THESIS

LOCAL UNDERSTANDING OF HYDRO-CLIMATE CHANGES IN MONGOLIA

Submitted by

Tumenjargal Sukh

Department of Ecosystem Science and Sustainability

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Master's Committee:

Advisor: Steven Fassnacht

Melinda Laituri
Maria Fernandez-Gimenez
Greg Butters

ABSTRACT

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Air temperatures have increased more in semi-arid regions than in many other parts of the world. Mongolia has an arid/semi-arid climate where much of the population is dependent upon the limited water resources, especially herders. This paper combines herder observations of changes in water availability in streams and from groundwater with an analysis of climatic and hydrologic change from station data to illustrate the degree of change of Mongolian water resources.

We find that herders' local knowledge of hydro-climatic changes is similar to the station based analysis. However, station data are spatially limited, so local knowledge can provide finer scale information on climate and hydrology. We focus on two regions in central Mongolia: the Jinst soum in Bayankhongor aimag in the desert steppe region and the Ikh-Tamir soum in Arkhangai aimag in the mountain steppe.

As the temperatures have increased significantly (more in Ikh-Tamir than Jinst), precipitation amounts have decreased in Ikh-Tamir which corresponds to a decrease in streamflow, in particular, the average annual streamflow and the annual peak discharge. At Erdenemandal (Ikh-Tamir) the number of days with precipitation has decreased while at Horiult (Jinst) it has increased. Herders observed that the amount of precipitation has decreased (71% in Jinst; 100% in Ikh-Tamir) in recent years. The long-term average streamflow of the Tuin River at Jinst has not changed significantly while the herders have seen a depletion of water resources (73% of respondents). The Khoid Tamir River at Ikh-Tamir has seen a statistically significant decline in the average annual streamflow and the annual maximum daily discharge, which was also observed by all herders surveyed.

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CHAPTER 1. INTRODUCTION AND OVERVIEW

1.1 GLOBAL CLIMATE AND HYDROLOGICAL CHANGE

Climate can be defined as an ensemble of many weather phenomena. Climate change is one of the most important global environmental challenges facing humanity with implications for our living conditions, social-economic structures, and ecosystems (Ravindranath *et al.,* 2003). Climate will continue to change in the future (NRC, 2008). According to the 2007 Intergovernmental Panel on Climate Change (IPCC) report, temperature increase is widespread over the globe and is greater in higher latitudes in the northern hemisphere (IPCC, 2007). From 1906 to 2006, global mean surface temperatures have increased by 0.4 to 0.8^{o}C, averaging 0.74^{o}C. Observed surface temperature increases in central and northeastern Asia in recent decades have ranged between less than 1^{o}C to 3^{o}C per century with warming being more pronounced in the winter months than in the summer (Savellieva *et al.,* 2000). Warming is likely to increase more in dry continental environments than in other areas (IPCC, 2007).

As the climate changes, several influences alter precipitation amounts, intensity, frequency and timing. With an increase in temperature over the last 140 years of between 0.3^{o}C and 0.6^{o}C (Nicholls *et al.,* 2004), we might expect an increase in the observed global mean precipitation of between about 0.5 and 1.8 percent. World precipitation however, is spatially and temporally variable. For example, north of the equator in the Western Hemisphere the annual mean precipitable water amounts occurring below 500 mb have increased over the United States, Caribbean, and Hawai'i at a statistically significant rate of about 5% per decade from 1970-1995 (Ross and Elliott, 1996). In an earlier study, Hense *et al.* (1988), found increases in moisture over the western Pacific. The amount of precipitation recorded over much of Canada has not increased and decreases are evident where temperatures have declined in northeast Canada (Ross and Elliott, 1996). In China, analysis by Zhai and Eskridge (1997), revealed an upward trend in precipitable water annually for all seasons from 1970 to 1990. Accompanied by a weakened summer monsoon circulation, precipitation has increased over the mid reaches of Yangtze River valley yet decreased over north China (Hu 1997; Chen *et al*., 2004; Yu *et al*., 2004). Yu *et al.* (2010) found late summer (July-August) precipitation changes over eastern China, with patterns of southern flooding and northern drought being observed in recent decades. Warming combined with variable precipitation will accelerate land surface drying and will potentially increase incidence and severity of droughts. This has already been observed in many places worldwide (IPCC, 2007).

Climate changes can manifest in the varying distribution of extreme values, while the mean does not (Yan *et al.,* 2002). For example, Katz and Brown (1992) showed from a theoretical viewpoint that in a changing climate, extreme values are determined more by changes in variability than changes in the mean. One of the most significant impacts of climate change is likely an increase in the intensity and frequency of extreme weather events (Beniston, 2007). Possible changes in extreme events have received considerable attention in conjunction with global warming, since extreme events directly impact the human social and economic environment, particularly in the developing world. These extreme events include heat waves, cold spells, floods, droughts and storms (Fang, 2008). With a background of global warming, it is very important to identify the changes of summer warm extremes that comprise the warm tail of the temperature distribution function in the warm season. The joint World Meteorological Organization (WMO) Commission for Climatology (CCI) World Climate Research Programme (WCRP) project on Climate Variability and Predictability (CLIVAR) Expert Team on Climate

Change Detection and Indices (ETCCDI) developed a suite of climate change indices, which focus on extremes (Aguiler *et al.*, 2003). These extreme indices are calculated from monthly and daily temperature and/or precipitation data (Nandintsetseg *et al.,* 2007). Many regional and local extreme analyses have been performed using these extreme indices, such as in central England (Jones *et al.,* 1999), central and southeast Asia (Klein Tank *et al.,* 2006), Europe (Klein Tank and Konnen, 2003), South America (Vincent *et al.*, 2005), and Central America and northern South America (Aguiler *et al.,* 2003).

In China there has been a decrease in the number of cold days over the 20th century (Yan *et al.,* 2002) and an increase in the number of warm days since the 1960s (Klein Tank *et al.,* 2006). Liu *et al.* (2005) also found that the increased frequency of heavy precipitation events contributed 95% of the total increase in precipitation over the period of 1960 to 2000. IPCC (2008) reports also indicated that heavy precipitation events would become more frequent and intense. Intensity of precipitation events is projected to increase in some tropical and high latitude regions. Increased drying in mid-continental areas is likely to increase the risk of droughts in these regions (IPCC, 2007).

Climate change and variability have many effects on the hydrological cycle and thus on water resources. Many aspects of the environment, economy, and society are dependent upon water resources, and changes in the hydrological cycle have the potential to severely impact environmental quality, economic development and social well-being (Arnell, 1999). Hydrological changes over the last few decades are associated with changes in a number of components of the hydrological cycle. These include changes in precipitation intensity and frequency, snow melting, evaporation, and runoff (IPCC, 2008). Some of these changes can be linked with temperature increases, such as earlier snowmelt and its associated runoff (Stewart *et* *al.,* 2005) and increased evaporation (e.g., due to earlier snowmelt as presented by Painter *et al.*, 2010).

In the temperate regions of northern and eastern Europe, northern Asia, and North America, the largest annual runoff is derived from spring snowmelt (Shiklomanov, 1989). There are many studies of changes in annual and seasonal runoff and in streamflow distribution due to climate change in these regions (Shiklomanov, 1989). IPCC (2008) reported that global warming could affect the hydrological regimes in arid and semi-arid regions even if the changes in climate characteristics are minor. For instance, an increase in mean annual temperature of 1- 2^{0}C, and a 10% decrease in precipitation could reduce annual river runoff as much as 40 to 70% (IPCC, 2008). These reduction estimates are particularly important for river basins in areas of water shortages, including those in the USA, Australia, Russia and Africa (Shiklomanov, 1989). In a warmer climate, snow will melt earlier in the year (Barnett *et al.,* 2005). The rising temperatures and changes in precipitation patterns affect the timing of runoff, typically leading to earlier runoff in the winter and spring and reduced flows in summer and autumn (Barnett *et al.,* 2005). These changes in runoff have been recorded in many snowmelt-dominated basins across western North America since the 1940s (Mote, 2003; Stewart *et al.,* 2005; Regonda *et al.,* 2005). Snowfall and snow cover patterns have changed across parts of North America associated with an average annual temperature increase of 1 to 3^{o}C since the 1940s. This is especially due to increases in the winter and spring (Karl *et al.,* 1993; Vincent *et al.,* 1999; Stewart *et al.,* 2005).

In many regions of the world, determination of changes to streamflow patterns is of great concern since extreme weather events can increase the risk of larger and longer floods and/or longer duration droughts (Wang *et al.,* 2008). These changes to climate, hydrology, and increases in extreme weather events are the principal phenomenon that can increase the vulnerability of peoples dependent on weather conditions (Downing, 2001).

1.2 POTENTIAL IMPACTS OF CLIMATE CHANGE

Groups or individuals are exposed to stresses and shocks from the consequences of social and/or environmental change. Stresses (and shocks) refer to when people face unexpected and unfavorable risk and disturbance to their livelihood (Adger, 1999). This risk is often referred to as vulnerability. The degree of vulnerability is defined by the states of susceptibility to harm, which consists of three different components: exposure to harm and/or risk, sensitivity to harm, and adaptive capacity (Turner *et al.,* 2003; Adger, 2006). Thus, human welfare and livelihoods are at risk due to climate variability and extreme events such as floods, droughts, and other hazards, some with human origins (Hewitt, 1997). There are number of methods to measure an individual or group's vulnerability (Galvin *et al.,* 2004). Adger *et al.* (2001) suggested that vulnerability could be measured by combining poverty indicators with a measurement of the diversity of resources. In this case, vulnerability has been used to determine the degree of exposure combined with a geographical location (Adger, 1999). Hence, developing countries are more vulnerable to climate change due to, among other things, their lack of institutional capacity and weak economic power (Ravindranath *et al.,* 2003). Galvin *et al.* (2004) summarized that people in the developing world, such as nomadic pastoralists in Mongolia, were more affected by multiple stressors associated with climate change and therefore were more vulnerable. They are also at a high risk of suffering negative outcomes as a result of climatic variability. This research does not address the vulnerability of the Mongolian pastoralists, but examines hydro-climatic change from local knowledge and station analysis.

1.3 THE MONGOLIAN CONTEXT

Mongolia is a landlocked country in north central Asia, bounded on the north by Russia, and on the west, south and east by China. The topography of Mongolia consists of a high plateau surrounded by mountain ridges in the north and west and dry steppes and semi-deserts in the south with elevations ranging from 518 m (Hoh Nuur) to 4374 m (Khuiten Peak). It has a total area of 1,565,000 km^2 and is thus the 19th largest country in the world (Dagvadorj *et al.*, 2009). It is one of the largest countries with no access to the sea and with a population of 2.8 million, is the most sparsely populated country (National Statistics Office of Mongolia, 2011). The country has an extreme continental climate consisting of four seasons. Characterized by long and cold winters, dry and hot summers with a distinct spring and autumn (Ma, 2003). Ecologically, the country is divided into six ecological regions: high mountains, taiga, forest steppe, steppe, desert-steppe, and desert (Marin, 2010).

Mongolian rangelands cover over 83% of the country's landscape (Angerer *et al.*, 2008). Rangeland health is threatened by pressure from changes in livestock herd numbers and composition, traditional management and nomadic use patterns and desertification (Angerer *et al.*, 2008; Dagvadorj *et al.*, 2009). Increasing urban expansion, increased mining, and changes in climate are also environmental threats affecting pastoralists (Dagvadorj *et al.*, 2009).

The condition of steppe vegetation directly affects livestock health, which is critical to herder livelihoods. Vegetation distribution and condition has been directly affected by changes in climate due to changes in temperature and water supply (e.g. Yu *et al.*, 2003; Angerer *et al.,* 2008). Mountain steppe areas in Mongolia are some of the most productive in terms of forage for livestock and also act as a source of water for adjoining arid steppe regions (Angerer *et al.*, 2008; Fassnacht *et al.*, 2011b).

In general, the amount of precipitation in Mongolia is low. Annual mean precipitation ranges between 50-100 mm in the southern Gobi desert-steppe, 300-400 mm in the northern mountainous regions (Khangai, Khentein and Khuvsgul), and 250-300 mm in the western forest steppe regions (Natsagdorj *et al.*, 2001). It is characterized by relatively intense rainfall events with most of the precipitation falls between April to September, of which about 50-60% falls in July and August and is from the summer monsoon (Dagvadorj *et al.*, 2009).

Temperatures across Mongolia range from -15° to -30°C in the winter and from 10° to 27°C in the summer. The annual mean temperature in Mongolia is 0.7^{o}C, and ranging from 8.5^{o}C in the warmest regions of southern Gobi to -7.8^{o}C in the coldest regions of the North. July is the hottest month of the year, with an average of 15- 25^{o}C. The extreme maximum temperature recorded was 43.1^{o}C. The coldest temperature of -52.9^{o}C occurred in January (Ma, 2003). The air temperature in the coldest month of January averages -30^{0}C to -34^{0}C in the high mountain areas of Altai, Khangai, Khuvsgul and Khentii, while it is -20 to -25^{0}C in the steppe, and -15 to -20^{0}C in the Gobi desert. In the southern Gobi region the temperature averages -15^{0}C to -12^{0}C (Dagvadorj *et al.,* 2009).

1.3.1 Mongolia's Pastoral System

Mongolia is a country of hundreds of thousands of pastoralists who herd their livestock throughout the different ecological zones. Over 40 million head of livestock are herded, providing a livelihood for one third of Mongolia's population and support for the national economy (Batima, 2006). Mongolian pastoralists herd five types of animals: camels, horses, cattle, sheep, and goats, with yaks herded in some regions. Mongolian livestock are herded in open pastures by nomadic pastoralists who migrate seasonally due to climatic variability, natural conditions, and water availability. Migration patterns differ considerably between ecological regions (Fernández-Giménez *et al.*, 2011). For instance, herder households in the arid and semi-arid areas move most frequently and farthest due to insufficient vegetation and lack of water availability while the herders in more humid regions move the least (Mearns, 1993).

Mongolian pastoralists depend directly upon natural resources for their livelihoods and are quite vulnerable to the impacts of climate change. The most influential extreme weather events for pastoralists are drought and *dzud* (Marin, 2010), which have caused frequent episodic mortality in the livestock population. Rise of temperatures and changing of the seasonality of precipitation affects forage and nutrition availability for livestock production and ultimately the livelihood of nomadic herders (Batima, 2006). Batima (2006) also reported that the long series and large scale of drought and *dzud* that occurred from 1999 to 2002 was unusual but livestock mortality could not be solely attributed to this sequence of extreme weather events, as poverty, and social-economic development and sustainability may have contributed to the losses. By the end of the 1999-2002 series of events, almost 35% of the nation's livestock had perished (~12 million heads of livestock) with 12,000 herder households losing all of their animals and many of them falling below the poverty line (NSOM, 2004). Due to the poverty of herders who had lost many or all of their animals, there has been a migration from rural areas to urban centers over the past two decades as herders seek to earn a livelihood through alternative means (Marin, 2010).

These herders often continue to live in a culturally nomadic way, such as living in *gers* and burning coal, etc., which has contributed to an increase in urban air pollution and heavy city congestion from an exploding migrant population.

1.3.2 Historical Climate and Weather Studies in Mongolia

Traditionally, Mongolian herders were able to recognize weather characteristics based on their knowledge of nomadic livestock husbandry. Early weather events in Mongolian regions have been documented in ancient Chinese scriptures originating in the state of Xiongnu (Natsagdorj, 2006). This document states that in 72 BC more snowfall occurred in the Xiongnu region and "*the snowfall reached to over two fathom* (over 2 meters) *and killed many herders and livestock*" (Tsedevsuren, 1983). Historical documents from the years 68 and 46 BC, and 1248, 1254, 1303, 1337, 1340, 1372, and 1450 AD contain writings about *dzud* and droughts occurring in Mongolia (Tsedevsuren, 1983). In addition, during the rule of the Manchu Dynasty, weather reports showed that in the blue dragon year of 1664 "*Mongolian people moved their herd to the Galby Gobi in the middle summer of July due to drought*" (Tsedevsuren, 1983).

The first meteorological patrol in Mongolia was established in 1869 and continued to operate over the next 40 years (1869-1875, 1889-1909), as documented in the books of History of Climatic Study in Mongolia (Jambaajamts, 1970). This meteorological record was interrupted in the time of the Bogd King of Autonomous Mongolia period (Natsagdorj, 2006). However, it was a political device of the Russian Empire to use Russian tourists as a means to study the geographical, linguistic, historical and architectural history of foreign countries (especially in periods 1883-1888, 1893, 1899-1926, 1900-1901) (Jambaajamts, 1970). In the Mongolian case, the studies of Russian tourist-researchers were a significant contribution to the study of climate and surface water resources in Mongolia (Natsagdorj, 2006). In 1924, meteorological patrol was again established in Ulaanbaatar, Uliastai, Khovd, Tsetserleg, and Zamiin-Uud provinces, which operated until 1935 (Natsagdorj, 2006). In 1936, permanent operational meteorological patrols were established in Ulaanbaatar, Khovd, Tsetserleg, Undurkhaan, Choibalsan, Dalanzadgad (currently operated as meteorological stations), due to the needs of national economy development and the need to defend the country. These meteorological patrols/stations have been expanded across Mongolia in the past 50 years (Tsedevsuren, 1997). Currently, 120 hydro-meteorological stations are operating in Mongolia and are working according to the World Meteorological Organization guidelines and procedures; they measure air temperature, precipitation, air pressure, soil temperatures, air humidity, wind velocity, snowfall, snow depth and other phenomena on an interval of 8 times a day (Dagvadorj *et al.*, 2009). These data form the basis for climate change studies in Mongolia.

1.3.3 Climate and Hydrological Changes in Mongolia

Arid and semi-arid regions are distinctly vulnerable to climate and environmental changes (Ma, 2003). Mongolia has an arid/semi-arid climate where much of the population is dependent upon limited water resources. From Mongolian meteorological observations, the annual mean temperature has risen by 2.1^{o}C with winter temperatures increasing by 3.6^{o}C during the last 60 years (Batima *et al.*, 2005). Scientists anticipate that climate in Mongolia will continue to change dramatically over the 21st century and beyond (Dagvadorj*et al.*, 2009), with regional climate models predicting an increase in the annual temperature of 3.5 to 4^{o}C across Mongolia over the next 100 years (Christensen *et al.*, 2007).

The number and duration of hot days has increased dramatically, and is statistically significant at the 95% level in most of the high mountainous areas while in most of the steppe and Gobi-desert zone, it is 99% statistically significant (Dagvadorj *et al.,* 2009). Seasonally, the observed and the predicted changes in annual precipitation across Mongolia have been variable. Recent global climate model simulations have predicted declining precipitation in all parts of Mongolia (IPCC, 2008), which would cause decreased soil moisture and increased drought duration (Batima *et al.*, 2005).

Various natural disasters such as drought, severe winter, flood, sand and windstorms, and extreme hot and cold temperatures are frequent throughout the year, and they may be directly and indirectly related to climate change (Nandintsetseg *et al.*, 2007). Future climate predictions suggest higher temperatures with less rain in the summer and more snow in the winter, which may cause more extreme events with longer and/or frequent droughts and *dzud* (severe winter disaster) (Dagvadorj *et al.*, 2009). In Mongolia, these recurrent extreme events cause water stress and pose the greatest risk to animal husbandry.

A *dzud* is a Mongolian term for winter disasters with varying conditions, with deep or no snowfall, severe cold and other weather conditions often resulting in large animal losses due to starvation and exposure (Natsagdorj and Dulamsuren, 2001; Begzsuren *et al.*, 2004). At least five types of *dzud* have been identified: (1) white *dzud* with deep snow; (2) black *dzud* with no accumulated snow; (3) combined-deep snow; (4) storm-increased snow wind speed and heavy snow; (5) iron *dzud* - a layer of ice cover that makes forage and pasture inaccessible (Begzsuren *et al.*, 2004; Tachirii *et al.*, 2008).

Drought is caused by a prolonged absence of rainfall, and is a chronic feature of arid regions (Elliot *et al.*, 1991). Drought events are increasing and widespread in the semi-arid regions of Mongolia (Sasaki *et al.*, 2009). A dry summer and drought has been observed to decrease pasture productivity by 12 to 48 percent in the high mountains and 28 to 60 percent in the Gobi desert-steppe regions (Batima *et al.*, 2006), and has become of particular concern in Mongolia where it may accelerate desertification and threatens the nomadic pastoralism-dominant rural livelihood (Bayarjargal *et al.*, 2006; Johnson *et al.*, 2006).

Livestock are raised outdoors at times in severe weather conditions including *dzud*, drought, sand and wind storms (Sternberg, 2008). The dynamics of the grazing system and availability of water resources are characterized by highly variable precipitation with drought and *dzud* causing livestock mortality (Chuluun and Ojima, 2001). The extreme climate events of *dzud* and drought are often prolonged, and are individually very destructive to livestock growth, animal production, and human subsistence in this dry land region. Combined *dzud* that follows a period of summer drought can lead to massive losses of livestock because animals are in poor condition going in to the winter and cannot survive the extreme cold and heavy snowfall. Thus, understanding the pattern and occurrence of these extreme events is of particular concern for Mongolians (Li *et al.,* 2007). Severe winters and drought have become more of a serious problem for pastoral livelihoods and their livestock in recent times.

The distribution of livestock is highly dependent upon the availability and distribution of water resources (Ojima and Chuluun, 2008). Temperature increases and uncertain precipitation intensities and duration are likely to affect hydrological patterns, in turn affecting animal husbandry. Mongolia has limited water resources with estimated of 599 cubic kilometers of surface water, including of 500 cubic kilometers in lakes and 90 cubic kilometers of salt water (Davaa, 2007). There is evidence that the volume of lakes and springs has decreased in last decade for various interacting reasons such as climate change, desertification, deforestation, and other human activities (UNDP, 2005). According to the surface water inventory conducted by the Ministry of Nature, Environment and Tourism in 2007, 852 rivers and streams (out of 5128), 2277 springs (out of 9306), and 1181 lakes and ponds (out of 3747 water bodies) have disappeared since the previous survey in 2003 (Dagvadorj *et al.*, 2009). However, Batima *et al.* (2005) analyzed 20 river basins and found that the water flow and discharge had not changed in the past 40-60 years, and there was no trend showing either an increase or decrease in the volume of the surface water.

1.4 OBJECTIVES AND HYPOTHESES

The primary motivation for this research is to examine parallels between local observations and indigenous knowledge (IK) of herders and meteorological station based analysis of hydro-climatic change. Two contrasting sites at the *soum* (county) scale were investigated. First, a quantitative and qualitative survey was administered to determine the local understanding and IK of hydro-climate changes, including (1) changes in temperature and precipitation, (2) extreme weather events such as drought, severe winter, and storms, and (3) changes in available water resources. Second, a statistical analysis of hydro-climate changes was performed using station based data to determine the significance and rate of change for (1) temperature, precipitation, and streamflow, and (2) extreme climate events, such as extreme cold and hot days, and intensity of rain. Third, the potential vulnerability of herders, and their livelihood due to changes in climate and water resources were examined based on the IK survey.

- **Hypothesis-1: There has been a change in the climate, hydrology, and extreme weather events in Mongolia.** Temperature change has been observed in Mongolia during the last 70 years, which negatively affects the hydrological cycle and water resources and increases the frequency of extreme weather events.

- **Hypothesis-2: Indigenous herders have observed and experienced changes in climate, hydrology, and extreme weather events.** The livelihoods of Mongolian pastoralists depend to a large extent on weather elements, they observe and record quantitative and qualitative characteristics of a large number of climate variables and extreme weather events.
- **Hypothesis-3: Herders have been affected by climate change and extreme weather events.** Mongolian pastoralists make up a large proportion of the rural population and their livelihoods are increasingly at risk of extreme weather events and vulnerable to the impacts of climate change on their culture, traditional lifestyle and social and economic system.

CHAPTER 2. LOCAL UNDERSTANDING OF HYDRO–CLIMATIC CHANGES IN MONGOLIA

2.1 INTRODUCTION

Climate change in high elevation regions is receiving increased attention. Studies show surface air temperatures at these elevations have some of the strongest warming trends in the world over the past 20 years (Beniston, 2003). From Mongolian meteorological observations, annual mean temperatures have risen by 2.1^{o}C, with winter temperatures increasing by 3.6^{o}C during the last 70 years (Batima *et al.*, 2005). Scientists anticipate that climate in Mongolia will continue to change dramatically through the 21st century and beyond (Dagvadorj *et al.*, 2009). Climate change studies show that Mongolia is highly vulnerable to climate variability and extremes due to multiple stresses and weak adaptive capacity (Batima *et al.*, 2006).

The number of increased hot days in Mongolia is significant at the 95% level in most of the high mountains while in most areas of the steppe and Gobi desert-steppe zone it is 99% significant (Dagvadorj *et al.*, 2009; Nandintsetseg *et al.*, 2007). Seasonally, observed and predicted changes in annual precipitation across Mongolia have been variable. Recent global models predict declining precipitation in all parts of Mongolia, which would cause decreased soil moisture and increased drought duration (Batima *et al.*, 2005).

Different kinds of natural disasters, such as drought, *dzud*, floods, sand and windstorms, and extreme hot and cold days are frequent throughout the year, which may directly and indirectly be related to climate change (Nandintsetseg *et al.*, 2007). Weather forecasts suggest that higher temperature fluctuations, and less rain in the summer, and more snow in the winter are likely to create more variable weather conditions and extreme events yielding longer and/or frequent droughts, and *dzud* events (Dagvadorj *et al.*, 2009). These recurrent extreme events cause water stress and pose the greatest risk to animal husbandry in Mongolia. Hence, various approaches and methods are crucial for the study of climate variables and changes. Multiple sources of information can provide a better understanding of climate change, which can help local peoples achieve more efficient mitigation and adaptation to these changes (Speranza *et al.*, 2010).

Indigenous knowledge (IK: Nakashima and Roue, 2002), and traditional ecological knowledge (TEK: Berkes, 2009; Marin, 2010) observations and practices may support climate change monitoring, and provide a valuable source of information regarding natural resources and environmental change. TEK has an empirical basis and is used to understand and predict climate variables and environmental events that the livelihood or even survival of the individual depends upon (Huntington, 2000). TEK has other additional benefits and applications: to improve scientific research, to improve resource management and allocation, and to provide better information (Brooke, 1993; Inglis, 1993). Studies (e.g., Marin, 2010; West *et al.*, 2008) have shown remarkable correlation between these observations and instrumental records, while others have compared TEK and formal science to show how involvement of local people and their understanding and observations can contribute to improved climate change analysis (Huntington *et al.*, 2004; Nichols *et al.*, 2004).

2.2 STUDY SITES

This study examines potential climate change, in particular, variability of precipitation, temperature, and hydrology in two different ecological zones. One is in the mountain steppe ecological zone of Arkhangai aimag (Ikh-Tamir soum), and one is in the desert-steppe ecological zone of Bayankhongor aimag (Jinst soum) (Figure 2.2.1). Ikh-Tamir is a soum that belongs to

Arkhangai aimag (administrative province of Government in Mongolia). It is located at approximately 47º51'N latitude and 101º18'E longitude. Ikh-Tamir lies on the northern slopes of the Khangai Mountains with an areal coverage of 4850 square kilometers with an elevation range of 2500-3450 m above sea level. The average temperature in summer is 16.6^{o}C, with a maximum 34.6^{o}C, and mean temperatures in winter averaging -16^{o}C with a minimum of -36.5^{o}C. Annual average precipitation is 340mm. The main rivers in this area are the Hanui and Khoid Tamir basins (Figure 2.2.1). The Hanui and Khoid Tamir Rivers originate on the north slopes of the Khangai Range and flow mostly through high mountainous areas. The Khoid Tamir is a tributary of the Orkhon River and the Hanui is a tributary of the Selenge River which is the biggest river in Mongolia. The Orkhon flows in to the Selenge, which drains into the Lake Baikal and is then into the Arctic Ocean.

Jinst soum is located in Bayankhongor aimag, covers an area of 5312 square kilometers of total territory of which 95% is rangeland (516,907 hectares). Jinst is located between 45º00′ and 45º50′ south latitude and between 98º35′ and 101º00′ east longitude. Jinst lies on a broad plain between the Khangai and the Gobi Altai Mountain Ranges in west central Mongolia with the highest peak elevated in 3,957m above sea level. The average annual precipitation in Jinst soum is 100 mm with a mean winter temperature of -18^{o}C, and mean summer temperature of 21^{o}C, with about 120-130 frost-free days. The major drainage in this area is the Tuin River basin, which originates from the south slope of the Khangai Mountain and flows to the Orog Lake and is part of the internal drainage basin of Central Asia (Figure 2.2.1). The total Tuin River basin area is 9410 km^2 with a length of 243 km. Summer floods dominate the Tuin River, with 60% of the annual runoff coming from summer rainfall. The summer floods usually begin in the early July reaching their peaks in late July through early August.

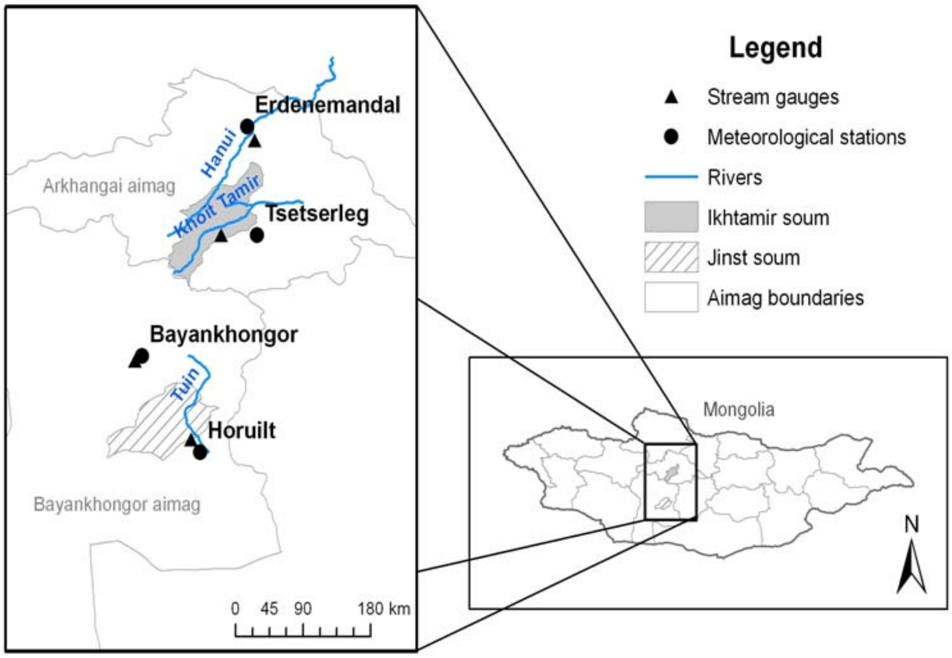

Figure 2.2.1. Location map for Jinst and Ikh-Tamir soum with the nearest hydrological and meteorological measurement stations.

2.3 STATIONS AND METHODS

2.3.1 Selection of Hydro-climate Stations

The four nearest long-term hydro-climate stations around Ikh-Tamir and Jinst were selected for this study. The Horiult and Bayankhongor stations were used to represent Jinst, and the Erdenemandal and Tsetserleg stations were used to represent Ikh-Tamir (Figure 2.2.1 and Table 2.3.1). The Horiult station had 25 years of records between 1971 and 2010 for daily maximum, minimum and average temperature and precipitation data, while the other three stations had at least 45 years of records between 1961 and 2010. For the hydrological analysis, daily streamflow from the Tuin River at the Horiult at Bogd and Bayankhongor stations, the Hanui River at the Erdenemandal, and Khoid Tamir River at Ikhtamir gages were used (Table 2.3.2).

Table 2.3.1. Meteorological stations used in this study

Station name	Station number	Period of record	Number of complete years	Latitude [N]	Longitude [E]	Elevation [m]
Tsetserleg (Цэцэрлэг)	47401500	1961-2009	9	47.27	101.28	1693
Erdenemandal (Эрдэнэмандал)	48501400	1964-2009	46	48.32	101.23	1510
Bayankhongor (Баянхонгор)	46100700	1963- 2009	47	46.08	100.41	1859
Horiult at Bogd (Хориулт)	46100700	1971-2009	26	45.17	100.73	1280

Table 2.3.2. Streamflow stations used in this study

Station name	Station number	Period of record	Number of complete years	Latitude [N]	Longitude [E]	Elevation [m]	Drainage area [km2]
KhoidTamir R at Ikh-Tamir		1976-2005	26	47.48	100.89	1740	2990
Hanui R at Erdenemandal		1976-2005	25	48.61	101.38	1487	4760
Tuin R a Bayankhongor		1976-2008	28	46.15	100.72	1863	2419
Tuin R at Bogd		1971-2008	32	45.22	100.71	1366	7282

2.3.2 Analysis of Temperature, Precipitation and Streamflow

The statistical significance of annual trends was computed using the Mann-Kendall test and the rate of change was determined from Sen's slope (Gilbert, 1987). For the Mann-Kendall test, the data are ordered into sequential time series, with missing years of data allowed. For each time series record starting at the first year, all subsequent years are computed to determine whether an increase or decrease is observed. The total number of increases between pairs are subtracted from the total number of decreases and converted into a probability using the number of points in the time series (Gilbert, 1987). This probability is equivalent to the z-score. This non-parametric test is not biased by outliers or missing data, i.e. years with no average value. The Sen's slope is subsequently computed as the median slope (50th percentile) computed from the slopes between all data pairs. These methods are routinely used for climatic change analysis (e.g. IPCC, 2007) and hydrological change analysis (e.g. Burn *et al.*, 2010).

2.3.3 Data and Average Values

The climate change analysis was performed using the annual average daily maximum, average, and minimum temperatures, as well as the annual total amount of precipitation and the number of precipitation days per year. Since most of the precipitation occurred seasonally as rainfall, there was less analytical emphasis on precipitation as snow. Zhang *et al.* (2004) provided a method for correcting daily precipitation values due to biases, with the largest being undercatch of solid precipitation due to wind effect on gauge catch. However, wind speed data were not available for the entire period of record. A standard undercatch ratio, such as the gauge efficiency for solid and liquid precipitation of 50% and 90% used by Knowles *et al.* (2006), could not be applied since the phase of precipitation was not recorded. Therefore the precipitation data used in this study were gauge measurements without bias corrections.

Annual averages were computed from daily data when fewer than 15 days of record were deemed missing or of poor quality. No further discrimination was needed since periods of missing data were continuous and a month or more in length. Missing data were more common for the streamflow records than the meteorological records. Data were obtained from the Mongolian Institute of Meteorology and Hydrology (Adyabadam, *pers. comm.*, 2010).

2.3.4 Extreme Climate Indices

Extreme indices are calculated using daily maximum (TX) and minimum (TN) temperature and precipitation data. Twelve indices of temperature and precipitation extremes have been selected from the list of indices for surface data that were recommended by the Expert Team for Climate Change Monitoring and Detection Indices (ETCCDMI) (see Peterson *et al.*, 2001). The averages of November-December, December-January, and January-February are used as the winter (NF) index, the averages of June-July and July-August are the summer (JA) index. Of the selected indices (Table 2.3.3), eight indices refer to temperature and four refer to precipitation. Temperature indices describe cold extremes and warm extremes while precipitation indices describe wetness and intensity.

Table 2.3.3. Temperature and precipitation indices with their definitions and units. Summer is defined as June through August (J-A) and winter is November through February (N-F).

Indicator Name	ID	Definitions	Units
frost day	FD-5	frequency of days when TN (daily minimum) < 0^{o}C	% days
summer days	SU25	frequency of days when TX (daily maximum)>25^{o}C	% days
cool days (summer & winter)	TX10p	percentage of days when TX<10th percentile	% days
cool night (summer & winter)	TN10p	percentage of days when TN<10th percentile	% days
warm days (summer & winter)	TX90p	percentage of days when TX>90th percentile	% days
warm night (summer & winter)	TN90p	percentage of days when TN>90th percentile	% days
indicator of hot days	WSDI	days with at least 6 consecutive days when TX>90 percentile	% days
indicator of cold days	CSDI	days with at least 6 consecutive days when TN<10 percentile	
simple daily intensity index	SDII	annual total precipitation divided by the number of wet days (defined as precipitation >=1.0mm in the year)	mm/day
number of heavy precipitation days	R10mm	annual count of days when precipitation >=10mm	days
consecutive dry days	CDD	maximum number of consecutive days with daily rainfall < 1mm	
consecutive wet days	CWD	maximum number of consecutive days with daily rainfall >= 1mm	

2.3.5 Household Survey

Herder household surveys were conducted in an informal individual group discussion plus a questionnaire-based survey was administered to 20 individual households in Ikh-Tamir, and 17 in Jinst. Households were randomly selected in each study location. Respondent ages ranged from 30 to 78 years old and each had at least 15 years of herding experience. The period of focus for hydro-climate changes was for herders to compare recent conditions to the period when they were in their 20's. The questionnaire focused on herder perceptions of hydro-climatic change including precipitation and weather extremes, as well as hydrological changes related to streamflow and river characteristics, and the state of springs and wells. The narratives of the survey were analyzed using a technique similar to that of Auerbach and Silverston (2003). Questionnaire data were entered into EXCEL spreadsheets and frequencies were calculated for each response. Qualitative analyses were coded through comments based on themes and sorted. When initial coding was completed, quotations were reviewed related to each theme that supported each of points. These were quantified by marking the number of codes according to different themes.

2.4 RESULTS FROM HERDERS

2.4.1 Changes in Temperature Observed by Herders

Herders in both Jinst and Ikh-Tamir soums described basic climate changes based on their experiences and observations. The herders reported that their environment has become more challenging because of frequent unpleasant weather events such as drought, *dzud*, storms, and extreme hot and cold days. Local herders observed and experienced increases in temperature and decreases in occurrence of precipitation, and a shortage of water resources. The following sections describe the herder responses to the questionnaire and their qualitative discussion related to these climate variables.

In discussion, many herders agreed that the average temperature had increased in recent years. This warming temperature was observed to be greater in winter season, and both herders and their animals were adapting to this warmer weather during the last 10 to 20 years. One Ikh-Tamir respondent reported, "*in the 1970s, the winters were very cold with lower temperatures reached minus 40 degree Celsius and we used fur coats, felt boots and sheep skin hat at that time. Due to warming temperature we had not used any of these warm clothes since the 1990s.*" One female elder added that they kept their warm clothes in small house at the soum center or in winter shelters and were unable to use them. However, herders in the Ikh-Tamir soum experienced an extreme cold winter in 2010 with lower temperatures and needed warm clothes again. Neither the herders nor the livestock had enough experience with severe cold weather to cope with the *dzud* in 2010. The lower temperatures started in December with both animals and herders getting frostbite on their noses and ears. One herder in Jinst said, "*…in the 1970's, I never observed snowmelt in winter. But in the past few decades, I have observed snowmelt earlier in winter occasionally due to higher temperatures; this is an unusual and unseasonal phenomenon.*"

2.4.2 Changes in Precipitation Patterns Observed by Herders

Variable precipitation patterns, intensity and rising temperatures are key factors to increased climate unpredictability and extreme events (Davi *et al.*, 2009). Herders in both soums commented on their concern about changes in amount of precipitation, patterns, timing, and magnitude over the past decade.

2.4.2.1 Precipitation Amount

Seventy one percent of herders surveyed in Jinst and one hundred percent in Ikh-Tamir noted that there has been a large decrease in rainfall with the remaining Jinst herders perceiving a small decrease in rainfall (Table 2.4.1). In recent years, in Ikh-Tamir the duration of rainfall has become shorter and it is seen to last only a few hours with high intensity and low infiltration into the soil, which adversely affects the availability of water sources such as wells and springs. Previously, they received a longer and softer rainfall. Herders in Ikh-Tamir reported, "*20 years ago, we had a long duration of rain which lasted 3 or 4 days and we did not have any dry clothes (deel traditional clothing) to wear and hardly found dry trees to make fire for cooking at that time*." One herder in Jinst said, "*…in the summer of 2009, rainfall occurred only in May and less rain than previous which caused prolonged drought during the summer and animal did not gain enough weight.*" Many of herders said, "*Generally, summers were very dry here [with] hardly any rain in recent years.*"

2.4.2.2 More Intense Rain

Marin (2009) noted that the herders identified two types of rain: hard and soft rain. According to the quantitative survey 80% of Ikh-Tamir herders and 65% of Jinst herders observed more intense rain, which was observed with low infiltration. For example, Ikh-Tamir herders stated, "*…in the past few years, short and intense rainfall has occurred which produced high runoff and did not saturate the soil moisture. Previously, rainfall duration was longer with soft rain and it's enough to saturate soil moisture and affect good quality grass growing*."

Table 2.4.1. Change in precipitation observed by local pastoral herders, as a percentage of the total herders surveyed (Jinst n=17, Ikh-Tamir n=20). Questions were asked on changes in the amount of rainfall and snowfall, rainfall intensity and the timing of snowmelt.

Location	large decrease/ much less intense / much earlier	small decrease/ less intense / earlier	no change	small increase/ more intense / later	large increase/ much more intense / much later
	The amount of rainfall has …?				
Jinst	71	29	0	0	0
Ikh-Tamir	100	0	0	0	0
	The amount of snow has ...?				
Jinst	24	29	35	6	6
Ikh-Tamir	55	15	25	5	0
	The rains have become...?				
Jinst	0	6	29	65	0
Ikh-Tamir	0	15	5	80	0
	The rains begin …?				
Jinst	0	0	0	42	58
Ikh-Tamir	5	0	20	50	25

2.4.2.3 Timing of Rains

The timing of rain is essential for pastoralists in multiple ways; they rely on the start of rains for early grazing, forage, and early production of dairy products for the winter preparation. When it begins to rain herders say it is summer. A late rain leads to reduced forage, yielding weaker animals, decreased weight and scarce dairy products. These conditions make it difficult for livestock and herders to cope in subsequent severe winters. Ikh-Tamir herders said, "…*rains now begin one month later than previously. Twenty years ago, summers usually started in May with earlier rainfall. Recently summer has been started around June 20th with late rain.*" The quantitative survey indicates that herders perceive rains beginning later (Ikh-Tamir 50% and Jinst 41%), and much later (Ikh-Tamir 25% and Jinst 59%) (Table 2.4.1).

2.4.3 Seasonal Characteristic Changes Observed by Herders

Both Ikh-Tamir and Jinst herders indicated that the conditions and characteristics of seasons have completely changed as compared to the past (Table 2.4.2). Almost all herders see summer coming later (100%) and being shorter (88% in Jinst and 100% in Ikh-Tamir). They see summer "*crushed*" by autumn and spring, meaning spring has become longer, autumn starts earlier, and summer is shorter. Fifty-nine percent of Jinst herders and 75% of Ikh-Tamir herders said spring comes earlier and longer and autumn comes earlier (Jinst 41% and Ikh-Tamir 90%). Seventy-five percent of Ikh-Tamir herders and 35% of Jinst herders observed an earlier winter and one that was shorter.

Table 2.4.2. Change in the seasonal condition observed by local pastoral herders. Questions were asked on changes in the timing of seasons and duration.

Location	earlier/ shorter	no change	later/ longer
	Does summer come…?		
Jinst	0	0	100
Ikh-Tamir	0	0	100
	Does summer become..?		
Jinst	88	0	12
Ikh-Tamir	100	0	0
	Does spring come…?		
Jinst	59	12	29
Ikh-Tamir	75	5	20
	Does autumn come…?		
Jinst	41	59	0
Ikh-Tamir	90	5	5
	Does winter come…?		
Jinst	35	18	47
Ikh-Tamir	75	10	15

Ikh-Tamir herders identified several indicators of season changes including timing of grazing, dairy products and herd movement, and changes in seasonal temperatures. They reported, "*20 years ago cattle began to graze around April 20th, but now summer arrives a month later, so grazing doesn't begin until end of May. Winter cold days shifted into spring, which means spring is getting colder than previously. I cannot distinguish now winter from spring season*." Similarly Jinst herders commented, "*In the early 1970's, we got abundant milk from cattle and started to produce dairy products by the end of May, but now dairy season starts one month later than previously*."

2.4.4 Extreme Weather Events Observed by Herders

2.4.4.1 Drought and Dzud

Herders in both soums have observed an increase in drought frequency and duration that negatively affects their livelihood in terms of livestock products, physiology, and grassland quality. Many Ikh-Tamir herders reported, "*…as a result of droughts, pasture quality has declined and now low nutrient grasses have replaced nutrient rich vegetation, and also pasture use patterns have changed with more livestock and households concentrating near the Khoid Tamir River due to water shortages that had led to overgrazing in the past decade. In the early 1980s, the grass grew higher than 6 year old kids and we could not find our kids in the grass, but now it grows just a little higher than the ground due to drought.*" Jinst herders reported that "*the drought has occurred often in this area and many rivers and springs have dried out and the water level in wells has decreased due to reduced rain and drought. We could not prepare enough hay due to short grasses caused by drought.*"

Herders have observed *dzud* occurring more often than in the past in Ikh-Tamir and Jinst (80% and 94%). All but 6% of the Jinst herders and all of the Ikh-Tamir herders stated that *dzud* snows last longer (Table 2.4.3). In particular, Ikh-Tamir herders and their livestock were severely affected by *dzud* and many felt the extreme cold winter of 2010. Most herders agreed with the comment that "*in generally, dzud occurs infrequently in the Khangai Mountain region, so we did not have enough experience to cope with the severe winter of 2010 due to previous warm winters. So some of herders lost all their animals and came under the poverty list, and many of herders lost more than 50% of their animals*." *Dzud* had been observed more frequently from 1999 to 2002 and in 2009-2010 in Jinst than Ikh-Tamir. During the *dzud* of 1999 to 2002, Jinst herders lost many of their animals, which may have lead pastoralists to gain experience and learn from the previous year's severe winter weather. Thus, during the 2010 *dzud* Jinst herders and their livestock were less affected than in Ikh-Tamir and fewer animals were lost compared to previous years.

Table 2.4.3. Percentage change in extreme climate events and variability observed by local herders. Questions were asked on changes in drought and *dzud* frequency and duration.

Location	more frequent/longer	no change/same length	less frequent/ shorter
		Does drought now occur…?	
Jinst	100	0	0
Ikh-Tamir	100	0	0
		Does drought now last …?	
Jinst	100	0	0
Ikh-Tamir	100	0	0
		Does *dzud* now occur…?	
Jinst	94	0	6
Ikh-Tamir	80	5	15
		Does *dzud* now last …?	
Jinst	94	0	6
Ikh-Tamir	100	0	0

2.4.4.2 Sand and Wind Storms

According to our survey, herders in Ikh-Tamir described that in the past they had never seen dust storms in the Khangai Mountains, but now due to variable precipitation and drought, dust and windstorms occur more frequently every year over the past 10 years. According to the quantitative results, all of the surveyed herders (except for 95% for sand storms in Ikh-Tamir) observed an increase in the occurrence of sand and windstorms (Table 2.4.4). Ikh-Tamir herders said, "*The frequency of sand storms has increased in the past years. When we have our herd movement from spring to summer camp, the felt roofs of our yurts (gers) were too heavy with packed sand due to sand storms*." One herder reported, "*I was reading an ancient script that was about Gobi sand storm called "Tebbad-Ugalz", but recently, this kind of unusual sandstorm has been occurring in the Khangai Mountain region*." A Jinst herder said, "*…the occurrence of dust and sand storm has increased with drought and strong wind during the last 10 years. Due to sand and wind storms, desertification and sand movement has increased and spread out which has created small sand dune everywhere*."

Table 2.4.4. Change in the extreme climate events variability observed by local herders. Questions were asked on changes in increase of sand and windstorm frequency and duration.

Location	more often	same frequency	less often
		Do sandstorms now happen …?	
Jinst	100	0	0
Ikh-Tamir	95	5	0
		Do windstorms now happen…?	
Jinst	100	0	0
Ikh-Tamir	100	0	0

2.4.5 Hydrological Changes Observed by Herders

From the household survey, all herders have observed changes in the magnitude and flow of water in rivers (Table 2.4.5). Access to water is becoming a serious problem for herders' livelihoods and their livestock in both areas. Ikh-Tamir herders customarily spend their summers along smaller tributary rivers and winters along springs, but in recent years, this has not always been possible due to decreasing water points. Due to water shortages, many herders reported that more households and livestock are concentrating around the Khoid Tamir River, which has led to overgrazing. Some herders have started to drill wells and use them even though they have no experience with this, particularly those who spend the summer along the Hanui River. The water levels in the Khoid Tamir and Hanui Rivers (100% of surveyed herders) have diminished in the 2000s, the Hanui River has become intermittent several times in its upper reaches. However, those reaches started flowing again in the summer of 2010 due to the previous winter's higher snowfall and earlier rains.

One herder who has spent time along the Hanui River said, "*…we have no idea where we should go if the Hanui River dries up. We could use wells but the drilling costs are expensive. Twenty years ago, the Hanui River was so deep it could reach the horses stirrups and I never saw this river dry previously.*" Another stated, "*The water level in the Khoid Tamir River has decreased; people and livestock can cross the rivers everywhere. The Bayantsagaan River [a tributary of the Khoid Tamir River] has dried out, we now started to use wells.*"

Some of the Jinst herders have traditionally spent their summers along the Tuin River and some of them use wells. Herders in this area have faced water shortages in the past 10 years, which has made it difficult to maintain their livelihood, and yielded problems with livestock growth. Many herders in Jinst agreed with one report that, "…*we have been experienced an increase in the occurrence of drought. Summers are not as usual, we had been losing our livestock every year because of drought combined with dzud. Watering points, including streams and springs have dried up, and streams in bigger river basins have changed their channel and blowing in narrow, sometimes disappeared. The volume of water in wells has decreased every year and could not support drinking and livestock sufficiently*." The quantitative survey showed 73% of Jinst herders have observed a decrease volume of water in river. One herder said that "*In 2001, when we came to this area, the upper stream of Tuin river was wider and deeper, but now it has changed a lot, streams are flowing narrower and springs have dried out*." In addition, one herder said,"… *the dried rivers and springs are not only caused by drought and variable precipitation but are also caused by human activity such as mining exploration near river basin*."

Table 2.4.5. Changes in hydrological variability observed by local pastoral herders. Questions were asked on changes in amount of water magnitude and flow in river basin.

Location	Have you observed any changes in amount of water magnitude and flow in river basin?			YES	NO
Jinst				100	0
Ikh-Tamir				100	0
	large decrease / much earlier	small decrease /earlier	no change	Small increase /later	large increase/ much later
	Has the volume of water in the river …?				
Jinst	73	27	0	0	0
Ikh-Tamir	100	0	0	0	0
	Has the timing of peak flow become …?				
Jinst	0	0	40	53	7
Ikh-Tamir	5	35	35	20	5
	Have you observed any river / spring dry up over time?				
	slight	moderate		severe	complete
Jinst	14 / 0	43 / 11		29 / 11	14 / 78
Ikh-Tamir	0 / 10	20 / 5		50 / 15	30 / 80

2.5 RESULTS FROM STATION DATA

Station data were analyzed to compare to the herders' statements of hydro-climate variability and change and their observation of changes in temperature, precipitation patterns and timing, and frequency and duration of extreme weather events (including extreme hot days and cold nights), and the change in water sources.

2.5.1 Air Temperature Change

Trends in annual average, maximum and minimum temperature were analyzed for the period of almost 50 years of data (1961-2010) at Tsetserleg, Erdenemandal, Bayankhongor, and at almost 40 years at Horiult (1971-2010). Increasing trends in the annual mean average, maximum and minimum temperatures are statistically significant at all stations, except for the maximum temperature at Horiult (Table 2.5.1, Figure 2.5.1). Average temperatures are increasing by 4.3^{o}C- 5.4°C per century, while maximums are increasing by 4.4°C per century for Tsetserleg and 3.5^{o}C per century for Bayankhongor. As observed in many semi-arid regions, average minimums are increasing the most at Erdenemandal with an increase of 7.3°C per century. Horiult (4.7°C per century), Bayankhongor (5.3°C per century), and Tsetserleg, (4.2 °C per century) also show increasing minimum temperatures.

2.5.2 Precipitation Amount Change

At the four weather stations, both yearly precipitation amounts and days with precipitation have reduced in the vicinity of the Khangai Mountains (Figure 2.5.2). More importantly, the largest decrease has been in the last 10 years (1999-2009). There has been a decrease in the annual precipitation amount of 186 mm per century at Erdenemandal (Figure

2.5.2b), and a less significant decrease in the occurrence of precipitation by almost 25 days per century (Table 2.5.1). The decrease in annual precipitation at Tsetserleg station (Figure 2.5.2a) of 122 mm per century is less statistically significant. The mean annual precipitation in Jinst was 100 mm over the period of 50 years. The increase in the number of days with precipitation of 50 days per century at Horiult station (Figure 2.5.2c) was more statistically significant than other changes in precipitation.

Table 2.5.1. Annual trend summary for meteorological stations from daily data. Statistical significance is shown when present.

	average temperature [deg C]	maximum temperature [deg C]	minimum temperature [deg C]	annual precipitation [mm]	days with precipitation
Station	Horiult (26 years: 1971-2009)				
Mann-Kendall Z-score	2.60	1.15	2.97	0.441	3.09
statistical significance	p<0.01		p<0.01		p<0.01
Sen's slope (per century)	4.27	1.87	4.65	23.1	50
Station	Bayankhongor (47 years: 1963-2009)				
Mann-Kendall Z-score	4.65	2.84	5.16	-1.26	-0.176
statistical significance	p<0.001	p<0.01	p<0.001		
Sen's slope (per century)	5.0	3.51	5.26	-94	0
Station	Erdenemandal (46 years: 1964-2009)				
Mann-Kendall Z-score	4.85	3.42	5.87	-2.20	-1.88
statistical significance	p<0.001	p<0.001	p<0.001	p<0.05	p<0.1
Sen's slope (per century)	5.38	4.12	7.25	-186	-24.6
Station	Tsetserleg (49 years: 1961-2009)				
Mann-Kendall Z-score	4.79	3.86	5.0	-1.77	-0.659
statistical significance	p<0.001	p<0.001	p<0.001	p<0.1	
Sen's slope (per century)	4.38	4.38	4.17	-122	-5.97

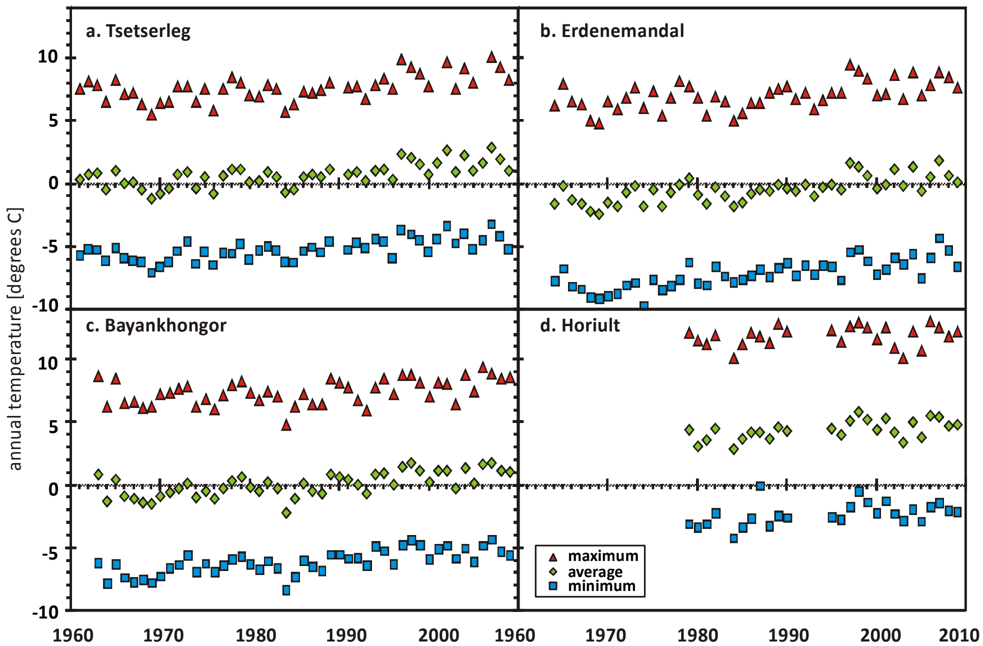

Figure 2.5.1. Annual time series of average daily maximum, daily minimum and daily average air temperature at a) Tsetserleg, b) Erdenemandal, c) Bayankhongor and d) Horiult stations from 1961 to 2010.

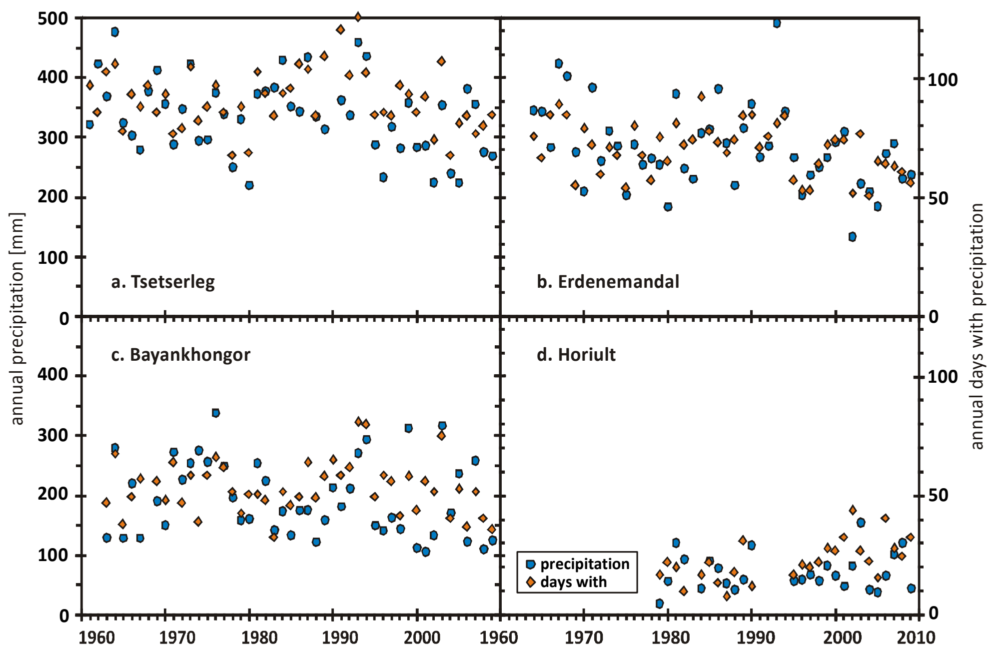

Figure 2.5.2. Time series of annual cumulative precipitation and occurrence of precipitation at the a) Tsetserleg, b) Erdenemandal, c) Bayankhongor, and d) Horiult stations from 1961 to 2010.

Year to year variability in precipitation is quite high. The autocorrelation of annual precipitation amounts was low; it was 0.03 at Horiult, 0.1 at Bayankhongor, 0.21 at Erdenemandal, and 0.19 at Tsetserleg. The precipitation time series was detrended with Sen's slope to compute the coefficient of variability. It was higher in Bayankhongor aimag (0.32 at both stations) than Arkhangai aimag (0.17 at Tsetserleg and 0.19 at Erdenemandal) since precipitation is much less in the south (Figure 2.5.2). The standard deviation was between 60 and 70 mm for all stations except Horiult, where it was 33 mm.

2.5.3 Streamflow Change

Annual daily discharge and streamflow were calculated for each year from the 1970s to 2008 at the four hydrometric stations (Figure 2.5.3 and Table 2.5.2). River flow in Ikh-Tamir has seen a highly statistically significant decrease since the 1970s. On the Hanui River at Erdenemandal and the Khoid Tamir River at Tsetserleg stations (Table 2.5.2 and Figures 2.5.3a and b) decreases are large. The annual maximum daily discharge declined by 166 m^3/s per century for the Hanui River and 314 m^3/s per century for the Khoid Tamir River while the average annual streamflow decreased by 24.7 m^3/s and 40.7 m^3/s per century for the Hanui and Khoid Tamir Rivers (Table 2.5.2). The decrease in annual streamflow on the Tuin River at Bogd was not significant, while the decrease in annual streamflow of 7.44 m^3/s per century was significant at the Bayankhongor gage (Figure 2.5.3c).

Table 2.5.2. Trend summary for hydrometric stations from daily data. Statistical significance is shown when present.

	annual average discharge	annual maximum daily discharge	date of peak flow
Station	Tuin River at Bayankhongor (28 years: 1976-2008)		
Mann-Kendall Z-score	-2.03	-0.85	-0.732
statistical significance	$p<0.05$		
Sen's slope (per century)	-7.44	-30.3	-35.9
Station	Tuin River at Bogd (32 years: 1971-2008)		
Mann-Kendall Z-score	-0.86	0.604	-1.1
statistical significance			
Sen's slope (per century)	-2.43	18.0	-64.3
Station	KhoidTamir River at Ikh-Tamir (26 years: 1976-2005)		
Mann-Kendall Z-score	-4.41	-3.61	0.927
statistical significance	$p<0.001$	$p<0.001$	
Sen's slope (per century)	-40.7	-314	62.5
Station	Hanui River at Erdenemandal (25 years: 1976-2005)		
Mann-Kendall Z-score	-4.27	-4.41	-0.724
statistical significance	$p<0.001$	$p<0.001$	
Sen's slope (per century)	-24.7	-166	-47.5

2.5.4 Extreme Climate Indices

The various extreme indices selected to match the herders' perceptions illustrated that significant change has occurred (Table 2.5.3). The time series for the four meteorological stations show significant warming from 1961 to 2010 based on the indices of frost days and summer days (Figure 2.5.4). The number of frost days from the nearest long-term stations shows a decrease of 40 to 46 days for Tsetserleg and Erdenemandal (Ikh-Tamir) and 24 to 47 days for Bayankhongor and Horiult (Jinst) (Figure 2.5.4a). The number of summer days has increased by 14 to 23 days for Tsetserleg and Erdenemandal and 24 for Bayankhongor (Figure 2.5.4b).

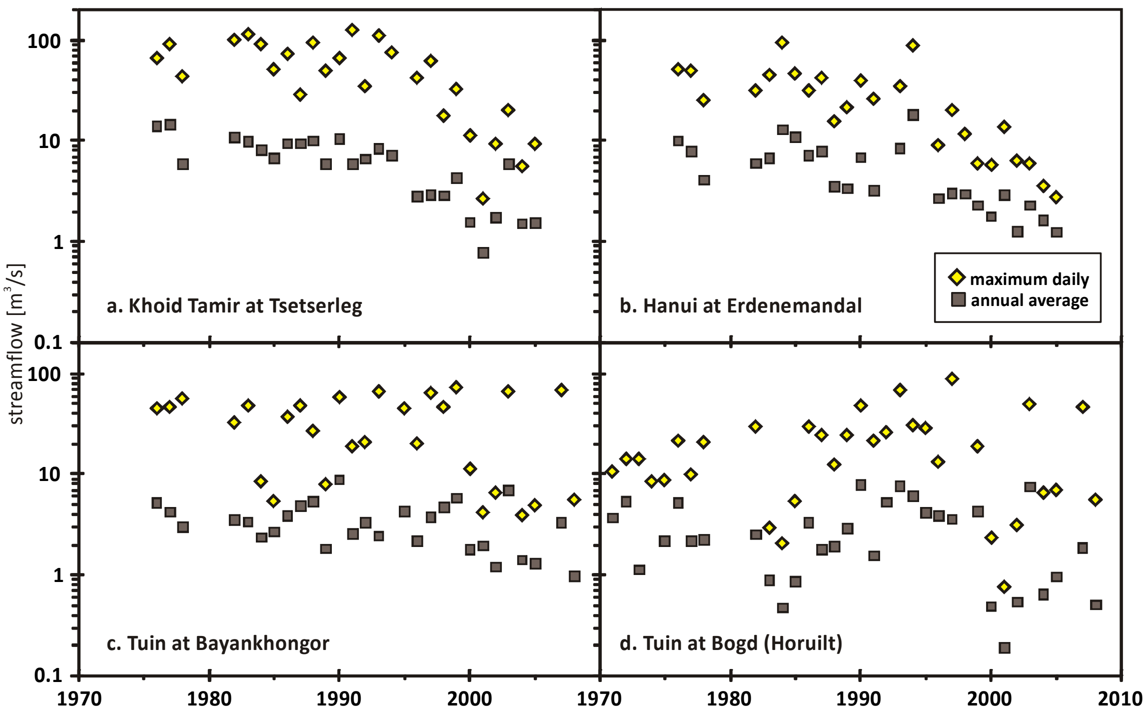

Figure 2.5.3. Time series of annual daily maximum and annual average daily streamflow on th ea) Khoid Tamir River at Tsetserleg, b) Hanui River at Erdenemandal, c) Tuin River at Bayankhongor, and d) Tuin River at Bogd from the 1970s to the 2000s.

The herders' narratives suggest an increase in the number of hot summer days, cold summer nights, and warm winter days and nights. An analysis of the number of summer warm days, represented as the annual number of summer days with a daily maximum air temperature warmer than the 90% percentile (TX90), has shown significant increases of 16-22 days for Tsetserleg and Erdenemandal and 10-12 days for the Bayankhongor and Horiult stations. Conversely, the number of summer cold nights (days with summer minimum temperatures less than the 10% percentile, TN10) has decreased by 7-10 days for Tsetserleg and Erdenemandal and 6-8 days for the Bayankhongor and Horiult stations, respectively (Figure 2.5.5a and b).

Table 2.5.3. Trends for indices of temperature and precipitation extremes. See Table 2.3.3 for definitions. All trends are in days per century, except SDII, which is in mm/day/century. Statistical significance is given as + for >90%, * for >95%, ** for >99%, and *** for >99.5% significant.

INDEX	SEASON	Tsetserleg	Erdenemandal	Bayankhongor	Horiult
FD-5	yearly	-44 ***	-48 ***	-40 ***	-57 ***
SU25	summer	32 ***	50 ***	50 ***	34 ***
COLD DAYS	summer	-9.1 **	-15 *	-15 ***	3.8
TX10P	winter	-17 *	-19 *	-16 *	-4.3
COLD NIGHTS	summer	-14 ***	-20 ***	17 ***	N/A
TN10P	winter	-15 +	-19 *	-16 *	-4.3
WARM DAYS	summer	49 **	33 ***	25 **	40 ***
TX90P	winter	0	0	7.7	27 **
WARM NIGHTS	summer	25 ***	16 *	29 ***	48 ***
TN90P	winter	13 *	16 *	11	30 ***
WSDI	yearly	56 **	74 ***	54 ***	48 *
CSDI	yearly	-28 +	-50 **	-40 *	53 *
SDII	summer	-0.7	-1.3	-3.6 +	-1
R10MM	summer	-5.6 *	-5.9 *	-2.7	0
CDD	yearly	-7.8	71 +	-64	-183
CWD	yearly	0	0	0	0

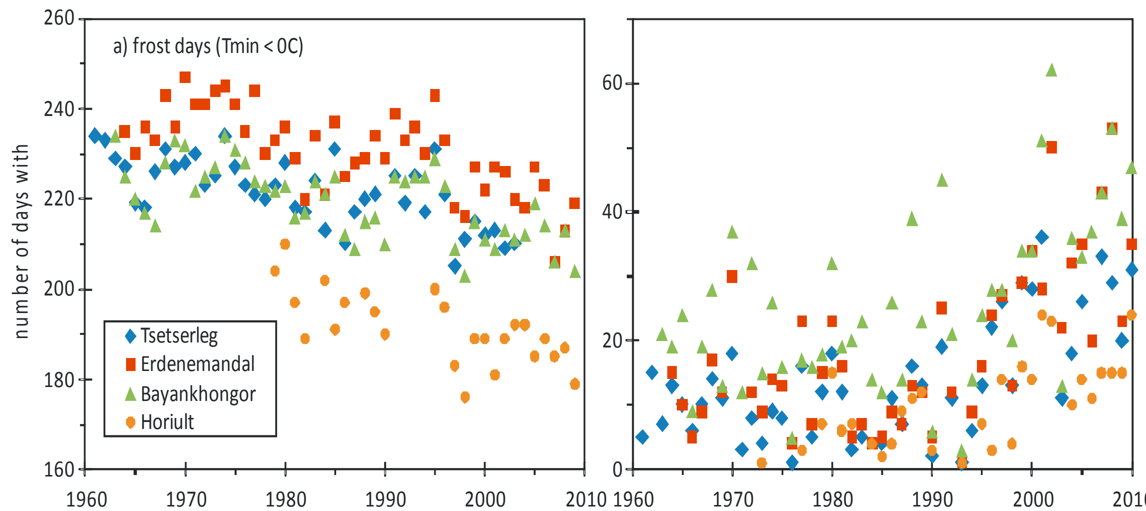

Figure 2.5.4. a) Frequency of frost days when the minimum daily temperature (TN) is colder than 0^{o}C and b) frequency of summer days when the maximum daily temperature (TX) is warmer than 25^{o}C.

Time series for the indices of winter warm days (TX90) and cold nights (TN10) are shown in Figure 2.5.5c and d, respectively. Number of winter warm days has significantly increased by 10 at Horiult while less significant increases were noted the at Tsetserleg and

Erdenemandal stations. The number of cold nights analyzed through the TN10 index, has less significantly decreased by 6-9 days for Tsetserleg and Erdenemandal and 2-8 days for the Bayankhongor and Horiult stations respectively. The trends for these indices have the same sign for each of the seasons but the magnitude of changes is greater during the summer season (June-August).

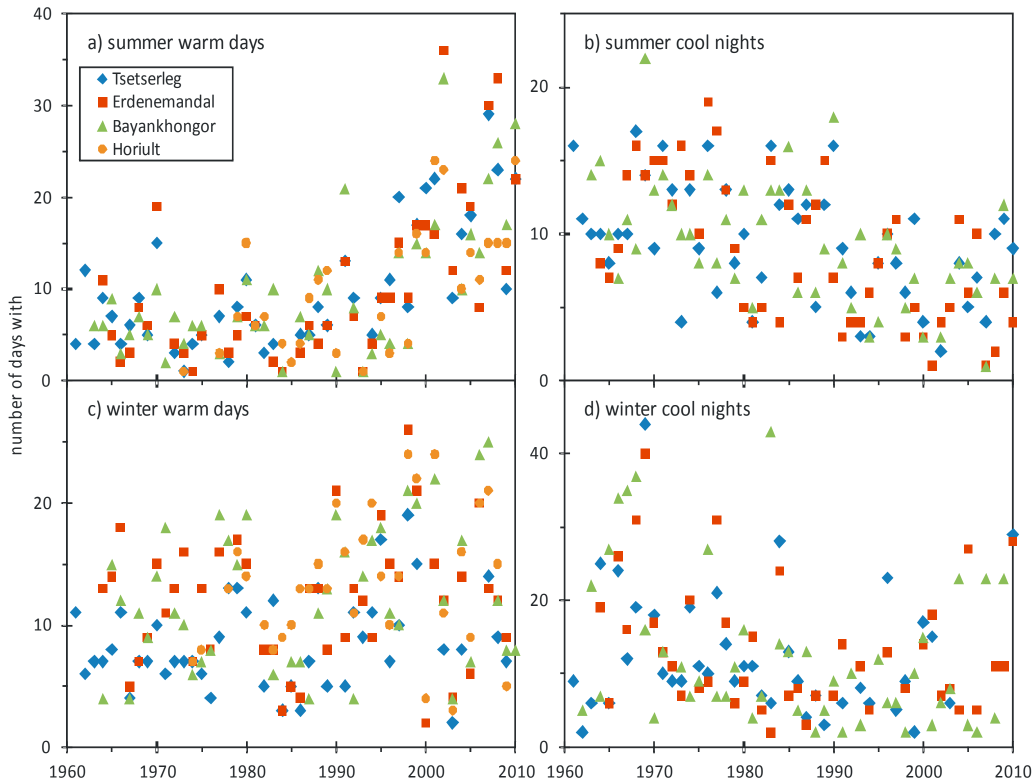

Figure 2.5.5. Time series for the indices of a) summer (June-August) warm days (TX90) b) summer cold nights (TN10), c) winter (November-February) warm days (TX90) and d) winter cold nights (TN10).

Of the two extreme indices used for assessing rain intensity, there was a significant ($p<0.05$) decrease in the number of heavy precipitation days (R10 mm) for the Ikh-Tamir stations of almost 6 days per century and a less significant ($p<0.1$) decrease in the simple daily intensity index (SDII) of 3.6 mm/day/century at the Bayankhongor station (Table 2.5.3). There were no significant changes in the number of consecutive wet days and only a low significance ($p<0.1$) of increase in the number of consecutive dry days of 71 days per century at Erdenemandal.

2.6 DISCUSSION

This study examines herders' observations and perceptions in the Khangai Mountain (Ikh-Tamir) and Gobi desert-steppe (Jinst) ecological zones related to hydro-climate variables that influence pasture quality, livestock production, and herders' livelihoods. Mongolian pastoralists depend to a great extent on the effects of weather and extremes forcing them to observe and record quantitative and qualitative characteristics of a large number of climate variables (Marin, 2010). The nomadic pastoralists' knowledge of weather and climate can influence their strategies to reduce vulnerability to extremes and in a broader sense to adverse climate changes (Speranze *et al.*, 2010). Examining individual and group knowledge is crucial for understanding why certain actions among pastoralists create different exposures and increased sensitivities to harm.

The herders' memories of past weather events were compared to when they were in their 20s with weather covering at least the previous 10 years; herders were able to recall pasture condition (grass height and quality), grass growing season, and water volume in rivers and springs, and shifts in the dairy season. In addition, herders' conversations always consisted of detailed information connected to weather elements, including changes in precipitation, extreme events, and water resources that were noted in their migration areas. The herders ranged in age from 30 to 78, and each of them have different memories. When they think of change over time, the length of time over which they consider that change, is likely different for each individual. Further work on the memory of specific extreme events in the past could assist in understanding how far back in time the local knowledge reflects.

2.6.1 Temperature Change

Understanding the complex and dynamic nature of the climate system is a serious challenge (Nichols *et al.,* 2004), especially in Mongolia, a country that has seen some of the strongest warming trends in the world with the greatest warming occurring during the last 60 years (Batima, 2006). Due to its location, fragile natural ecosystems, lifestyle of the rural people, and the economic situation, Mongolia is extremely sensitive to such climate changes. The most significant impacts of climate change are likely to arise from shifts in the intensity, frequency, and duration of extreme weather events (Beniston and Stephenson, 2004).

Herders in two different ecological zones, described their perceptions of changes in weather and climate. The statements of herders suggest that temperature has increased, and particularly warmed in winter. These perceptions are supported by analyses of the station data (Table 2.5.1). Both herders and their livestock have experienced and adapted to warmer weather during the last decade. Due to warm winters, herders in recent years had not used any of their traditional warm clothes (made of felt and fur) and many in Ikh-Tamir felt the extreme cold of the winter of 2009-2010 when temperatures were amongst the lowest on record (Venable *et al*., 2012). The long-term meteorological stations nearest to Ikh-Tamir and Jinst showed a significant increasing temperature trend of on average 4.3^{o}C to 5.4^{o}C per century. The mean maximum and minimum temperatures also increased significantly from 4.1^{o}C to 4.4^{o}C and 4.2^{o}C to7.2°C in Ikh-Tamir and 5.3°C to 4.7°C and 3.5°C in Jinst, with non-significant changes at Horiult. Spatially, air temperature increases are much higher in the mountainous region than in the Gobi desert (Batima, 2006). Nandintsetseg *et al*. (2007) illustrated that this warming is most pronounced in the winter season, which corresponds to herders' observations.

From the monthly station data, winter warming is greatest in February (Appendix G), yet the coldest winter temperatures are usually in December and January and these have not significantly warmed. March is the transition into spring, and March warming is only significant at two stations (Horiult and Erdenemandal). April and May (all stations, but not at Bayankhongor) have also seen significant warming. These changes match some of the herders' observations, as they see that winter is warming, but their comments about less cold does not match the statistical lack of change (warming) in December and January.

Temperatures are warming most in the summer months (Appendix G). This includes June (not at Erdenemandal) but at a lesser rate than earlier or later months. July through September temperatures are warming between 4 and 6.6 degrees per century (9.6 degrees per century at Horiult in July), but these are not as great as the February or April warming (7 to 11 degrees per century). In the fall only October temperatures (not at Horiult) are warming, so changes in this season are limited.

Mongolian livestock are raised outdoors in occasionally severe weather conditions, including *dzud*, drought, sand and windstorms, and extreme hot and cold days (Sternberg, 2008). These extreme weather events are causing serious problems not only to the practice of animal husbandry but also to the national economy (Batima and Dagvadorj, 2000). Long-term station time series for extreme temperature indices show that in the two study areas there have been significant decreases in the frequency of extreme cold days and increases in the frequency of extreme hot days. In Ikh-Tamir and Jinst, for example, summer hot days have dramatically increased while cold nights have decreased since 1960's. However, herders reported an increase of summer hot days and cold nights during the last decade. A reduction of cold extremes during warming periods for the winter indicates the opposite (Yan *et al.*, 2002). Comparatively, the extreme warm winter temperatures have increased more than the lowest temperatures at all stations that correspond to the herders' statements of a warming winter. An increase of warm extremes and decreases of cold extreme days have accompanied the strong warming trend since 1961.

In some areas of the world, increasing temperatures have been driven not by a changing climate but rather by changes at or near the recording stations. At some locations large increases have been due to instrumentation changes (e.g., a 2 degree warming over 20 years observed in Northern Colorado by Fassnacht *et al.*, 2011a). In Mongolia, the same monitoring equipment has been used since the 1960s. At other locations, populations have increased dramatically in urban centers and the associated infrastructure change has created an urban heat island effect that produces an apparent warming at the recording stations. In Mongolia, population increases have been dramatic only in the capital of Ulaanbaatar (NSOM, 2004). There have been some increases in the population at the aimag centres (Tsetserleg and Bayankhongor) but less so at the soum centers (Erdenemandal and Horiult). Three of these stations were visited (all except Erdenemandal) and the recording conditions were observed to ascertain any heat-island or other measurement change effects. These stations were located away from the urban center (Bayankhongor and Horiult) or had a large non-infrastructure buffer (Tsetserleg). Therefore, infrastructure/urbanization induced warming has likely been minimal.

2.6.2 Changes in Precipitation Amount and Timing

Continued fluctuations in precipitation, such as the amount, timing and magnitude, coupled with increasing temperature trends create an environment where variability and extreme events affect drought occurrence in Mongolia (Gong and Wang, 2000). Average annual precipitation in Mongolia is highest in the northern regions and decreases southward. It ranges from 50 mm in the Gobi Desert to 400 mm in the northern parts, with more than 60% occurring during the summer months. Batima and Dagvardorj (2000) saw no changes in total annual recorded precipitation when combining stations across Mongolia, while Jamiyansharav (2010) reported increased precipitation across central Mongolia and decreased precipitation in drier areas such as the Gobi-desert. Changes in precipitation at the study stations (Appendix G) have been during months with limited precipitation (most record less than 6 mm per month on average); the significant rates of change are for April at Tsetserleg (-17mm per century) and Erdenemandal (-14mm per century), January (+3mm per century) and December (+5mm per century) at Bayankhongor, and March at Horiult (+1.4mm per century). However, at Tsetserleg, the average April precipitation was 15.1 mm, and the largest decrease was in August of 74 mm per century for an average precipitation of 70 mm per month. Except Tsetserleg, these significant decreases in precipitation cannot be accommodated, as the monthly non-summer amounts are already small.

All herders surveyed in Jinst and Ikh-Tamir observed a decrease in precipitation. They specifically refer to the recent decrease in large amounts of rainfall, and have observed changes in time scale, spatial distribution, and magnitude of precipitation. Their statements regarding the decreased amounts of rainfall were quite consistent. They stated, "*…rainfall has decreased a* *lot*." This observation is supported by the statistical analyses of meteorological station records. The results show that the annual precipitation of 186 mm per century has decreased significantly with a less significant decrease in occurrence of precipitation by 25 days per century in the Ikh-Tamir (Khangai Mountains) for the time period of 1961-2010. In the Jinst (desert-steppe) area, annual precipitation has decreased 94 mm with an increase in the number of days with precipitation of 50 days per century at the Horiult station, which is statistically significant. There could possibly be a change in the phase of precipitation, with more rainfall occurring rather than snowfall (Fassnacht, pers. comm., 2012). These changes could have significant impacts in terms of flooding, drought, and water availability on the local and regional environment.

A majority of the precipitation occurs in the summer months (May through September as illustrated in Appendix G). The herders are reliant on this precipitation for the growth of vegetation in the pastures. Some have stated that they are most reliant on the first two rainfall events to start plant growth in the rangelands. This intra-annual variability is large, and inter-annual variability can also be substantial (Figure 2.5.2). Statistically this inter-annual variability is almost random with a year-to-year autocorrelation of approximately 0.20 in Arkhangai aimag and less than 0.10 in Bayankhongor aimag. The detrended coefficient of variation (COV) reflects this inter-annual randomness with values of approximately 0.20 and 0.32 in the north and south, respectively. The latter are larger due to the less precipitation in the desert-steppe region. This randomness in annual precipitation quantities would make it difficult for herders to plan their grazing season even if they regularly accessed meteorological station information.

2.6.2.1 Late Summer Rains

Herders in Ikh-Tamir and Jinst described a delay in summer rains. Mongolian herders often refer to the "summer condition" (*zunshlaga*) in relation to pastures (Marin, 2010). Good summer condition usually indicates enough fodder, hay and water, but herders often used the term to imply abundant rain. Herders more often observed that rains are shifted one month later with an effect of delaying summer, which in turn, affects vegetation quality, livestock health, and the timing of dairy products. The grass grows shorter and is less dense due to late and reduced precipitation. This phenology is not supported by station record analysis (Table 2.5.1), except perhaps by decreased April rains in Arkhangai (Appendix G). Nevertheless, the decreased precipitation trend for Ikh-Tamir (statistically significant) and Jinst (not statistically significant) and the reduction in occurrence of precipitation days indicates that summer condition may indeed have worsened, with a negative impact on vegetation and livestock. Iwasaki and Nii (2006) have explained the break in the mid-July rains as a result of the development of a barotropic ridge in Central Mongolia, effectively suppressing all rains except local, heavy rains due to thermally induced local circulation around mountains (Iwasaki and Nii, 2006).

2.6.2.2 More Intense Rain

Extreme precipitation trend analyses show that the average amount of rain recorded during rainy days has not changed (>=1mm) and there is less decline in the occurrence of heavy precipitation. However, Nandintsetseg *et al.* (2007) and Dagvadorj *et al.* (2009) found a slight increasing trend in the number of days with precipitation in northern Mongolia and the mountain regions, but there has been a slight decrease in the average intensity of the four highest precipitation events. Examination of extreme precipitation events indicates that heavy precipitation increases in locations where precipitation increases and decreases in places where precipitation typically decreases (Groisman *et al.*, 1999). This evidence rejects the claim of the pastoral herders that rains have become more intense with high runoff. There is however an important qualitative difference between the observations made by the herders and the station records. Herders more likely made reference to what they perceived was "*more intense and shorter rain*" relating to its impact on soil moisture, vegetation, and runoff.

A study from the steppe region of Mongolia (Onda *et al.*, 2007) showed that peak rain intensity, the highest amount of rain recorded in 10 minutes, was not able to explain variations in runoff and the amount of sediment discharged. Instead, runoff and discharge were much better correlated with the impact energy of raindrops, which in turn was independent of the (peak) intensity of the rain event or its total amount. Therefore, if herders statements do record a quality of rain similar to raindrop energy, such as its "hardness", a comparison between their observations and the studies suggesting no change in rainfall rates and in the number of rain events with certain rainfall rates is not meaningful. This incompatibility is nevertheless illustrative of the potential contributions of traditional knowledge to uncovering important but ignored elements of change. The measurement of impact energy may provide a much more useful set of data, but its contribution to trends estimation however, is limited by the lack of base-line records (Marin, 2010).

2.6.3 Hydrological Change

Previously, no statistically significant climate-driven hydrological changes have been determined for Mongolia. However, the water inventory completed in 2007 estimated that there were 4157 rivers, lakes, springs and wells that had dried up (Dagvadorj *et al.*, 2009). In other parts of the world, these have been defined by changes in annual runoff volumes, peak flows, the timing of peak flows and the centroid of the runoff volume (Fassnacht, 2006). For example, Stewart *et al*. (2005) observed an earlier peak flow in most of the U.S. Pacific Northwest, associated with a change in the timing of peak snow accumulation. However, observational data

(Fernández-Giménez, 2006) and herders' perceptions (Sternberg, 2008) indicate that warming and drying may be affecting the availability and abundance of surface water.

Availability and distribution of watering points play a key role in livestock management, use of grazing land, and the pastoral livelihood (Ojima and Chuluun, 2008). The volume of water in rivers and lakes has reduced in recent years associated with various issues such as global warming, deforestation, land degradation, and mining activity (UNDP, 2005).

Beyond the decreases in precipitation, declines in streamflow have likely been influenced by hydrological processes such as increased evaporation, possibly due to increased temperatures. There could also be a change in the phase of precipitation, with more rainfall occurring than snowfall, resulting in less snowpack or an earlier onset of melting. These changes may cause flooding, drought, and changes in water availability.

The long-term average streamflow of the Hanui and Khoid Tamir Rivers has reduced significantly by $24.7 m^3/s$ and $40.7 m^3/s$ per century, which corresponds to the herders' observations in Ikh-Tamir. The diminished water supply in Ikh-Tamir has caused problems for herders and their livestock. The long-term average streamflow of the Tuin River has not changed significantly, but the herders (Jinst 73%) have observed a depletion of water resources in the area, possibly due to the fact that the drainage point of the Tuin River, Orog Lake, has been completely dry for a number of years. However, it filled in the summer of 2010 due to larger amounts of winter snow and earlier rains. The effects observed by the herders may be due to a seasonal depletion of water resources from a change of the river water regime. The surveys recorded a decrease in the infiltration of water into the soil, which has been attributed by some locals to pasture overgrazing, soil compaction, forest logging activities, and fire and insect outbreaks. Consequently, direct surface runoff may have increased contributing to river flow while precipitation has decreased, resulting in lowered water tables. Water resources in semi-arid regions are limited and water is a crucial resource throughout the world, as highlighted by the U.S. Commissioner of the Bureau of Reclamation Michael Connor who recently stated that the "*impacts to water are on the leading edge of global climate change*" (taken from < http://indiancommunitynews.com/climate-change-to-reduce-us-west-water-supply-report/>). Climate change may further reduce water supplies in the semi-arid and arid parts of Mongolia.

2.6.4 Extreme Climate Events

2.6.4.1 Drought and Dzud

Qualitative data suggest that an increased drought frequency and duration negatively affects herders' livelihoods, livestock production, animal physiology, and grassland quality. All herders surveyed in the mountain and steppe zones observed and experienced more frequent and longer droughts. Drought is associated with a lack of precipitation and often high temperatures that contribute to drying (Trenberth, 2005). As a result of those droughts, pasture quality could decrease and cause a change in vegetation type, possibly to lesser quality vegetation. Sternberg *et al*. (2011) identified that droughts were associated with a significant negative variation from mean precipitation and are recurrent features of the Mongolian steppe. Drought severity is affected by climate variability in regions of variable precipitation, increasing temperatures and extreme events, impacting and influencing pasture conditions (IPCC, 2007; Nandintsetseg *et al.*, 2007).

The statistical analyses of precipitation and extreme hot temperatures support herders' claims of increasing amounts of drought. Extreme temperature indices show that there have been significant increases in the frequency of hot extreme days both in Ikh-Tamir and Jinst. For example, summer hot days have dramatically increased while cold nights have decreased since 1960's. Frequent long-duration drought causes problems both in the Khangai Mountains and for Gobi-desert pastoral herders and their livestock in terms of drying up rivers and springs and reducing the water level in wells. Occurrence of frequent drought increases the vulnerability of the herds during *dzud* conditions.

Combined *dzud* events that follow periods of summer drought have led to mass losses of livestock because animals are in poor condition going into the winter and cannot survive the extreme cold temperatures and heavy snowfall (Bayarjargal *et al.*, 2006; Johnson *et al.*, 2006). *Dzud* has occurred more often in Jinst than Ikh-Tamir. Nevertheless, Ikh-Tamir herders and their livestock were severely affected by *dzud* and extreme cold in the winter of 2009-2010 and many of the herders lost 50% or more of their animals. Many of those herders suffering losses fell into poverty and were forced to move from the soum to improve their livelihoods. Droughts and *dzud* may occur as often as once every 2 or 3 years especially in the Gobi-desert region (Begzsuren *et al.*, 2004). In Jinst, *dzud* was observed in 1999 and 2002, and also in 2009-2010. During the dzud of 1999 and 2002, Jinst herders lost three quarters of the soum's herds. As a result, Jinst herders gained experience from dealing with the previous severe winter and were less affected by the *dzud* of 2009-2010 than the Ikh-Tamir herders (Fernández-Giménez *et al.*, 2011).

2.6.4.2 Sand and Wind Storms

The occurrence of dust storms is highly related to the geographical dispersion of days with massive amounts of wind and the surface soil characteristics of the country. Wind and sand storms occur frequently in Mongolia. The phenomenon of dust and sand storms cause negative environmental consequences for the practice of animal husbandry and impact the herders' livelihoods, which in turn becomes a factor in the eventual destruction of pasture (Dagvadorj *et al*., 2009). As a result of frequent sandstorms, accumulated dust on animals decreases wool quality and complicates the processing of wool products.

All herders in the Khangai Mountains and Gobi-desert steppe responded that recent sand storms were unusually frequent and tended to last longer. In general, sandstorms are an unusual weather phenomenon in the Khangai Mountain region where there is a wetter climate with more precipitation and more abundant water resources. In recent years however, the frequency of sand storms has increased. Jinst herders and their livestock faced more frequent sand and windstorms combined with drought and desertification. However, these herder observations cannot be compared to statistical analyses due to a lack of this type of station data. Marin (2010) stated that due to the consistent herders' reports, and the agreement among scientists (Dulam, 2005), sand storms have become more frequent since 2000. Frequent occurrence of drought and windstorms can also cause an increase of sand storms and can accelerate desertification in the semi-arid ecological zones. A study of Natsagdorj *et al.* (2003) showed that wind speed had moderate values during the sand storms, raising doubts regarding the connection between wind speed and storms. They found a significant increasing trend of the number of days with sandstorms from 1960 to 1989. Dagvadorj *et al.* (2009) demonstrated an increased occurrence of dust storms of 5 days a year in the Khangai Mountains and 30-37 days in the desert steppe regions. One herder specifically commented on the increased occurrence of sand storms.

2.7 CONCLUSIONS

This study compares indigenous knowledge from nomadic pastoralists with statistical analysis from meteorological station records to examine indicators of climate variability and change. The herders surveyed in Mongolia provided a detailed description of weather and climate elements and extremes. Which provided supportive information on climate change using multiple indicators. Observations from herders were consistent for many of the climatological change elements used in station-based analyses. They provided evidence of change in such variables as temperature, magnitude and timing of rains, and the frequency and duration of sand storms, wind storms, drought, and *dzud*. Changes in precipitation defined using extreme indices were not however, statistically significant. It is possible that other indices are necessary to identify the types of changes that herders observed. It should be noted that the station-based analysis did not assess some types of changes observed by herders such as, increased sand storms, windstorms and *dzud*.

Mongolian herders traditionally spend much of the year outdoors in their environment which allows them to gather, interpret and transmit weather and climate observations through many generations, which strengthens the credence of their claims of change. As with other resource dependent peoples, they also tend to integrate climate variables and extreme events, but in a way unlike scientific methods that often rely on average changes of individual variables.

On some occasions, herders' observations did not correspond to the station record analyses but their observations may be more important at certain spatial and temporal scales because they may remember most climate variables and extreme events in terms of impacts on their livelihood's; they live on the land and thus integrate areas of change whereas station meteorological data are only representative of a point in space.

While the statistical analyses are objective, they have limitations. For example, some individual important extreme events may be missed and/or subtle trends may not be identified as statistically significant while these events and/or trends are identified by herder observations due to their importance to their lifestyle. In particular, traditional scientific analysis may have limitations for advising herders due to sampling duration and related time series issues.

When asked, Mongolian herders can make clear statements on the local and regional understanding of change that identify possible feedback mechanisms between ecological processes. For example, they indicated the consequences of changes by relating the negative and positive aspects of changes to precipitation, drought, water resources and vegetation cover that affect them. For the most part, the herders' observations supported the statistical results and thus could help models of environmental change in the area, as could also be used to contribute insight to policy makers.

The apparent differences between the two sets of observations were not completely explained in this research and further work can help. The increase in frequency of extreme precipitation observed by herders was not captured by station record trend analysis but such an increase could be identified in the station data using a more appropriate, or new index and/or using a different period of record to match the herders' apparent period of record, i.e., use of the long-term data (almost 50 years) may have concealed shorter term remembered trends. Nevertheless, station records did show a decrease in annual precipitation and a change in the occurrence of precipitation days which could be indicative of recent droughts. The results shown in this research do not agree with the work of Natsagdorj and Dulamsuren (2001) however, which showed a significant long-term increase in precipitation in Mongolia.

It has been shown in other studies that local ecological knowledge from resource dependent people may significantly improve assessments of climatic change and impacts, and this is likely the case for information from Mongolian pastoralists. Therefore it is recommended that ecological knowledge from herders be combined with station record analysis to provide information using different approaches, covering different spatial scales, and to increase the relevance of future assessments for adaptations to climate change.

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APPENDIX A: HERDER SURVEY

1. Respondent ID#:________________
2. Age: _____________
3. Land location: ________________
4. The name of soum : __________________

I. CLIMATE CHANGE

My first part of question is about changes in climate in past decades.

1. Please tell me how climate is changing and how it affects seasonal conditions in your area.
    a. Compared to when you were in your 20s, does summer now come earlier, later or no change?
    b. Compared to when you were in your 20s, is summer now shorter, longer or has not changed in length?
    c. Compared to when you were in your 20s, does spring now come earlier, later or no change?
    d. Compared to when you were in your 20s, does autumn now come earlier, later or no change?
    e. Compared to when you were in your 20s, does winter now come earlier, later or no change?
    f. Compared to when you were in your 20s, does winter now last shorter, longer or has not changed in length?

2. Please tell me how have you observed extreme climate events variability in past decades?
    a. Compared to when you were in your 20s, is drought now more frequent, less frequent, or not changed in frequency?
    b. Compared to when you were in your 20s, are droughts now longer, shorter or the same length as then?
    c. Compared to when you were in your 20s, does dzud now happen more often, less often or about the same as then?
    d. Compared to when you were in your 20s, are dzud now longer, shorter or about the same length as then?
    e. Compared to when you were in your 20s, do sandstorms now happen more often, less often or about the same frequency as then?
    f. Compared to when you were in your 20s, do windstorms now happen more often, less often or about the same frequency as then?

3. Have you observed any precipitation changes in past decades? In answering these questions, please think about what the precipitation was like when you were in your 20s.
    a. The amount of rainfall has decreased a lot, decreased somewhat not changed, increased somewhat, increased a lot?
    b. The rains begin much earlier, somewhat earlier, at the same time, somewhat later, much later.
    c. The rains have become much less intense, somewhat less intense, about the same intensity, somewhat more intense, much more intense.
    d. Rainfall is much less patchy, a little less patchy, the same, a little more patchy, much more patchy.

e. The amount of snow has decreased a lot, decreased somewhat, is about the same, increased somewhat, increased a lot.
f. The frequency of snowstorms has decreased a lot, decreased somewhat, is about the same, increased somewhat, increased a lot.
g. The frequency of heavy snows has decreased a lot, decreased somewhat, is about the same, increased somewhat, increased a lot.
h. The timing of snowmelt is much earlier, a little earlier, about the same, a little later, much later.

II. HYDROLOGICAL CHANGE

In this section, we are interested in learning how surface water sources have changed over time.

4. Have you observed any changes in amount of water magnitude and flow in river basin? If yes, Please tell me when did you see it first time? How has it been changed over time?

☐Yes ☐ No

As you answer the following questions, please think about the conditions today compared to when you were in your 20s.

a. Has the volume of water in the river decreased a lot, decreased somewhat, is about the same, increased somewhat, increased a lot.
b. Has the depth of the river decreased a lot, decreased somewhat, is about the same, increased somewhat, increased a lot.
c. Has the timing of the peak flow become much earlier, a little earlier, about the same, a little later or much later?
d. Does the river freeze-up much earlier, a little earlier, about the same, a little later or much later?
e. Does ice in the river break-up much earlier, a little earlier, about the same, a little later or much later?

5. Have you observed any river, lakes, springs or ponds dry up over time? If yes, please tell me what water sources dried up? How severe the water decline is and when it started?

Name of water sources	Year that drying began	Slight	Moderate	Severe	Completely Dried-up
River		1	2	3	4
Lake		1	2	3	4
Spring		1	2	3	4
Ponds		1	2	3	4

APPENDIX B: CODING OF HERDER SURVEY RESPONSES

Table B-1. Coding for soum.

Soum
1=Ikhtamir
2=Undur-Ulaan
3=Jinst
4=Bayantsagaan

Table B-2. Coding for ecozone.

Ecozone
1=Mountain
2=Forest
3=Step
4=Desert

Table B-3. Coding for land location.

Land Location
1=Ishgent-heseg
2=Bugat brigad
3=Bart bag
4=Khan-Undur bag
5=Dongoi bag

Table B-4. Coding for question 1 answers.

Q1a	Q1b
1=Earlier	1=Shorter
2=No change	2=Not changed
3=Later	3=Longer

Table B-5. Coding for question 2 answers.

Q2a	Q2b	Q2c
1=More Frequent	1=Longer	1=More often
2=Not changed	2=Same Length	2=Same as then
3=Less frequent	3=Shorter	3=Less often

Table B-6. Coding for question 3 answers.

Q3a	Q3b	Q3c
1=Decreased a lot	1=Much earlier	1=Less intense
2=Decreased somewhat	2=Earlier	2=Somewhat less intense
3=No change	3=At the same time	3=Same intensity
4=Increased a lot	4=Somewhat later	4=Somewhat more intense
5=Increased somewhat	5=Much later	5=Much more intense

Table B-7. Coding for question 4 answers.

Q4a	Q4b	Q4c
1=Yes	1=Decreased a lot	1=Much earlier
0=No	2=Decreased somewhat	2=A little earlier
	3=About the same	3=About the same
	4=Increased somewhat	4=A little later
	5=Increased a lot	5=Much later

Table B-8. Coding for question 5 answers.

Q5
1=Slight
2=Moderate
3=Severe
4=Completely dried-up

APPENDIX C: SUMMARY OF HERDER SURVEY RESPONSES

Table C-1a. Herder survey responses for Ikh-Tamir for questions 1 and 2.

ID#	Soum	Eco-zone	Age	Location	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f
01	1	2	31	1	3	1	3	1	1	3	1	1	1	1	1	1
02	1	2	38	1	3	1	1	1	1	1	1	1	1	1	1	1
03	1	2	60	1	3	1	1	1	1	3	1	1	1	1	1	1
04	1	2	40	1	3	1	1	3	1	3	1	1	1	1	1	1
05	1	2	67	1	3	1	1	1	1	3	1	1	1	1	1	1
06	1	2	67		3	1	1	1	1	1	1	1	1	1	1	1
07	1	2	74		3	1	1	1	3	1	1	1	1	1	1	1
08	1	2	47		3	1	3	1	3	1	1	1	1	1	1	1
09	1	2	47		3	1	1	1	1	3	1	1	2	1	1	1
10	1	2	75	3	3	1	1	1	1	3	1	1	1	1	1	1
11	1	2	48	4	3	1	3	1	2	1	1	1	3	1	2	1
12	1	2	67	4	3	1	1	1	3	1	1	1	3	1	1	1
13	1	2	49		3	1	1	1	1	1	1	1	3	1	1	1
14	1	2	43	2	3	1	1	1	1	1	1	1	1	1	1	1
15	1	2	56	2	3	1	2	2	1	3	1	1	1	1	1	1
16	2	1	45	5	3	1	1	1	1	1	1	1	1	1	1	1
17	2	1	36	5	3	1	1	1	1	1	1	1	1	1	1	1
18	2	1	37	5	3	1	1	1	1	3	1	1	1	1	1	1
19	2	1	78	5	3	1	1	1	1	1	1	1	1	1	1	1
20	2	1		5	3	1	3	1	2	2	1	1	1	1	1	1

Table C-1b. Herder survey responses for Ikh-Tamir for questions 3, 4 and 5.

ID#	Q3a	Q3b	Q3c	Q3d	Q3e	Q3f	Q3g	Q3h	Q4	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5c
01	1	3	4		1	2	4	2	1	1	1	2	4	3	3	4
02	1	3	4		3	4	3	3	1	1	1	3	3	3	3	4
03	1	1	4		3	4	3	2	1	1	1	2	2	4	4	4
04	1	3	4		1	3	3	4	1	1	1	4	4	4	4	4
05	1	3	4	3	2	3	3	4	1	1	1	1	4	3	4	4
06	1	4	4	1	1	4	3	3	1	1	1	3	3	3	3	4
07	1	4	4	4	1	4	1	4	1	1	1	4	4	3	4	4
08	1	4	4		4	3	4	2	1	1	1	3	2	4	3	2
09	1	5	2		1	1	3	2	1	1	1	4	4	4	2	4
10	1	4	3	4	2	4	4	3	1	1	1	2	1	4	3	3
11	1	5	2	1	1	1	1	5	1	1	1	5	4	3	3	4
12	1	5	4	5	1	1	1	3	1	1	1	4	4	3	2	4
13	1	5	2	4	1	3	3	2	1	1	1	2	2	5	2	3
14	1	4	4	3	1	3	3	2	1	1	1	2	3		3	4
15	1	4	4		2	3	3	3	1	1	1	3	3	3	4	4
16	1	4	4		1	4	4	4	1	1	1	2	4	4	3	4
17	1	4	4		1	4	4	4	1	1	1	2	4	4	4	4
18	1	5	4		3	3	3	4	1	1	1	3	4	4	3	4
19	1	4	4		3	4	4	4	1	1	1	3	2	4	3	4
20	1	4	4		3	4	4	4	1	1	1	3	2	4	2	3

Table C-2a. Herder survey responses for Jinst for questions 1 and 2.

ID#	Soum	Ecozone	Age	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f
01	3	4	74	3	3	2	2	3	2	1	1	1	1	1	1
02	3	4	30	3	1	3	1	1	3	1	1	1	1	1	1
03	3	4	69	3	3	1	2	2	1	1	1	1	1	1	1
04	3	4	60	3	1	1	2	1	3	1	1	1	1	1	1
05	3	4	53	3	1	1	2	3	3	1	1	1	1	1	1
06	3	4	56	3	1	2	2	2	2	1	1	1	1	1	1
07	3	4	47	3	1	1	1	3	1	1	1	1	1	1	1
08	3	4	32	3	1	3	2	1	2	1	1	1	1	1	1
09	3	4	40	3	1	1	1	1	3	1	1	1	1	1	1
10	4	3	32	3	1	1	1	1	2	1	1	1	1	1	1
11	4	3	40	3	1	3	1	2	1	1	1	1	1	1	1
12	4	3	50	3	1	3	2	1	3	1	1	1	1	1	1
13	4	3	46	3	1	1	1	3	1	1	1	3	3	1	1
14	4	3	45	3	1	3	1	3	3	1	1	1	1	1	1
15	4	3	37	3	1	1	2	3	3	1	1	1	1	1	1
16	4	3	53	3	1	1	2	3	3	1	1	1	1	1	1
17	4	3	43	3	1	1	2	3	3	1	1	1	1	1	1

Table C-2b. Herder survey responses for Jinst for questions 3, 4 and 5.

ID#	Q3a	Q3b	Q3c	Q3d	Q3e	Q3f	Q3g	Q3h	Q4	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c
01	2	4	3	4	3	3	3	3	1	1	3	4	3	3	3		
02	2	5	4	4	2	3	3	3	1	2	2	4	3	3			2
03	1	5	4	4	5	5	5	5	1	2	1	4	3	4	4		
04	1	4	3	4	1	5	4	4	1	1	2	4	4	3	3		4
05	1	5	4	5	3	3	3	3	1	1	2	3	3	3			4
06	1	5	3	4	2	3	3	3	1	1	1	3	3	4		4	4
07	1	4	4	4	1	4	1	4	1	1	1	4	4	3	2		4
08	2	5	3	4	3	3	3	3	1						2		4
09	2	4	4	4	2	3	3	2	1	1	1	4	3	3	2		4
10	1	4	4	4	1	3	1	2	1				0	0	1		3
11	1	5	2	1	1	1	1	5	1	1	1	5	4	3			
12	1	5	4	4	2	2	4	3	1	1	1	3	4	3			4
13	1	5	3	4	3	3	4	2	1	2	2	3	4	3			
14	2	4	4	4	4	4	3	4	1	2	2	3	3	4			
15	1	4	4	4	2	3	3	3	1	1	2	3	3	3			
16	1	5	4	4	3	4	3	4	1	1	2	4	3	4			
17	1	5	4	4	3	4	3	4	1	1	2	4	3	4			

APPENDIX D: SUMMARY OF HERDER COMMENTS

Table D-1. Summary of Herder comments.

	ARKHANGAI PROVINCE (IKH-TAMIR SOUM)	BAYANKHONGOR PROVINCE (JINST SOUM)
OBJECTIVES	**HERDER'S OBSERVATION**	
CLIMATE CHANGE: TEMPERATURE	Herders in this region were identified that climate and weather have changed during the last 20 years and it affects seasonal conditions. The extreme hot days in summer have increased, and nights and mornings are getting colder than previously. Herders were also mentioned that they could not distinguish between spring and winter. It means winter is getting warmer and spring is colder than before. However, winter of 2010 was the coldest winter they had experienced in many years. Since the 1980's winter has warmed like spring. In the 1970's herder's never observed snowmelt in the winter. But in the past few decades, they observed snowmelt earlier in winter occasionally due to warmer winter temperature.	Herders in this region have also same perception with Ikhtamir soum. They observed climate and weather changes in the past years. Winter has warmed up since 1980's.
CLIMATE CHANGE: PRECIPITATION	Based on qualitative data from herders it is apparent that summer precipitation amount has decreased in the past years considerably. Some herders mentioned that when they were a child, rainfall duration was longer, lasting 3 or 4 days, and all their clothes (deel) got wet, and they did not have any dry deel to wear. But rainfall is now rare. During the last 10 years, the duration of rainfall has become shorter with high intensity, low infiltration and high runoff. The amount of snowfall in winter has decreased in the past few years. 20 years ago, they had a lot of snowfall in winter about 20-30cm, and sheep and goats had to dive under the snow to eat the bushes and grasses.	Herders identified that from 1970' to 1980's, they had a lot's of rainfall with low intensity and lasts during the 1-3 days. Now precipitation comes later about a month with high intensity and low infiltration and it last 3-4 hours. 20 years ago, the duration of precipitation was last 2-3 days with high infiltration. Precipitation is becoming patchier in this area. The amount of snowfall has decreased during the last years. But we had more snowfall in 2000, 2002 which killed a number of livestock.

SEASONAL CONDITION	"*20 years ago cattle began to graze around April 20th, But now summer arrives a month later, so grazing doesn't begin until end of May*" Summer and winters are getting shorter. Autumn now comes earlier. The spring is becoming longer with lower temperature. Winter cold days shifted into spring, which means spring is getting colder than previously. I cannot distinguish now winter from spring season. I cannot distinguish between spring and winter. It means winter is getting warmer and spring is colder than previously. Autumn comes earlier now with lower temperature. In general seasons are changing completely, summer is getting colder, springs are colder and winters are warmer. The grass growing season now start one month later.	
HYDROLOGICAL CHANGES: STREAMFLOW	Nomadic herders observed that water level in Ikhtamir river is decreasing every year. They mentioned 20 years ago water in Ikhtamir river was so deeper with a stronger stream and horseman and cars could not cross through the river in 1970's -1980's. But now river has decreased and its flow has been very narrow in the last few years. Only this summer, water level in river is higher than previously due to snowfall and earlier rainfall. The Hanui river dried up, which cut off in some places in the last few years but river stream is flowing again this year.	Water level in Tuin river has severely decreased and cut off in some places especially near Jinst soum. In 1970-1980's water level in Tuin river was so deeper with more rainfall.
HYDROLOGICAL CHANGES: SPRINGS, STREAMS AND WELL	Nomadic herders spoke of that most of springs and streams dried up in the last few years. They used to be spring and stream in their winter and spring site. Some of spring was very big and cars could not cross through it and some of them were perpetual. Unfortunately most of them dried up completely. According to the water shortages, herders started to use well in the last few years. But in previous 5 years, water level in well is also decreasing every year due to drought and reduced rainfall.	Most of spring and lakes dried up in the last few years. Water level in well has decreased since 2008. Some of herders are using well during the last year because of water shortages.

APPENDIX E: EXAMPLE HERDER RESPONSES

Table E-1. Evidence of herders responses in changes of hydro-climate in Ikh-Tamir and Jinstsoum.

CLIMATE INDICATORS	ILLUSTRATIVE QUOTATION	
	IKH-TAMIR	JINST
TEMPERATURE	"In the 1970's, the winters were very cold with lower temperatures reached minus 40 degree Celsius and we used fur coats, felt boots and sheep skin hat at that time. Due to warming temperature we had not used any of these warm clothes since the 1990's". "They kept their warm clothes in small house of soum center or kept it in winter shelter and were unable to use it because of previous warm winter.	"In the 1970's, I never observed snowmelt in winter. But in the past few decades, I have observed snowmelt earlier in winter occasionally due to higher temperatures; this is an unusual and unseasonal phenomenon".
PRECIPITATION	"20 years ago, we had a long duration of rain which lasts 3 or 4 days we did not have any dry clothes (deel traditional clothing) to wear and hardly find dry trees to make fire for cook at that time". "Generally, summers were very dry here-hardly any rain in recent years". "In the past few years, short and intense rainfall has occurred which produced high runoff and did not saturate the soil moisture". "Previously, rainfall duration was longer with soft rain and it's enough saturated soil moisture and effect good quality grass growing". "The rains now begin one month later than previously. 20 years ago, summers usually started in May with earlier rainfall. "Recently summer has been started around June 20^{th} with late rain".	"In the summer of 2009, rainfall occurred only in May and less rain than previous which caused prolonged drought during the summer and animal did not gain enough weight"
SEASON CHARACTERISTIC		
HYDROLOGY	"We have no idea where we should go if the Hanui River dries up. We could use wells but the drilling costs are expensive. Twenty years ago, the Hanui River was so deep it could reach the horses stirrups (holds the foot of a rider) and I never saw	"We have been experienced an increase in the occurrence of drought. Summers are not as usual, we had been losing our livestock every year because of drought combined with dzud."

	this river dry previously." "The water level in the KhoidTamir River has decreased, people and livestock can cross the rivers everywhere. The Bayantsagaan River which is tributary of the Khoid Tamir River has dried out, we now started to use well".	Watering points, including streams and springs have dried up, and streams in bigger river basins have changed their channel and blowing in narrow, sometimes disappeared. The volume of water in wells has decreased every year and could not support drinking and livestock sufficiently".
DROUGHT AND DZUD	"As a result of droughts, pasture quality has declined and now low nutrient grasses have replaced nutrient rich vegetation, and also pasture use patterns have changed with more livestock and households concentrating near the Khoid Tamir River due to water shortages that had led to overgrazing in the past decade." "In the early 1980s, the grass grew higher than 6 year old kids and we could not find our kids in the grass, but now it grows just a little higher than the ground due to drought". "In generally, dzuds occur infrequently in the Khangai Mountain region, so we did not have enough experience to cope with the severe winter of 2010 due to previous warm winters."	"The drought has occurred often in this area and many rivers and springs have dried out and the water level in wells has decreased due to reduced rain and drought". "We could not prepare enough hay due to short grasses caused by drought".
SAND AND WIND STORMS	"The frequency of sand storms has increased in the past years. When we have our herd movement from spring to summer camp, the felt roofs of our yurts (gers) were too heavy with packed sand due to sand storms". One herder reported "I was reading an ancient script that was about Gobi sand storm called "Tebbad-Ugalz", but recently, this kind of unusual sandstorm has been occurring in the Khangai Mountain region."	Jinst herder said that "the occurrence of dust and sand storm has increased with drought and strong wind during the last 10 years. Due to sand and wind storms, desertification and sand movement has increased and spread out which has created small sand dune everywhere".

APPENDIX F: SPECIFIC HERDER COMMENTS

F-1 HOUSEHOLD SURVEY IN 2010 (IKHTAMIR AND UNDUR-ULAAN)

1. S.E. (Undur-Ulaan Hanui–Guur)

Summers were very nice when I was in my 20 years old. We had 4 seasons herd movements in each season when we had enough water resources. But now we move my herd only 2 times per year due to water shortages. We have no idea where we should go if Hanui River dries up. We could try to use well water but it is drilling costs expensive. 20 years ago, water in the Hanui river was so deep it could reached the horses stirrup (holds the food of a rider). 20 years ago we never saw this river dry. However, over the last to decade the quantity of water flow in the Hanui River has decreased and is frequently so low that it dries up completely. Fortunately, the amount of rain has recently decreased since 2004 has been reduced rainfall and water flow.

2. Ts. C. (Undur-Ulaan, Dongoi bag), Age - 78

The winter of 2009-2010 was abnormally cold with temperature lower than we have experienced in last 40 years. In addition all of the springs and rivers have dried up. 20 years ago, cattle began to graze around April 20th, but summer arrives a month later, so grazing doesn't begin until the end of May. Since the warming trend began all of the weather and climate have changed since when I was in our 20's. Winter has become shorter and colder. In the past, when we boiled tea we raised the yurt's side cover. But now we can't because dust storms have increased. In the past, dairy season which corresponds with the beginning of summer began around June 10th, and wool clip time was finished at the that time. But now we are moving the herds to the summer place at the end of June due to late rain and grass growth. There used to be springs with a lot of water and many channels near our summer side but now they have dried up. The river freezes up earlier in the autumn.

The priority issue for herders is water due to decreasing water flow and spring and rivers have dried up completely. We are trying to drill wells and use them even though we have no experience with it.

3. **B.M. (Undur-Ulaan, Dongoi bag),** Age-36

Dust storms have increased in last the decade. Rainfall became shorter and more intensive with low infiltration and high runoff. Most springs and streams have dried up. I move my herd following the snowfall in winter, go to the well in spring, and the rivers in summer. I started to use well water 3 years ago. Well water is decreasing 2m every year. In 2008 well water decreased very much due to drought. River streamflow have decreased since 2004. This year we have high river streams due to more snowfall in winter and more rainfall in summer. But streams have decreasing over time so we must move to downhill near the lake to avoid staying where streams may dry up. During the period of transition to a free market system, the costs of movement increased due do water shortages. Water shortages also cause more household and livestock density with many household along the rivers. So many households and increased livestock in one place, we have experienced a decrease in grassland quality and other rangeland changes. The chief priority problems for herders are water shortages and vegetation decline. If less water becomes available, we will see a decrease in the number of livestock.

4. **Ch.E. (Undur-Ulaan, Dongoi bag)**, Age-37

When snowfall comes it usually occurs as snowstorms here. When I was in my 20's, the river was deeper with a stronger stream. But now the river has almost dried up, and its flow has been very narrow in the last few years. River stream has been growing smaller since 2001. The horseman could not cross through the river in 1970's-1980's because river was very deep and streamflow was very strong. Currently the Tairaha burd river is only still flowing because its supported by tributary streams from the lake. In addition, upper stream has already been cut off in some places. We are planning to use well water, and we have already talked with a company who can drill a well. In the early 1970's, we got abundant milk and started to produce dairy products by the end of May. Now dairy season starts one month later than previously. Grass grew higher than 6 year old kids and we could not find our kids in the grass at that time. But now it grows just a little higher than the ground. The number of extremely hot days in summer has increased and now the summer nights are cold due to decreased humidity. Even though the summer has more extreme temperatures, the season is now shorter than previously and autumn comes earlier.

Wind and dust storms have increased in spring. Spring is getting colder sometimes with the temperatures colder than in winter. Our cattle are weak and stagger in the spring strong winds. Vegetation quality has declined and now low nutrient grasses have replaced nutrient rich vegetation due to decreased rainfall and drought. Although rainfall has decreased, it comes with more intensity and sometimes hail, causing low infiltration and high runoff over the ground.

Summer has become shorter, and is crushed between autumn and spring. In the 1970's, the winters were very cold and we were used fur coats, felt boots and kalpaks. Due to global warming and rising temperatures we had not used any of these warm clothes since the 1980's. Since the 1980's winters have warmed like spring. But this winter was very severe and very cold like previous years, and we needed warm clothes again. I had never seen dust storms in Khangai mountain region when I was a child but now dust storms occur every season.

The river freezes up later than previously. Formerly the edge of river streams froze in October, but now they freeze up in November. Likewise, the river used to thaw and begin flowing again in March, but now it doesn't thaw until April. In addition, Salhit spring has dried up, whereas before, it was a very big spring with water plentiful that cars could not cross it. Now of course, cars drive across it regularly.

Last winter was the coldest winter in the last 20 years. Dust storms have increased in the last several years due to drought. Water is becoming a more serious issue in this area. People are trying to use well water due to water shortages. Herder's livelihoods directly dependent on natural resources available and these environmental issues will cause more serious problems for herder's livelihood. Mongolian cows are not eating snow, they only drink water. Last winter, many cattle were weak and unable to survive due to shortage of water resources and low quality rangeland. We will use well water in the future and will hire a company to drill which costs around 500$.

5. **Ch.L. (Ikh-Tamir, - Uzuurt burgas),** Age-67

Gan has increased in summer due to drought and less rainfall. Soil erosion is increasing due to windstorms. In the past, rainfall occurred lasts during the 3-4 days and we were hardly found dry trees to make fire and cook. Now, rainfall has become shorter with more intensity. In the summer, extreme hot days increased and nights are colder than previously. Dust and windstorms have increased in spring. The Hanui River dried up, which cut off in some places in the last few years. The Hanui River stream is flowing again in this year due to more snowfall in winter and more rainfall in summer.

One of the human causes of water shortage is tree logging. The ancient indigenous ancestors had an instinct about possible impacts of climate change that there might be only two seasons (spring and autumn) without winter and summer. I think their perception was right. Summers and winters are getting shorter, which means summer is getting colder and winter is warmer.

Most of the streams and springs with many channels have dried up in the past few years. Rivers freezes and break up have shifted due to the decreased water in the rivers. The amount of snowfall in winter has decreased in the past few years. Sometimes, we observe snowmelt in winter, this is an unusual and unseasonal winter phenomenon. Thus, winter is getting warmer. 20 years ago, we had a lot of snow fall in winter, and sheep and goats had to dive under the snow to eat the bushes and grasses.

6. **A.O. (Ikh-Tamir, Bugat bag)**, Age-67

Autumn now comes earlier. Last winter, we had more snowfall than previously, which killed a large number of livestock. When I was in my 20’s, the weather and environment was so nice, streamflow was stronger, springs had plentiful water, and vegetation growth was higher. In addition, there were no wind and dust storms. But now all the springs and streams have dried up, and also dust and wind storms have increased, and these changes cause negative environmental consequences on herders livelihood.

In the 1970’s, I never observed snowmelt in the winter. But in the past few decades, I have observed snowmelt earlier in winter occasionally due to warmer winter temperatures. There used to be perpetual spring near my winter site. Unfortunately, this spring has dried up completely. In addition, the Bayantsagaan River which we used to supply drinking water for our livestock dried up 3 years ago, so we started to use well water.

7. **S.G. (Ikh-tamir, Ishgent bag),** Age-40

The spring season is becoming longer with lower temperature. Winter cold days have shifted into spring, which means spring is getting colder than previously. I cannot distinguish now winter from spring season. 20 years ago, I did not see any dust storm occurrences in the Khangai region, but now, the duststorms occurred more frequently every year.

All of the springs and streams have dried up in the past few years. Extreme hot days in summer have increased, and nights and mornings in are getting colder than before. The winter is getting warmer than previously. However, this winter was the coldest winter we had experienced in many years. We used well water in spring and winter. But in the previous 5 years, the level of well water decreased every year due to drought and reduced rainfall.

8. **Ts.B. (Ikh-Tamir, Ishgent bag),** Age-60

Although this summer, we have seen much rainfall around this area. In previous years, logging has caused a decrease in river and spring water levels. However, the shortages of water resources make herders daily lives difficult and have trouble coping with winter. Wind storms are increasing which affects grass quality. The livestock weight was so weak in last summer due to drought and reduced rainfall. This year, springs and rivers are flowing again due to increased rainfall. Recently, plant species are changing in this area. The some of species which grew here in 20 years ago, do not exist here anymore.

9. **D.A. (Ikh-Tamir Ishgent heseg),**Age-31

In winter of 2010, the snow cover was patchy. Unusual weather activity and natural phenomena have increased in the past years due to climate change. Frequent snowstorms occurred as usual but the duration of drought increased due to reduced rainfall. Shorter rainfall with higher intensity produced runoff and did not saturate the soil moisture that affects in turn of vegetation growing season. I think, dzud frequency has increased in recent years and I heard, it will continue to increase in the future. When I was a child, plants such as plantain (latin name) and veronica grew everywhere in this region but recently these plants are not exist anymore.

The frequency of dust storms increased in the past years. When we have our herd movement from spring site to summer site, the felt roofs of our yurts were too heavy with packed sand due to sandstorms. Now we dig the ground, there is no frozen soil. I think, this is due to the drought duration, which means, there is not enough moisture in the ground to freeze up. In the past few years, windstorms have increased, causing soil erosion and drought.

Recently, summer is unlike previous summers. Extreme hot days and cold nights have increased in summer. I cannot distinguish between spring and winter. It means winter is getting warmer and spring is colder than previously.

This year, we had a lot of snowfall in the spring. In the past years, snowmelt was more gradual, it caused earlier grass growth in spring. But this spring, rising temperatures caused short rapid melting of snow cover and higher runoff in this area. Nowadays, the water level in the Tamir river is decreasing every year.

10. B. (Ikh-Tamir Tamriin gol),Age-74

Autumn now comes earlier now with lower temperatures. 20 years ago, there were usually no dust storms during the winter but recently dust storms have been occurring increasingly in spring. In general, seasons are changing completely, for example summers is getting colder, springs are colder winters are warmer.

Our family is now using well water, from a second well because that we use dried up. Unfortunately, well water has dried up that was used to be in the past. The Bayantsagaan river dried up sometime after 1990 due to tree logging.

11. N.S. (Ikh-Tamir, Tamiriin gol), Age-47

We now receive snowfall instead of rainfall at the end of spring. The rainfall has decreased and low infiltration due to the hard soil type and the water level in the Tamir river has decreased due to tree logging.

12. Ch. Sh. T. (Ikh-Tamir. Tsaluu), Age-47

The grass grown shorter and is less dense due to reduced precipitation. In addition, the growing season now starts one month late. Summer nights and mornings are now getting colder.. When I was younger, we sent our kids to school on November 7th when we were at our spring site. But recently, we have had to move our herd in to the winter site at the end of October.

The amount of precipitation has decreased in the past few years. I remember that our ancestors told us that they could not find their horse catching poles in the grass because the grass was so tall. But now the grass grows short and low to the ground. Also we now observe earlier snowmelt in winter due to warm winter.

13. T.-A. (Ikh-Tamir, Bart bag), Age-75

The winter of 2010, was more severely cold than we had experienced in 40 years ago. This year, the water level in the river is higher than previously. The springs and rivers have water again whereas before it was dried up. The Onoogiin am which is a main tributary of the Tamir River doesn't thaw completely in summer. This means summer is getting colder and shorter. Seasonal changes have impacted horse reproductively and milk as well as dairy products from cattle, sheep, and goats. Airag (horse milk) and dairy products have become rare, and our kids have been unable to eat sufficient dairy products in recent years.

14. B.Z. (Undur-Ulaan, Dongoi bag), Age-48

In the past few years, short and intense rainfall has occurred with low infiltration and high runoff flow through the ravines. But this year, we have recieved more rainfall with high infiltration. The frequency of gan and dzud has increased in the past years. Seasonal milk and dairy products have shifted ahead one month later due to late summer. In the past winters, usually there were less snowfall and warmer days. Winter of 2010, we had more snowfall than previously.

We are now experiencing more droughts and their duration is increasing. In 2010, we received earlier rainfall which caused earlier vegetation growth. Last winter, dzud occurred with extremely low temperatures and is starting from the beginning of autumn. Livestock losses began occurring from the beginning of December. However, there was no deep snowfall, livestock losses resulted from extremely cold weather and weakness due to the previous dry summer that left them unable to cope with the harsh winter and cold weather. My parents told me that this kind of cold winter with lower temperature was happened in that past, most important impacts a large number of livestock death in this winter was increase of drought duration and gan.

The dust storms have increased. When I was a child, rainfall duration was longer, lasting 3 or 4 days, and all our clothes (deel) got wet, we did not have any dry deel to wear. We did not use a plashy area which could cause cattle hoof disease. But now, if we find this kind of plashy area we move there to be obtain water. In addition, the plashy areas are drier now, so there is reduced risk of hoof disease. The rainfall is now rare. Wind storms have increased and strong winds affect cloud formation which causes less rainfall. However, this year, we had a very nice summer with nice weather.

The weather and climate have changed. Our Ancestors told us that earlier snowfall protects vegetation and provide good grazing for livestock in the spring. Now snowfall comes late, and causes grass to wither affecting livestock grazing in the spring. The Hanui River dried up several times in the past 4-5 years, but this year it is flowing again due to increased rainfall and snowfall in winter.

In the 1990's, we often used fur coats and felt boots in winter time due to lower temperatures. But we had not been used any fur coats or felt boots since 1990's due to warmer winters, so neither the herders nor the animals had enough experiences with cold winter temperature to cope with the dzud in last winter. This winter, extreme cold winter started in December and both animals and herders got frostbite on their noses and ears. In generally, dzud occurr infrequently in the Khangai region but now we are experiencing dzud more often. In response to the dzud, we bought 20 cows from Bayankhongor aimag where dzud often occurs these animals coped with dzud very well winter. None of the cows from this region died.

15. Sh.N. (Ikh-Tamir, han-undur bag), Age-67

During the last 10 years, the duration of rainfall has become shorter with high intensity and high runoff. The weather has changed completely and precipitation has decreased a lot. Thus, winter is getting warmer and spring is becoming longer. Seasonal conditions and characteristics are changing. Forty years ago, we had nice summers with nice weather, more humidity, and a longer duration of rainfall. Recently, however the duration of rainfall has become shorter it lasts only a few hours. Most of young herders have no experience with tha rain coat (Russian military raingear herders regularly used 20 years ago) due to reduced rainfall.

The frequencies of drought have increased. I was reading an ancient script that was about a govi sand storm was called "tebbad". Recently, this kind of unusual sandstorm has been occurring in the Khangai region.

All of rivers and springs have dried up due to drought. In total, 30% of river and springs have dried up in the past few years. The water level in the Tamir River has decreased, people and livestock can cross the rivers everywhere. The amount of snowfall has decreased, and we have not had permanent snow cover (herders call it "Silver white winter") in recent years. 20 years ago, cows ate grass grabbing it with their tongue because plants grew higher, but recently, they have had to eat grass pulling it with their teeth due to shorter plants height. Additionally, in the past summers were very hot, making the dogs whine and paint.

Recently, this kind of hot summer has not been occurring in this region. We also had extremely cold winters in recent years, when we went out we got frostbite our ears and noses. This kind of extreme cold winter had not occurred in the previous 15 years.

16. S.B. (Ikhtamir_Tsagaan burgas), Age-43

Summer comes later and has grown shorter in the past few years. Sometimes, we have seen snowfall after summer began. Snow and wind storms have increased. Autumn is getting shorter with more mizzle, and grasses dry up earlier. Frequency of drought is increasing. When I was in my 20's, there were no sandstorms in this Khangai region, but recently the frequency of sandstorms have increased in the spring. Windstorms are also increasing every year. The frequency of dzud has remained constant; however an extreme dzud occurred in the winter of 2010.

We received more rainfall this summer, whereas before, rainfall occurred rarely. The rainfall now begins one month later than before. When I was younger, summers usually started in May. Recently, summer has been starting around June 20th. The late and shorter summer has negative impacts on animal weight and strength, which makes it difficult for them to cope with harsh winters. Last winter, we had a lot of snowfall whereas before there was little snowfall. Generally, snowfall has decreased in the past few years. When I was a child, more snowfall occurred and the livestock adapted well. Recently, duration rainfall has decreased. Now rainfall lasts only few hours with more intensity and high runoff.

APPENDIX G: MONTHLY CLIMATE CHANGE TRENDS

Table G-1. Monthly trends in average air temperature and precipitation amount at Tsetserleg and Erdenemandal.

		average temperature			precipitation			
month	n	monthly average	Sen's slope [deg C/century]	Significance	n	median amount	Sen's slope [mm/century]	Significance
					TSETSERLEG			
Jan	49	-14.9	1.55		49	1.9	1.82	
Feb	48	-12.7	7.63	$p<0.05$	49	1.78	0.466	
Mar	49	-6.35	3.89		49	7.2	5.18	
Apr	49	1.92	8.08	$p<0.01$	49	15.1	-17.0	$p<0.1$
May	49	9.08	3.27	$p<0.05$	49	28.7	8.51	
Jun	49	13.6	2.60	$p<0.05$	49	61.5	-33.3	
Jul	49	15.1	5.69	$p<0.001$	49	83.1	-49.2	
Aug	49	13.4	4.33	$p<0.01$	49	69.8	-73.7	$p<0.05$
Sep	49	8.07	5.24	$p<0.001$	49	25	-5.07	
Oct	49	0.79	3.68	$p<0.05$	49	10.5	-0.861	
Nov	49	-7.39	2.62		49	6.1	-1.27	
Dec	49	-12.9	1.15		49	2.2	0.800	
					ERDENEMANDAL			
Jan	47	-18.6	-0.126		0	1.2	0	
Feb	47	-15.6	10.9	$p<0.05$	47	0.8	0	
Mar	47	-7.70	4.23	$p<0.05$	47	1.7	0.385	
Apr	47	1.27	7.15	$p<0.01$	47	5.5	-14.6	$p<0.05$
May	47	8.85	3.78	$p<0.05$	47	19	-3.13	
Jun	47	13.8	2.93		47	52.8	-37.8	
Jul	47	15.4	6.60	$p<0.001$	47	83.9	-56.4	
Aug	47	13.4	4.43	$p<0.001$	47	64.5	-31.7	
Sep	47	7.74	6.16	$p<0.001$	47	20.1	-14.3	
Oct	47	-0.011	3.66	$p<0.05$	47	4.5	-2.22	
Nov	46	-9.08	4.07		47	1.9	0	
Dec	46	-15.9	5.95	$p<0.05$	46	1.5	-1.71	

Table G-2. Monthly trends in average air temperature and precipitation amount at Bayankhongor and Horiult.

		average temperature			precipitation			
month	n	monthly average	Sen's slope [deg C/century]	Significance	n	median amount	Sen's slope [mm/century]	Significance
				BAYANKHONGOR				
Jan	47	-18.2	-0.148		47	1.5	2.96	p<0.1
Feb	47	-15.3	9.27	p<0.05	47	1.2	0	
Mar	47	-7.59	3.33		47	2.75	-2.22	
Apr	47	1.84	6.83	p<0.01	47	4.7	0	
May	47	9.78	2.57		47	12.7	8.75	
Jun	47	15.3	2.39	p<0.05	47	28.6	-10	
Jul	47	16.9	6.55	p<0.001	47	50.7	-20	
Aug	47	15.1	5.05	p<0.01	47	40.9	-43.1	
Sep	47	8.79	5.91	p<0.001	47	13.9	-5.67	
Oct	47	0.177	4.00	p<0.1	47	3.7	0.571	
Nov	48	-9.80	3.45		47	1.2	0.625	
Dec	48	-16.1	2.33		47	0.9	5	p<0.01
				HORIULT				
Jan	38	-17.5	1.37		38	0	0	
Feb	38	-12.7	10.6	p<0.05	38	0.2	0	
Mar	38	-3.46	7.50	p<0.1	38	0.7	1.35	p<0.1
Apr	37	6.61	9.92	p<0.01	37	1	0	
May	37	14.4	7.33	p<0.01	37	2.2	2.75	
Jun	35	20.6	5.18	p<0.01	35	8.2	-12.8	
Jul	36	22.7	9.60	p<0.001	36	14.3	14.2	
Aug	36	20.7	5.31	p<0.01	36	14.6	-10	
Sep	35	14.1	4.78	p<0.05	35	4	-2.94	
Oct	35	4.51	3.47		35	0.8	0	
Nov	38	-6.25	2.31		38	0.15	0	
Dec	39	-14.9	0.583		39	0.3	0	

APPENDIX H: SENSITIVITY TO CLIMATE CHANGE

H.1 INTRODUCTION

People in the developing world are more sensitive to climate variability and extremes, due to increased exposure to the environment and other issues, such as their lack of institutional capacity to adapt and weak economic power (Ravindranath *et al.,* 2003). For Mongolia, long-term assessments illustrated that more than 60% of total land is highly sensitive and vulnerable to climate change and extreme weather events (Batima, 2006). Mongolian pastoralists make up a large proportion of the rural population and their livelihoods are increasingly at risk from extreme events, making them more vulnerable than other populations to the impact of these changes (Angerer *et al.,* 2008). Their livestock are raised outdoors in severe weather conditions and are significantly exposed to hazards including *dzud*, droughts, sand and wind storms and grass land cover changes (Nandintsetseg *et al.,* 2007).

A rising of global mean temperatures increases the probability of extreme weather events such as days with very high or very low temperatures, extreme floods, droughts and storms (Smith *et al.,* 2001). These climate changes and extreme events have already occurred in Mongolia including increased temperatures and extreme hot days (Dagvadorj *et al.,* 2009; Batima, 2006;Nandintsetseg *et al.,* 2007) and changes in precipitation pattern and amount (Zhang *et al.,* 2004; Peterson *et al.,* 2001; Sato, 2007), frequent sand and wind storms (McTainsh, 2007; Goudie and Middleton, 1992; Natsagdorj *et al.,* 2003), droughts (Begzsuren *et al.,* 2004; Sternberg *et al.,* 2010; Nandintsetseg *et al.,* 2010; Xue *et al.,* 1996) and their affects on social-ecological and economic systems.

H.2 IMPLICATIONS OF CLIMATE CHANGE AND EXTREME EVENTS

Many herders indicated that the weather and environment are becoming worse, and that these changes may negatively impact herders' livelihoods and their livestock. The results from the herder survey and station record analysis show a significant increase in temperatures and some decrease in precipitation and water availability in the Khangai Mountains and Gobi-desert steppe. Summer precipitation declined 53.5mm in Arkhangai and 53.4 mm in Bayankhongor aimag (Gomboluudev, 2009). Increased temperatures and reduced summer precipitation increases the probability of drought, especially over the long term (Cancelliere *et al.,* 2007). While Mongolian herders often face a degree of harsh and unpredictable weather (Begzsuren *et al.,* 2004), the weather conditions could become more extreme in the future.

Drought and *dzud* frequency and duration were seen to have increased over two areas based on herders' observations. However, it should be noted that there have only been two major *dzud* (1999-2002 and 2009-2010) in the past 20 years so caution should be used when considering the memory of such extreme events. Drought events could lead to forage failure, water shortages and reduced availability of supplemental feed for livestock (Angerer *et al.*, 2008). This has already been observed where droughts decreased pasture productivity by 12-48% in the high mountains and by 28-60.3% in the desert steppe (Batima, 2006). One herder reported in Ikh-Tamir "*in 1970s, grass grew higher than our six year old kids and we could not find our kids at that time. But now it grows just a little higher than the ground.*" Droughts also cause a weak animal condition due to poorer pasture quality and other lack of resources. During a dry summer and prolonged drought, animals become unable to gain sufficient mass and strength to cope with *dzud* and wind storms in the following year (Batima, 2006).

Dzud typically occurs 1 to 2 times per decade and these leads to high livestock mortality which directly affects the livelihood of herders (Gomboluudev, 2009). As can be seen from the winter warm days (Figure 2.5.5), winter is warming faster (Appendix G). These warmer winters can yield unusual and unseasonal weather phenomena. In the past, there were usually no winter wind storms in Mongolia, but recently wind storms have occurred in January and December (Batima, 2006), which corresponds to all herder observations of an increase in wind storms. Extreme winters can include strong wind storms that are now more severe for animals due to their weakened condition from drought and thus many die due to exhaustion. Winter warming also cause earlier snowmelt but this water can turn into ice sheets over a larger area when temperatures drop; these ice sheets greatly prohibit animal access to grazing. Pastoral herders and their livestock can also be stressed from extreme cold temperatures, even if only for short periods. For instance, the winter of 2009-2010 had extreme cold temperatures with deep snowfall yielding a two-part *dzud* that severely impacted these pastoralists. Herders, in particular those in the high mountains, were more affected by this very cold winter and stated "*this winter was extreme cold and both animals and herders got frostbite on their noses and ears.*" Such *dzud* after warming winter weather can have an increased impact due to decreased preparedness.

For grazing land, the main function affecting the spatial scale of livestock management is the availability and distribution of watering points (Ojima and Chuluun, 2008). The combination of precipitation decrease and temperature increase, in conjunction with drought, can cause a shortage of water availability due to diminished water sources.

H.3 EXPOSURE AND SENSITIVITY

People who depend directly on pasture and water resources for their livelihood are highly sensitive and more exposed to climate variables and extremes. Herders perceived that summers are delayed and have a shorter duration which, associated with a decrease of precipitation and more drought, generates less plant matter in pastures and a shortage of water sources. In Arkhangai, there has been a significant decrease in April precipitation (Appendix G) which can yield a later start of the growing season. At Bayankhongor there was an increase in snowfall (precipitation in the winter) which could produce more snowmelt runoff, except snowfall amounts are limited.

During the last decades, pasture quality has decreased and thus less forage and hay could be prepared for the livestock to cope with winter. Due to this lack of resources, the livestock conditions have become worse. Livestock cannot gain enough weight and strength during the summer. Ikh-Tamir herders stated "*last winter, many cattle were weak and unable to survive due to water shortage and low quality pasture.*"

Due to dry summers and increased shortage of water, herders' movement and pasture use patterns have changed and more household and livestock are concentrating and staying closer to watering points in the Khangai Mountain zone (Fernández-Giménez, 2006; Ojimaand Chuluun, 2008). Herders in this area have moved less due to dried spring and rivers. One Ikh-Tamir herder said that when "*we had 4 herd movements in each season when we had enough water resources. But now we move my herd only 2 times per year.*" It is opposite for the Gobi-desert zone herders who have historically used wells and now have increased the frequent and distance of movement in looking for good pasture and water for their livestock (Marin, 2010).

Herders have experienced a change in temperatures. Many Ikh-Tamir herders have adopted to warmer temperatures in previous winters and thus the winter of 2010 felt quite severe. This kind of extreme cold winter had not occurred in that area since 2000. Many herders perceived an increase of extreme hot days in the summer. Their animals cannot graze on pastures when the air temperature is very hot; this reduces their daily intake and leads to insufficient weight and strength.

H.4 POTENTIALIMPACTS

H.4.1 Climate Impact on the Environment

In addition to climate change, a warmer and drier climate has promoted the expansion of activities, including livestock grazing, into the areas that were formerly less used and a decline in rangeland cover (Ojima and Chuluun, 2008). An increase in drought and decrease in precipitation leads to less water resources and flow. The frequency of natural disasters including drought, dzud, sand storms and wind storms has increased which causes a significant amount of damage to the economy and society (Batima, 2006).

H.4.2 Impacts on the Pastoralist System

Resource dependent people are more impacted by climate, its variability and change, and extreme weather events. Extreme hot and cold temperatures observed by herders and the station records and their related effect on herders and their animals have been documented in Mongolia. The most severe and influential extreme weather events on social and ecological systems in Mongolia are droughts and *dzud*. The combination of drought and *dzud* during the period from 1999 to 2002 resulted in mass livestock losses with decreases up to 24 million in 2002 (Ojima and Chuluun, 2008). The *dzud* of 2009-2010 also caused a high number of livestock death with 69,000 head of livestock perishing in Ikh-Tamir and 39,000 in Jinst. All of this has resulted in a declining livestock population and increased poverty in Mongolia.