Evaluating the impact of climate change based on herders' observations and comparing it with hydro-climatic and remote sensing data

Odgarav Jigjsuren[1], Batkhishig Baival[2], Kherlentuul Nayanaa[3], Azjargal Jargalsaikhan [2], Khurelbaatar Dash[4], Bayarmaa Badamkhand[4], Amarzaya Bud[4]

[1] Information and Research Institute of Meteorology, Hydrology and Environment, <odgarav.j@gmail.com>
[2]Nutag Partners, batkhishig@nutagpartners.mn, <azjargal@nutagpartners.mn>
[3]Oyu Tolgoi LLC, <KherlentuulN@ot.mn>
Head of Livestock Units of Khanbogd, Manlai, Bayan-Ovoo *soums*, <hurelbaatar_dash@yahoo.com>, <bayrmaa_0919@yahoo.com>

ABSTRACT

Studying the impact of recent years' climate change on Mongolian rangeland livestock husbandry and on pastoral herders' livelihoods, based on herders' observations and their experience, is an approach that is of considerable interest to many scientists. Our research identifies changes in natural conditions and climate, as well as the changes in rangeland conditions, as observed by herders, and compares them against weather stations' multi-year observations and remote sensing data. Our research region of Khanbogd, Manlai and Bayan-Ovoo *soums* of Umnugobi *aimag* has been, in the recent years, experiencing a rapid development of the mining industry and human population growth. According to local herders, current rangeland quality greatly decreased compared to the period before the year 2000, while the area of barren land, sand movement and soil erosion increased. Herders also said that the amount of rainfall diminished and the rainy season's duration shortened, short high intensity rains grew in number, and it became extremely hot in summer. Soum weather station records of air temperature, precipitation and evaporation confirmed herders' observations, and were consistent with Normalized Difference Vegetation Index (NDVI) or the results of observations of rangeland vegetation phenology. To develop local adaptive capacity in the face of changing social-ecological systems it is important to use and integrate multiple sources of information that are essential for making policy implementation mechanisms and measures more locally appropriate and relevant.

Key words: herders' observations, climate change, rangeland degradation

INTRODUCTION

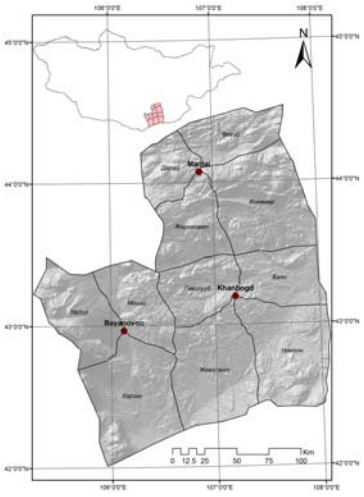
In Mongolia, there are relatively few climate and rangeland monitoring points in the national network of hydro-climatic and environmental research, and consequently data coverage is poor and inconsistent (Addison et al., 2012). Due to this situation, the

traditional knowledge of local environments can be used as one of the sources of information revealing rangeland transformation and change (Berkes, 2008; Bruegger et al., 2014). Herders are able to observe and indicate climate and rangeland changes which not yet been confirmed by weather measurement (Fassnacht et al., 2011; Addison et al., 2012; Venable et al., 2012). Climate change in Mongolia in recent years has been 2.4 times more intense than the world average, and the agriculture sector is more vulnerable than other sectors to its impact (MARCC, 2014). Temperature increases are clearly observed in the mountain regions, while they are relatively less revealed in the gobi desert zone (Batima et al., 2005; Hilker et al., 2013; Liu et al., 2013), although the desert steppe area's northerly expansion has been detected (Angerer et al. 2008). The desert steppe region is a non-equilibrium ecosystem, thus it is transforming because of climate change rather than livestock grazing (Fernandez-Gimenez and Allen-Diaz, 1999). Combining herders' long-term observations and experience with the expert-generated hydro-meteorological data, for the purpose of adaptation to climate change, can be seen as an indicator of capacity building suitable to particular region specifics (Batkhishig, 2012).

According to The Second Assessment of Climate Change, while generally the amount of winter precipitation is gradually growing in Mongolia, it is increasing more in the western and central parts of the country than in other areas, whereas in the southern and south eastern parts the summer precipitation is declining, the aridity index is increasing, the number of extremely hot days is growing, and this situation is likely to persist (MARCC, 2014).

Based on the assumption that herders' observations and their traditional practices and experiences can play an important role in evaluating local climate and rangeland change (Bruegger et al., 2014), we evaluated the changes occurring in the rangeland of our target region by comparing herders' observations with multi-year weather and remote sensing data. We predicted that the perceptions of herders, who observe the weather and their local rangelands on the daily basis, would be consistent with the multi-year observation data from weather stations.

STUDY SITE



Research was undertaken in Khanbogd, Manlai and Bayan-ovoo *soums* of Umnugobi *aimag*, and these *soums* belong to the desert and desert steppe region, where the dominant vegetation includes *Anabasis brevifolia*, *Nitriria sibirica*, *Caragana gobica*, *Salsola passerine, Cliestogenes songorica and Stipa gobica* (Ulziikhutag, 1989; Grubov, 2008). 63-102 mm of precipitation per year falls in this region. Due to the recent intensive development of the mining industry in this region, the human population and number of livestock in the area is rapidly growing. In particular, in Khangai *soum* 43,725 head of stock, in Manlai *soum* 65,517 head of stock, and in Bayan-Ovoo *soum* 53,375 head of stock were counted in 2003, while in 2013 that number became 126,003 head of stock in Khanbogd *soum*, 117,787 head of stock in Manlai *soum* and 89,577 head of stock in Bayan-Ovoo *soum*.

Figure 1. Study region

STUDY METHODS

A survey of herders, time-series of precipitation and air temperature data from the weather stations and AVHRR Normalized Difference Vegetation Index (NDVI3g) were the data used in the study.

In June 2014 a field research team together with the team leaders met with the herders of above mentioned three *soums*, and interviewed them using a closed-ended survey. A total of 124 herders participated in the survey, out of which 40 were from Khanbogd *soum*, 46 were from Manlai *soum*, and 38 were from Bayan-Ovoo *soum*. When choosing the survey participants the research team randomly select herders who have lived in the particular *soum* for a number of years and who were qualified and experienced in raising livestock. The survey had in total 15 questions and included questions about changes in rangeland conditions, vegetation, precipitation, air temperature, lakes, water wells, water table, sand and dust storms and the distribution of animals.

Statistical analysis of precipitation and air temperature data using regression and correlation were done on data collected between 1981 and 2012 by the weather station in Khanbogd *soum,* and between 1993-2012 by the weather station in Manlai *soum*. Analyses were conducted using SPSS software. Data quality from the weather station at Bayan-Ovoo *soum* was inadequate for statistical analysis, and only qualitative data are presented for this *soum*. Evaporation is rarely measured in Mongolia, and so was calculated using the Penman–Monteith equation (1) by Instat software (Stern et al., 1998).

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} \cdot u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \qquad (1)$$

where ET_o = evapotranspiration (in mm/day), R_n = net radiant flux received by vegetation cover surface (in W/m^2 per daytime), G = soil heat flux (in W/m^2 per day), T = daily average air temperature (in °C), u_2 = wind speed at 2 meters height (in m/sec), $e_s - e_a$ = humidity deficit (in kPa), Δ = humidity deficit curve slope (in kPa /°C), and g = psychrometric constant (in kPa $°C^{-1}$).

To evaluate vegetation condition AVHRR Normalized Difference Vegetation Index (NDVI3g) we used data from 1982-2012, the processing was done by cartography software such as GIS 10.1 and ENVI 4.4.

RESULTS

Changes in the weather and rangeland according to herders' observations

Herders believed that less precipitation, higher air temperature and more soil erosion and consequent dust storms in the research area over the last 20 years have led to rangeland degradation. Specifically, 54% of herders thought that rangeland production had decreased, and 64% thought that the number of plant species had decreased, in the last 20 years (Table 1). Herders said that nutritious livestock grasses such as *Artemisia frigida*, *Allium polyrrhizum*, *Allium senescens*, *Psammochloa villosa* had stopped growing, and plants such as *Artemisia adamsii* and *Corispermum mongolicum* had become dominant in the steppe, which they used as evidence of rangeland degradation. 61% of herders thought that nutritious edible plants had diminished in number and 37% said that size of bare patches in the rangeland had expanded, and they explained the reason as being due to increases in sand movement (39.5%) and soil erosion (50.8%) due to loss of topsoil. Also herders said that 20 years ago medicinal herds such *Rhodiola rosea* and *Thymus gobicus* were abundantly growing, but had now become scarce.

Table 1. The changes in rangeland, soil and vegetation, as observed by herders. Note**:** Values show the number of herders which observed each change and the percentage rate for the total survey.

Changes occurring in the rangeland (*compared to the period before the year 2000*)	Khanbogd (n=40)		Manlai (n=46)		Bayan-Ovoo (n=38)		Total (n=124)	
	%	(n)	%	(n)	%	(n)	%	(n)
Rangeland production worsened	57.5	(23)	47.8	(22)	57.9	(22)	54.03	(67)
Vegetation species number decreased	77.5	(31)	50	(23)	68.4	(26)	64.5	(80)
Nutritious plants stopped growing	70	(28)	45.7	(21)	71.05	(27)	61.3	(76)
Size of barren patches expanded	40	(16)	32.6	(15)	39.5	(15)	37.1	(46)
Sand movement increased	45	(18)	36.9	(17)	36.8	(14)	39.5	(49)
Soil erosion increased	60	(24)	36.9	(17)	57.9	(22)	50.8	(63)

When comparing current climate conditions with conditions before the year 2000, herders perceived that in the last 20-30 years the rainfall amount had dropped, its intensity increased, and its duration shortened (Table 2). Herders thought this had led to heavy intense rainfalls with a short duration and flooding, causing topsoil erosion, and a shorter plant growing season. Herders also reported that the amount of snow has slightly increased, and has started melting earlier. In the last 20 years they thought that the water levels of rivers, lakes, springs, and wells have declined and there have been more instances of water bodies drying up.

Table 2. The changes in weather and climate, as perceived by herders. Note**:** Values show the number of herders which observed each change and the percentage rate for the total survey.

Weather changes (*compared to the period before the year 2000*)	Khanbogd (n=40)		Manlai (n=46)		Bayan-Ovoo (n=38)		Total (n=124)	
	%	(n)	%	(n)	%	(n)	%	(n)
Amount of precipitation reduced	82.5	(33)	73.9	(34)	44.7	(17)	67.7	(84)
Temperature changes (Intense heat, increased cold weather)	35	(14)	36.9	(17)	47.4	(18)	39.5	(49)
Drop of water level of wells and springs	87.5	(35)	93.5	(43)	73.7	(28)	85.5	(106)
Increase in frequencies of dust storms	55	(22)	43.5	(20)	52.6	(20)	50	(62)

Khanbogd *soum's* Gaviluud *bag's* herder S.Bud (age 71) said: "In the last years the rain either doesn't fall for some time or when it rains it falls very heavily and intensily in a short period of time", Manglai *soum's* Oekhii *bag's* herder B.Luvsannorov (age 62) said: "Now even the rainfall has ceased happening, only sometimes when it rains it falls heavily and intensily, pulling out a little remainder of short grass by root", Bayan-Ovoo *soum's* Kharzag *bag's* herder Tseren (age 64) said: "The soil lost its strength to hold plant roots and when a little heavy rain falls plants are washed away with it".

Climate and remote sensing (NDVI)

In order to compare the herders' observations with multi-year data documentation we analyzed each *soum's* air temperature, precipitation, evaporation and vegetation conditions (Figure 2).

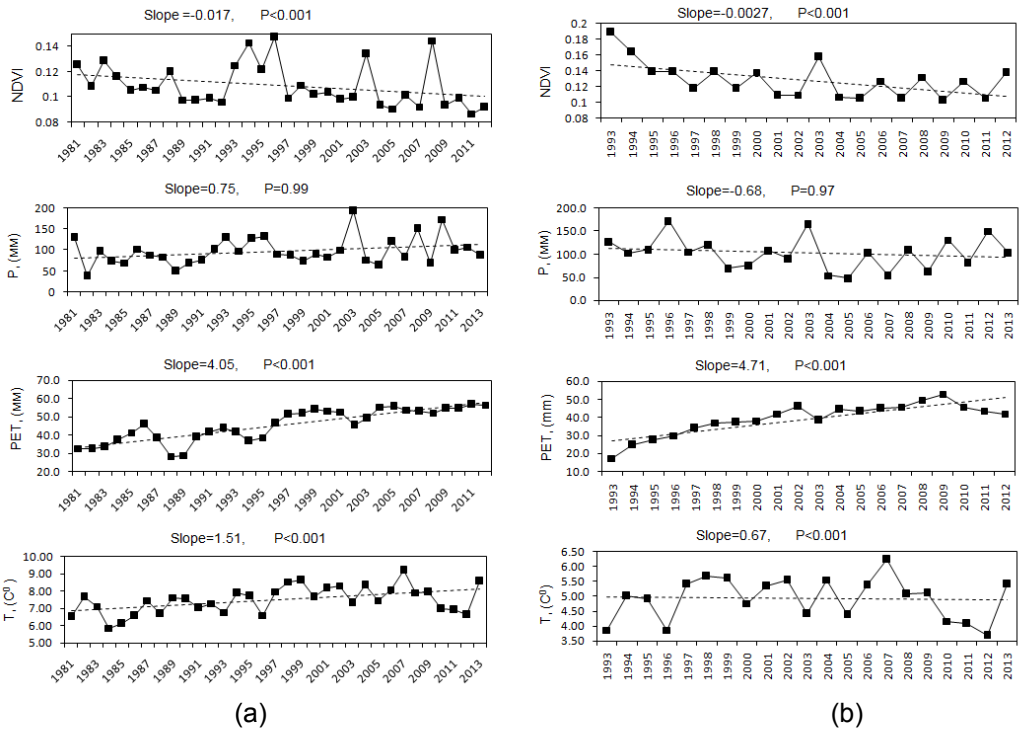


Figure 2. Changes in NDVI, precipitation (P), evaporation (PET) and air temperature (T) and in (a). Khanbogd *soum* of Unmugobi *aimag* (b). Manlai *soum* of Unmugobi *aimag*.

From the last 32 years pattern in Khanbogd *soum* (Figure 2a) the vegetation condition or NDVI value has decreased on average by 0.017 (p<0.001), air temperature increased by 1.51 degrees (p<0.001) and evaporation increased by 4.05 mm (p<0.001). While a trend in precipitation increase by 0.75 mms was observed, this was not statistical significant (p=0.99). From the last 20 years pattern in Manlai *soum* (Figure 2b) the vegetation condition or NDVI value has decreased on average by 0.0027 (p<0.001), precipitation decreased by 0.68 mms was observed, this was not statistical significant (p=0.97), evaporation increased by 4.71 mms (p<0.001) and air temperature increased by 0.67 degrees (p<0.001).

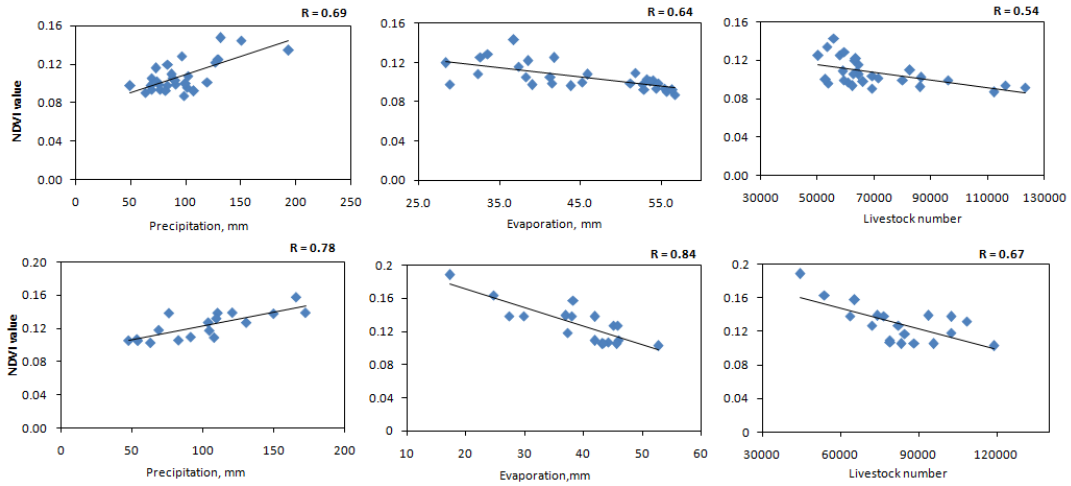


Figure 3. Correlation of precipitation, evaporation, livestock number and NDVI value in (First row-Khanbogd *soum* of Unmugobi *aimag,* Second row- Manlai *soum* of Unmugobi *aimag)*.

The results above indicate that precipitation, evaporation and livestock number considerably influence vegetation growth in Khanbogd and, Manlai *soums* (Figure 3). As seen from the figure, relation between NDVI value and precipitation or correlation coefficient in Khanbogd *soum* is r=0.69 and in Manlai *soum* is r=0.78, and as for evaporation in Khanbogd *soum* it is r=0.64, and in Manlai *soum* it is r=0.84 and as livestock number in Khanbogd *soum* it is r=0.54 and in Manlai *soum* it is r=0.67.

THE ROLE OF EXTERNAL FACTORS

Herders said that the changes occurring in their local rangeland were not only influenced by climatic factors, but also impacted by human activities. In particular, they attributed changes to factors including many new boreholes being sunk, high levels of groundwater use, a large number of heavy machines roaming over the land causing breaking and crushing of soil layers, multiple new roads being formed, and widespread mining.

The Oyu Tolgoi mine in Khanbogd *soum* of Unmugobi *aimag* began intensive activities in 2008, and mine site occupies 0.67% of total *soum* territory of 10058.67 ha[1]. There are several other projects are being operated in this *soum, such as* other small-scale private mines, China Sonhua LLC[2], and road infrastructure associated with these mining projects. As of 2014, all these small to large scale projects occupied an area 572779 ha or 38.2% of total *soum* territory. In Manlai soum the area affected by mining and associated roads takes up 6.5% of the total *soum* area, and in Bayan-Ovoo *soum* the area affected by coal mining and roads is 22.7% of the total *soum* area. These values support herders' observations of the rangeland diminishing in size in the recent years.

We compared human population and livestock number (Figure 4). In recent years, the population of Khanbogd soum has rapidly grown, and livestock numbers have grown gradually, especially after *dzud* 2010 the livestock number has grown rapidly.

Based on our results, it is seen that climate indicators and increase in livestock number have a complex impact on the rangeland vegetation. In other words, the trend is observed that in the years with increased precipitation, NDVI value increases, and in the years with higher rate of evaporation and higher livestock numbers, NDVI value decreases. In all three *soums* the multi-year average of air temperature and the evaporation increased, and, compared to the year 2000, livestock number increased by 42% in Bayan-ovoo *soum*, by 68% in Manlai *soum*, and by 83 % in Khanbogd *soum*, and by 2014 reached highest level ever registered (96,465 in Bayan-ovoo *soum,* 128,835 in Manlai *soum* and 126,467 in Khanbogd *soum*).

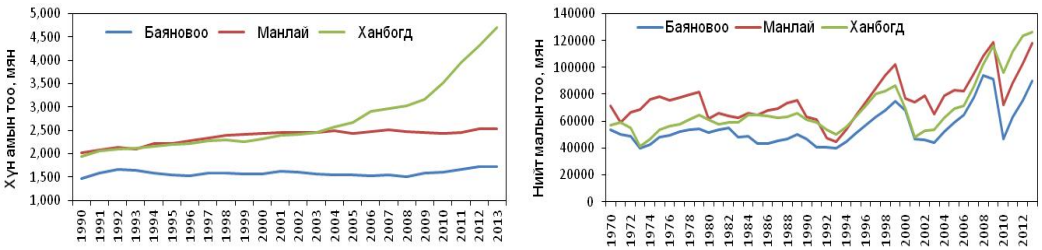


Figure 4. Human population and livestock number changes in three *soums*: (а). Population number, (б). Livestock number (*Source:* National Statistical Office)

[1] Source: "Oyu Tolgoi" LLC, Local and regional development department officer N.Munkhbayar

[2] The chief of Khanbogd *soum* "Gobi land and soil" NGO L.Battsengel and the governors of *soums*.

DISCUSSION AND IMPLICATIONS

Herders of the three *soums* share a common conviction that the decrease in rangeland area size contributes to rangeland degradation by increasing the grazing pressure on the remaining rangeland area. The rapid development of the mining industry in recent years was responsible for rangeland loss, as some areas previously used for pasture were converted to mining infrastructure and road construction.

Our general hypothesis that herders' daily observations of the weather and local rangeland conditions will conform to the results of statistical analysis of the weather stations' multi-year observation data, was confirmed by our study results. However, the station data did not show significant declines in precipitation, as herders observed. Herders, using their long term knowledge and experience, have acquired their own concept of exploring natural conditions (Berkes, 2008), which tends to guide their daily decisions and practices (Gadgil et al., 2003). Appropriate adaptation to the social-ecological changes would require ability to use information from different sources (Batkhishig and Fernandez-Gimenez, 2012) and there is potential to integrate expert and traditional knowledges at local soum level to inform rangeland management.

In this study, we compared the time series of climate data collected from the stations with herder knowledge that guides their livelihoods and it could be considered as relevant only for the local scale (Sillitoe, 1998). It appears that herders' knowledge could serve as one of the information sources to explain the trends in local scale rangeland vegetation and local climate change. Recognizing the limited network of rangeland monitoring stations in Mongolia, herders knowledge and observation of climate and vegetation changes could complement climate time-series of data and provide more accurate and practical explanations to the trends.

The question of carrying capacity in the face of changing climate, livestock growth and decreased rangeland area has become a main concern for three *soums*. The local government and community herders are eager for prompt implementation of locally and ecologically appropriate rangeland management practices. It may be helpful to consider using local knowledge to understand climate and vegetation trends and inform local and *aimag* policy and planning on rangeland and risk management and early warning.

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