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Limiting factors for nomadic pastoralism in Mongolian steppe: A hydrologic perspective

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SUMMARY

In this study, limiting factors for continuing nomadic pastoralism in steppe areas were studied based on a hydrologic perspective. Two small watersheds in central Mongolia were selected for an assessment of water balance and hydrologic processes. We determined that the majority of annual precipitation, ~88–96 mm, was lost by evaporation (82%) while only a small proportion went to groundwater discharge, surface runoff, and groundwater consumption by nomadic activities. The soil column was found to absorb large fluctuations in precipitation although its connection to groundwater was very weak. Groundwater recharge was, therefore, very small and occurred only rarely during heavy rainfall events in valley bottoms. However, current water storage in shallow groundwater was determined to be quite sufficient for continuing nomadic pastoralism when compared to the drinking water requirements of livestock. The main limiting factors identified were a temporal lack of feed to animals due to a loss of aboveground biomass resulting from soil moisture shortages during drought conditions, and a decline in the number and maintenance level of the traditional well network that, due to access to shallow groundwater, has allowed herders to migrate to areas with better conditions in remote Mongolian steppe.

1. Introduction

In remote rangelands, water is often considered to be a limiting factor for continued nomadic pastoralism because drinking water limitations influence the sustainability of livestock. In most cases, with the exception of camels which can survive for extended periods without drinking water, livestock must consume water on a daily basis. Since perennial streams are rare to non-existent in many arid regions, daily water consumption largely depends, with the exception of regions near mountains where spring water is expected and the winter season when accumulated snow and ice serve as a water, on shallow groundwater.

Since nomadic pastoralism has continued over centuries (e.g., Miyawaki, 2002; Matsubara, 2005; Cribb, 1991), implying sustainability, the impact of livestock on shallow groundwater stocks should not be very large. Crude estimates of annual water balance support this assessment. For example, by assuming an annual rainfall value of $P = 150$ mm, an evaporation value of $E = 0.8 \times P = 120$ mm, a daily water consumption value for sheep of 4 L, and a typical stocking rate of 0.5 head/ha, an annual sheep water consumption of 730 L/ha and an annual available water value ($=P - E$) of 3.0×10^5 L/ha can be derived. Given these values, water consumption by livestock only constitutes 0.2% of available water. However, such an argument is based on average conditions. A relevant question is whether or not water is sufficiently available everywhere and at all times, and if not, what could induce a temporal/local water shortage. Additional questions include the following: (i) Is water abundant in every season of the year? (ii) Is there enough water even under drought conditions when annual rainfall is much less than the climatic mean value? (iii) Is the stocking rate as low as the assumed value everywhere? (iv) Will the stocking rate continue to be at the same level as the assumed value? (v) Were stocking rates and water balance regimes different in the past? Such questions address some of the relevant factors that could influence the sustainability of nomadic pastoralism. To answer such questions, crude estimations are not sufficient. A comprehensive study with more reliable data and statistics is clearly required.

The above discussion presents a brief background for the present study. We determined a detailed water balance and estimated

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hydrologic processes for pastureland in order to shed some light on the limiting factors for nomadic pastoralism. Additionally, vegetation dynamics in relation to the water deficit were considered by referring to information presented in the companion study of Satoh et al. (2012) based on detailed ecohydrologic observations, and to the carbon dynamic simulation results of Chen et al. (2007), among others. Since a lack of water can also limit nomadic pastoralism due to the influence of water availability on vegetation growth, information on vegetation dynamics was also obtained. Combining water balance estimates and ecohydrological information allowed us to answer the question of why nomadic pastoralism has been able to continue over centuries under arid conditions.

When a water balance approach is applied for estimating minor hydrologic components such as groundwater recharge rates, the resulting estimates tend to involve a large error (e.g., Healy, 2010). Therefore, our estimations were not only based on the water balance method but also on supplementary observations. Analyses were also applied whenever possible in order to enhance the reliability of water balance estimates. Two small watersheds located in the central portion of Mongolia were selected for our analyses. Therefore, the work presented here is essentially a case study. However, Mongolian steppe is a part of the largest rangeland belt on Earth, extending from northeastern to Central Asia (Shiirevdamba, 1998), thus, our results should be applicable to larger areas containing similar vegetation and topography.

2. Method

2.1. Study area

For the study, two small watersheds, W1 and W2, were selected within a gentle hilly terrain in Saintsagaan soum (county) in Dundgobi aimag (prefecture), located approximately 4 km northeast of the city of Mandalgobi in Mongolia (Fig. 1). The watershed area of W1 is $A = 3.3967\ \text{km}^2$ and that of W2 is $A = 11.3567\ \text{km}^2$ (see the Appendix A for watershed boundary determinations). The soil in this area is classified as semidesert brown soil or semidesert brown friable sandy soil (Dorzhgotov, 2003). The morphology of the A horizon can be characterized by high compactness, a brown color, and weak development of the soil structure. A high sand and gravel content can also be observed within the surface soil (Asano 2010, personal communication). The bedrock is composed mainly of Permian felsic rocks such as dacite, rhyolite, or quartz porphyry (Mineral Resources Authority of Mongolia, 2001; Mineral Resources Authority of Mongolia and Mongolian Academy of Sciences, 1998). The climate is classified as arid and has a mean annual precipitation of 150 mm (for 1944–2011, see also Fig. A1), as measured by the nearby meteorological station (located approximately 5.5 km southeast from the study area) at the Research and Information Institute of Meteorology, Hydrology and Environment (hereafter referred to as the IMH station). According to the Standardized Precipitation Index (SPI) for three, six and 12 months, the observation period from 2008 to 2011 can be classified as "near normal" to "moderately dry" (WMO, 2012). Approximately 78% of annual precipitation falls during the summer from June to August. The mean annual air temperature is 1.5 °C, while the annual range of monthly means is as large as 37 °C, with a low of −17.7 °C in January and a high of 19.3 °C in July.

According to the Mongolian vegetation classification scheme, the area is located within a boundary zone between the desert steppe class and the steppe/dry steppe class. Dominant vegetation consists of the C_3 herbaceous plant *Allium polyrrhizum* and some dotted communities of the C_3 shrub *Caragana microphylla*. However, during the study period, even during the typical growing season from May through August, only intermittent appearances of

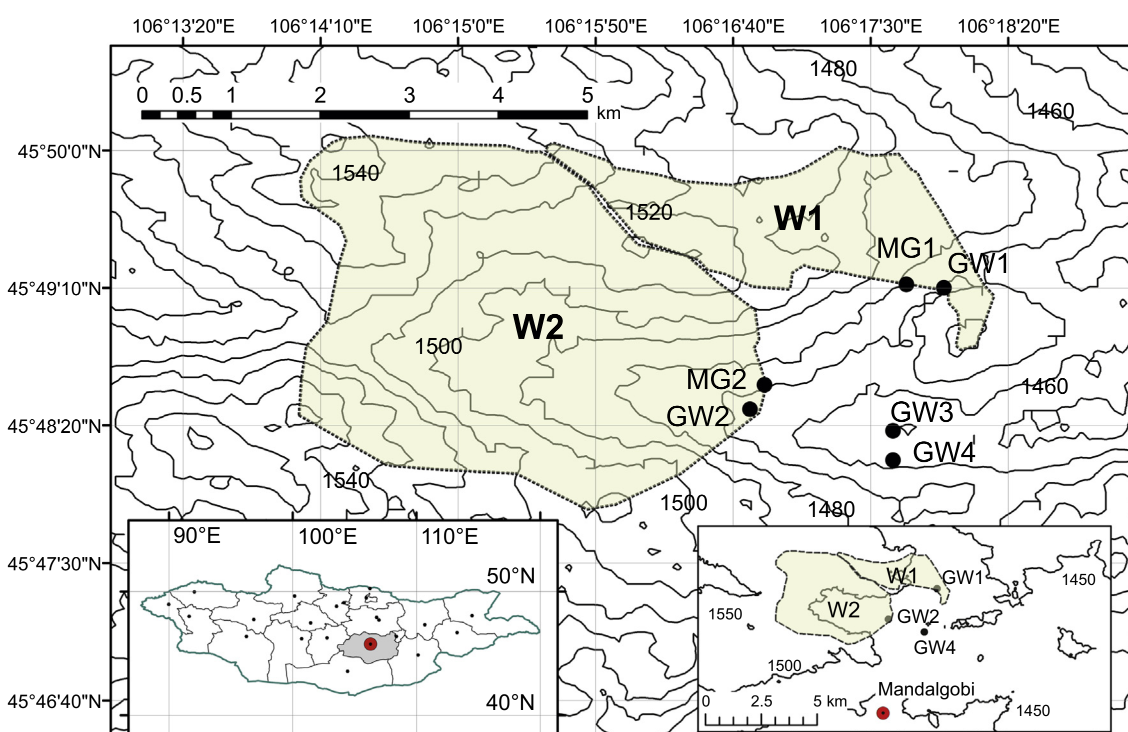

Fig. 1. The topography of the study area. Closed circles indicate the locations of automatic weather stations (AWS) MG1 and MG2 and wells GW1–GW4. Watersheds boundaries are shown with dotted lines, while contours are given by continuous lines at 10 m intervals. The smaller watershed located to the east is W1 and the larger watershed to the west is W2. Also shown as an inset is a map of Mongolia with aimag (prefecture) boundaries and capital cities, and those of the surrounding area of the two watersheds. The study area is located near Mandalgobi in Dundgobi Aimag (shown in the map as a red circle with a center dot and as the shaded area).