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Research paper

Water use in agro-pastoral livelihood systems within the Bulgan River watershed of the Altay Mountains, Western Mongolia

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ABSTRACT

Watersheds in the arid and semi-arid regions of Mongolia are especially vulnerable to the effects of climate and land cover change, which will likely exacerbate the disparity between water availability and demand. This study was conducted to analyse land cover changes between 1972 and 2013 and to characterize the currently prevailing livelihood strategies and farming practices in the river oasis Bulgan *sum*, Western Mongolia. The Soil and Water Assessment Tool (SWAT) was used to simulate the water-use efficiency for the concerned Bulgan River watershed.

Comparison of the two land cover maps (1972 and 2013) of the Bulgan *sum* river oasis showed a major change from natural rangeland to mostly built-up areas (+288%) and river water receiving sites (+594%). The Bulgan River watershed covers an area of 7409 km^2 and the river itself has a long-term annual average discharge of 9.53 $m^3 s^{-1}$. Overall, an area of 769 ha was actively irrigated (2013). A total withdrawal of 555460 m^3 irrigation water was estimated, 86% of which was applied to hay fields (2013). The irrigation water productivity ranged from 5.38 (fruits of fruit trees) to 0.43 (hay) $m^3 kg^{-1}$ fresh matter yield and a related average income of 0.58 € per kg dry matter per m^3. The SWAT model simulated an average evapotranspiration of 100 mm and potential evapotranspiration of 993 mm per year. Water-use efficiency varied from 11 to 52 kg dry matter $ha^{-1} mm^{-1}$ for rangeland and wetland. Auto-irrigation (whenever plant growth drops below this threshold, the model will automatically apply water until field capacity is reached) and fertilization management simulated by the SWAT model increased yields of irrigated crops, vegetable, hay and fruit trees by about 46 and 77% on average. To enhance biomass productivity per unit water transpired and income per unit water applied, improved irrigation technologies and management practices would be needed.

1. Introduction

Owing to their scarce and susceptible agro-ecological resources (Liu and Chen, 2006), watersheds in the arid and semi-arid regions of Mongolia are especially vulnerable to the effects of climate and land cover change which will likely exacerbate the disparity between water availability and demand in the near future (Lioubimtseva and Henebry, 2009; Malsy et al., 2012, 2015; Pederson et al., 2013). As an example to study these effects we choose the Bulgan River watershed in Western Mongolia where water scarcity is an increasing threat. In other parts of Mongolia, a rise in water demand as a result of mining activities, intensification of agriculture production, increasing sedentarism and urbanization following socio-economic change and rapid economic expansion has already been documented (Grit et al., 2015; Priess et al., 2015; Hartwig et al., 2016; Hofmann et al., 2016). In recent years water scarcity problems are aggravated by raising ambient temperatures resulting in rising (potential) evapotranspiration (ET) and an overall increase in precipitation variability, which together lead to decreasing water availability (Batima et al., 2005; IPCC, 2007; Menzel et al., 2011; Malsy et al., 2012; Grit et al., 2015; Hofmann et al., 2015, 2016; Priess et al., 2015; Hartwig et al., 2016). Traditionally, land use in Western Mongolia was dominated by a well-adapted animal husbandry system characterized by a high degree of mobility and flexibility, while field based agriculture played only a relatively minor role (Lkhagvadorj et al., 2013b,a; Jordan et al., 2016). However, recent national policies target the intensification of agricultural land use with the aim of

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achieving food self-sufficiency and enhancing hay and fodder production to lower livestock mortality, particularly during harsh winters (Regdel et al., 2012; Pederson et al., 2013). Overall, irrigated crop and fodder production is already a major consumer of surface water, much more than the watering of animals, this is certainly also true for the Altay Mountains (Rockstrom et al., 2007; Pederson et al., 2013). Against this background, water distribution among water consumers in the watershed and across country borders will be of increasing importance and a more efficient use of the available water is a necessary to reduce potential conflicts between users.

Besides the short growing season, the harsh continental climate and limited access to agro-chemicals, fertilizers, quality seeds, irrigation equipment and agricultural machinery, the cropping sector in the study region is particularly restricted by temporarily limited water availability and high potential ET (PET, Priess et al., 2011; Hofmann et al., 2016). ET is a key component of the hydrological cycle and of the effective use of agricultural water, it is therefore closely linked to (agro) ecosystem productivity (Liu et al., 2013, 2015). Typically, in semi-arid regions, more than 70% of rainfall evaporates from land surfaces into the atmosphere, while the remaining proportion recharges groundwater and rivers (Wimmer et al., 2009; Menzel et al., 2011; Priess et al., 2011; Hülsmann et al., 2015). Moreover, rainfall in semi-arid areas is restricted to few events or periods during the year (Nadal-Romero et al., 2015; Anache et al., 2017). To efficiently manage scarce water resources in such environments, adequate estimates of ET are of major importance (Rockstrom et al., 2007; Lal and Stewart, 2012). The 'Soil and Water Assessment Tool' (SWAT) model is a physically-based semi-distributed model which has been widely used in numerous watersheds worldwide to describe the use of water resources (Arnold and Fohrer, 2005; Schuol et al., 2008; Hülsmann et al., 2015). Its particular strength is the integration of plant growth and agricultural management and its reasonable prediction of ET values under a wide range of agro-climatic conditions (Earls and Dixon, 2008; Liu et al., 2015). The above mentioned circumstances in the Bulgan River catchment call for a detailed understanding of local hydrological processes and water use, which is of particular interest as the Bulgan River is a cross-border water resource shared between Mongolia and China (Xia et al., 2016).

In view of the above, the overall aim of this study was to evaluate the current farming practices with a special focus on irrigation management. This study also wanted to support decision makers in developing more resilient and productive farming systems under changing socio-economic and climatic conditions in this arid/semi-arid watershed and similar watersheds in Central Asia. Therefore, the objectives of this study were (i) to describe land cover changes between 1972 and 2013, (ii) to characterize the prevailing livelihood strategies and farming practices (such as management, irrigation systems and water use) in the river oasis Bulgan *sum ('sum'* is a second level administrative subdivision of Mongolia), Western Mongolia and (iii) to simulate water-use efficiency (WUE: aboveground biomass divided by ET) for different land cover classes with the SWAT model in the Bulgan River watershed (Table 1).

2. Materials and methods

2.1. Study region

The research was conducted in the Bulgan River watershed with its outlet at the Bulgan *sum* center, the administrative capital of Bulgan district in Khovd province, located at the foothills of the Western Mongolian Altay Mountains and at the border of the Dzungarian Desert (45 − 47°N, 89 − 91°E, Fig. 1). The Bulgan district covers a total land area of 8 105 km^2 and in 2012 hosted a human population of 9018 plus 154,058 domestic animals (2012, National Statistical Office of Khovd). For Bulgan *sum* (WMO code 44265, 1963–2014, 1186 m a.s.l.) and Duchinjill (WMO code 44263, 1977–2011, 1951 m a.s.l.), minimum average monthly air temperatures of −21 and −35 °C, respectively, are reported for January, while maximum temperatures of 21 and 24 °C are reached in July, accompanied by an average annual precipitation of 75 and 128 mm (coefficient of variation of 45% and 26%), respectively.

The Bulgan River originates on the southern slopes of the Mongolian Altay, flows southwards entering the river oasis of Bulgan *sum* center after which it crosses the Chinese border. It finally discharges into the Ulungur Lake in China (Zukosky, 2008). Since rangeland covers a large part of the watershed, Kastonozems and Umbrisols predominate, while the soils in the floodplain are classified as Fluvisols and Cryosols (IUSS Working Group WRB, 2014; Karthe et al., 2016). Given the harsh continental climate, livelihoods depend largely on water drawn from the Bulgan River and groundwater wells allowing small-scale cultivation of crops, hay and fruits (mainly apple (*Malus domestica*) and plum (*Prunus domestica*)). The animal husbandry systems in the region can be described as classical mountain transhumance systems with seasonally migrating herds (mainly consisting of goats, sheep, cattle, in addition to horses and camels), but there are also settled herders who own cattle, sheep and goats (namely fat-tail sheep, cashmere goats and Turano-Mongolian cattle; Jordan et al., 2016; Tsevegmed, 2016).

2.2. Land cover change

Different land cover sites were recorded using a GPS device (Trimble Juno SB Handheld, Trimble Navigation Ltd., Sunnyvale, CA, USA) during field surveys from May to September 2013 (in total 329 representative validation sites were captured covering all typical land cover types of the watershed). The areas of irrigated plots were mapped in their entirety, owing to their small physical size but potentially large socio-economic importance. Subsequently, changes in land cover between 1972 and 2013 were analysed on the basis of two land cover maps derived from high-resolution satellite images taken by Corona (30-04-1972) and Pléiades (pansharpended Pléiades satellite images, 50 cm resolution, date: 12-08-2013, Astrium, Toulouse Cedex, France). The panchromatic Corona (KH-4B) satellite image was obtained from the U.S. Geological Survey's Earth Resources Observation and Science and had a maximum resolution of 1.8 m at nadir (Dashora et al., 2007). The image was georeferenced using readily recognizable features as ground control points, which were verified based on georeferenced satellite images. Land cover maps were generated on the basis of an independent supervised classification using the 'Sequential maximum a posteriori classifier' in Quantum GIS (QGIS version 2.12.0, Quantum GIS Development Team, 2010; Geographic Information System, Open Source Geospatial Foundation Project) with the GRASS plugin (Version 6.4.4; GRASS Development Team, 2010). Similar reflectance resulted in misclassification of mountainous areas and urban areas which had to be reclassified by visual identification and mapped manually (Lillesand et al., 2014). The small size of irrigated fields hampered their automatic detection. Additionally, irrigated fields, areas where hay was grown, rangelands receiving water from the river and natural meadows showed similar spectral characteristics and were therefore combined as 'river water receiving sites'. In addition, the following classes were identified: 'urban area' (single houses, settlements, and industrial facilities), 'water' (bodies of open water such as rivers, streams and irrigation canals), 'rangeland' (grassland, bushes, areas with low vegetation cover, mainly dominated by *Krascheninnikovia ceratoides*, *Ephedra przewalskii*, *Stipa caucasica* and *Plantago major* communities), 'shrubland and woodland' (mainly *Salix turanica, Caragana leucophloea, Populus laurifolia* and *Hippophae rhamnoides* stands), 'sandy soil' (non-vegetated areas such as bare soil, sand dunes and river banks) and 'mountains' (rock outcrops within and outside the oasis). Based on this preliminary work, a detailed land cover and land use map was processed for 2013, including supplementary classes of 'irrigated crop land' (cereal, potato (*Solanum tuberosum*), melon (*Citrullus lanatus* and *Cucumis melon*) and various vegetables), 'hay' (irrigated fenced rangeland), 'fruit trees' (apple and plum) and 'sea buckthorn' (*H. rhamnoides*)). The land cover maps produced were validated by ground truth observations with 100