister. MNE is now the implementation organization of the second national communication and Dr. Bayasgalan designated a coordinating officer, thus the results of our project will be the direct input to the second national communication.

One member of our project is participating in the IPCC IV assessment report being Lead author of chapter 5 and 10.

Stakeholder participation was enhanced: Partnership development for information exchange, knowledge sharing among the stakeholders of climate change study and livestock sector (researchers – content developers and user-decision makers, bodies responsible for policy development and implementation, general public) was one of the key priority tasks in project management. We achieved this goal through different mechanisms such as workshops, direct involvement of different stakeholders in the day to day activity of the project and round table discussion and were built into the project to ensure maximum stakeholder participation. The project Technical Expert Team consisted from the key policy makers (Parliament member, Ministry for Nature and Environment, Ministry of Food and Agriculture), experts and scientists from related agencies, research institutes, consulting companies, and NGOs to implement the project.

We have organized 12 workshops at local, scientists and policy/decision makes level. More than 1000 people made their contribution to the project activity through these workshops and interview, informal discussions and questionnaires obtained during field survey conducted in 2002-2004.

8. Outputs of the Project

Final as well as annual results of the project published as a series book and summary for policy makes in Mongolian language. This books are for various public and distributed to libraries of universities, research institutions, local governors office of each province (these are 22), ministries and Central State Library. Executive summary has published in English and distributed to representatives of international organization located in Mongolia.

8.1 Books

1. Mongolia climate change and its projections, 2005, ISBN: 99929-0-615-4
2. Impacts of climate change, 2005, ISBN: 99929-0-614-6
3. Vulnerability to climate change, 2005, ISBN: 99929-0-616-2
4. Adaptation to climate change, 2005, ISBN: 99929-0-613-8
5. Summary for Policy makes, 2005, ISBN: 99929-0-617-0
6. Executive summary, 2005, ISBN: 99929-0-617-0 (in English)
7. The Freshwater Systems of Western Mongolia's Great Lakes Basin: Opportunities and Challenges in the Face of Climate Change jointly with WWF Mongolia Programme office, 2004. ISBN: 99929-0-279-5 (in English)
8. Climate change: pasture - livestock. 2003.Synthesis report. ISBN: 99929-0-193-4
9. Regional climate change. 2002. Workshop proceedings.
10. Climate change impacts on agriculture 2002. Workshop proceedings.

There are have been published 24 papers in Mongolian language in different peer-reviewed special publications of institutions. 52 presentations have been made in international and national workshops during lifetime of the project. The full papers and abstracts most of presentations have been published in the workshop proceedings. Bellow is some papers and abstracts published in English:

8.2 Peer-reviewed

1. Chuluun, Togtohyn and Ayurzana Enh-Amgalan. 2003. Tragedy of commons during transition to market economy and alternative future for the Mongolian rangelands. African Journal of Range & Forage Science, vol. 20 (2): 115.
2. Ojima, Dennis, Togtohyn Chuluun and Boldyn Bolortsetseg. 2003. Climate change impact on rangeland productivity. African Journal of Range & Forage Science, vol. 20 (2): 154-155.
3. Batima P., 2002. Climate change impact on river ice regime in Mongolia. in *Ice in the Environment*. Proceedings of the 16th International Symposium on Ice. Volume one. 2-6 December 2002, Duneden, New Zealand. 122-126. (English).

8.3 Others

2002

1. Natsagdorj L and Tsatsral B., 2002. Studying of drought over Mongolia. in Extended abstracts of the Fifth China-Mongolia Workshop on Climate Change in Arid and Semi-Arid Regions over Central Asia. 12-14 August 2002. Xining, China. (English)

2. Erdenetuya M., Bolortsetseg B., 2002. Climate change impact to the pasture yield of Eastern steppe zone in *Proceedings of Mongolia-Russian joint workshop on "Regional Climate Change"*, 24-25 September 2002, Choibalsan, Dornod, Com: Batima P., Azzaya D., Khishigjargal N. pp. 53-60.
3. Gomboluudev P., Azzaya D., 2002. Climate Change Sceanrois in Mongolia, in *Proceedings of Mongolia-Russian workshop on "Regional Climate Change"*, 24-25
4. Batima P., 2002. Climate change impact on river ice regime in Mongolia. in *Extended abstracts of the International conference on Geographical study in Central Asia and Mongolia,* 9-11 September 2002, Ulaanbaatar. (English)
5. Batima P., 2002. Climate change impact on spring flood of the rivers in Mongolia. in *Extended abstracts of the First Mongolian and Korean Joint seminar in Environmental changes in North-East Asia*, 14-15 September 2002, Ulaanbaatar. (English)

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6. P.Gomboluudev. 2003. Experiment and Verification of Mesoscale Model (MM5V3) over the Mongolia. Proceedings: The 2nd Workshop on Regional Climate Modeling for Monsoon System. Yokohama, Japan, No 39, p33-38.
7. Dagvadorj.D, Gomboluudev.P, Natsagdorj.L, 2003. Climate change Concerns in Mongolia. Proceedings of the second Korea-Mongolia joint seminars on Global environmental changes of northeast Asia, p28-34.
8. Batima, P. L. Natsagdorj, B. Bolortsetseg, G. Tuvaansuren, B. Bayarbaatar, B. Erdenetsetseg, and N. Natsagsuren, 2003. Past and Present Changes in the Climate, Rangelands, and Livestock of Mongolia. AIACC Notes. June 2003. Volume 2, Issue 1: 7-8

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9. Gomboluudev P. and Natsagdorj L. 2004. Regional climate change simulations of summer season of Mongolia in "*Proceedings of the sixth international workshop on climate change in arid and semi-arid region of Asia*' Ulaanbaatar, Mongolia
10. Natsagdorj L., 2004. Climate factors of desertification. in "*Proceedings of the sixth international workshop on climate change in arid and semi-arid region of Asia*' Ulaanbaatar, Mongolia
11. Erdentuya M. and Bolortsetseg B., 2004. Monitoring of pasture productivity using long term satellite and ground observation data. in "*Proceedings of the sixth international workshop on climate change in arid and semi-arid region of Asia'* Ulaanbaatar, Mongolia
12. Ganbaatar T, Erdenetsetseg B, ¨Climate change impacts on natural resources base in "*Proceedings of the sixth international workshop on climate change in arid and semi-arid region of Asia'* Ulaanbaatar, Mongolia.
13. Batima P.,Batnasan N., and Bolormaa B. 2004. Trends in River and Lake Ice in Mongolia. AIACC Working Paper No.4.

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14. Natsagdorj L.and Gomboluudev P., 2005. Evaluation of Natural forcing to Desertification in Mongolia. in *Proceedings of National Conference: Mongolian Geoscientist*. Geology and Geo-ecology of Mongolia:7-18.
15. Tumerbaatar D., Battogtokh D., and Solongo D., 2005. Permafrost in Mongolia. in *Proceedings of National Conference: Mongolian Geoscientist*. Geology and Geo-ecology of Mongolia:62-67.
16. Erdenetuya M., Hudulmer S., Bolortsetseg B., Batima P., 2005. in *Proceedings of National Conference: Mongolian Geoscientist*. Geology and Geo-ecology of Mongolia:78-82.
17. Gomboluudev P., Natsagdorj L., Batbold A., Oyunjargal L., 2005. Mesoscale numerical case study and anaysis of cyclone development. In *Proceedings of First National Symphosium on Terristirial and Climate Change in Mongolia* . Ulaanbaatar. ADMON: 58-60.

18. Erdenetuya M., 2005.Assement of pasture land change using remote sensing data in Eastern steppe of Mongolia. In *Proceedings of First National Symphosium on Terristirial and Climate Change in Mongolia* . Ulaanbaatar. ADMON:124-126.

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Student thesis:

20. Erdenetuya M. Remote sensing methodology and technology for pasture monitoring. 24 Sep 2004. Ph.D. Mongolian National University.

9. Policy Implications and Future Directions

The Mongolian government perceives that any negative effects, which may be experienced from potential climate change, could be equivalent to a national disaster. Extreme climatic events with or without a superimposed change in climate could have tremendous adverse effects on Mongolian economy and social welfare.

This project has assisted the Mongolian government in implementation of the National action plan on climate change that was approved in July 2000 and prepare second national communications to the Conference of Parties (COP) as set forth in the UNFCCC. Specifically,

- Article 4.1 of the UNFCCC calls on all countries to formulate and implement programs to mitigate and adapt to climate change.
- Article 4.8 (c) and (e) of the UNFCCC specifically call for particular attention be paid to those countries with arid and semi-arid areas and countries with areas prone to drought and desertification.

Implementing this project, a climate change dialogue process, among governmental, non-governmental, academic, business, and grassroots sectors, has created and strengthened, with the intent to foster understanding of climate change issues such as vulnerability and adaptation and linkages with sustainable development strategies.

Information to reduce vulnerability was produced and discussed with the herders and local administration and policymaking to build adaptive capacity options in the context of development, sustainability and equity were evaluated in collaboration of all stakeholders.

In Mongolia, the national economy depends largely on livestock and harsh (locally known as *dzud*) is a real problem there and there are several government policies to reduce the impact of *dzud*, a climatic phenomenon. From this point of view many benefits will arise from an integrated adaptation-development policy. Taking into account that adaptation to climate change is a development issue and has to be part and parcel of any development plans, we have selected adaptation measures that will support the implementation of sectoral developmental policy documents (lows and action programmes) such as

- Protection of Livestock Gene Fund and Health Law
- State Reserve Law
- Cooperatives Law
- Improvement of livestock quality and reproduction
- Livestock health
- Social program on Development of Cooperatives
- Green revolution (Alternative source of income for herders)
- White revolution (Milk production)
- Food provision, security and nutrition
- Assisting to protect against drought and dzud disaster
- Elite breeding male sub program

In any event that the adverse impacts of climate projected do occur, the adaptation measures could then be made to reduce the vulnerability of the affected systems. But if they do not occur, the adaptation measures would still have brought real benefits to the not only the sector but also national development.

Recommendation to policy/decision makers produced and disseminated on the base of identified clear definition of climate change impacts on pasture, herd structure and production, and adaptation measures that will add new set of measures of climate change that enable agriculture and food sector to adapt to the potential climate change.

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