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# Current and potential conflicts for ecosystem services caused by agricultural land use in Central Asia, and essential implications for research on sustainable land management in the region

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## ABSTRACT

The increasing demand for food, bioenergy and other agricultural products, as well as the intensification of climate change, pose special challenges for Central Asia's agricultural sector in terms of implementing sustainable land management. Central Asia is a climate change hot spot. Adaptation measures of agricultural land use to climate change imply new trade-offs in terms of quality and provision of ecosystem services. Based on literature studies, this paper identifies examples of such trade-offs and presents possible solutions. The ecoregions of Central Asia show strong interdependencies. Therefore, a special focus has to be put on the transregional effects of the use of ecosystem services. Against the background of different concepts of sustainable development (ESS, SDG, Global Environmental Syndromes) integrative approaches for sustainable use and design of landscapes are necessary.

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## 1. Introduction

Use of land resources can negatively impact ecosystem processes and functions. Land use change can also threaten other usages of natural resources (Kim & Arnhold, 2018). In a broader sense, land use relies on different ecosystem services, i.e. benefits that people derive from ecosystem processes and functions (Costanza et al., 1997). But these services may be of interest for other users, nature, or the common. For example, agricultural land use usually leads to a reduction of the regulatory services of soils, e.g. carbon sequestration (Foley et al., 2005), which in turn is of paramount importance for climate mitigation. On the other hand, as for instance in Central Asia, agricultural production is the backbone of many national economies as it generates income for the major part of the population (Hamidov, Helmig & Balla 2016). Consequently, the existing land use system can hardly be replaced. Moreover, unsustainable management practices have increased the pressure on ecosystem services in a way that solutions e.g. for achieving the target of water, energy, and food security at the same time, or biodiversity conservation, which also have specific demand for ecosystem services, requires enormous changes of these practices in the first place.

As described for many regions in the world, external drivers, such as enormous economic transformation, an increasing number of climatic extreme events, and ongoing climate change (Lioubimtseva, 2015) increasingly affect the demand for and supply of systems ecosystem services for agricultural land use and production also in Central Asia (Lioubimtseva, 2015). In addition, agricultural land use of the region increasingly exhibits its internal but also international telecoupled character (Wang et. al., 2021). Telecoupling is understood as interactions between social-ecological systems over long distances (Liu et. al., 2019), e.g. cotton production in Uzbekistan is coupled with other parts of the world also beyond Central Asia through the value chain and market demands. The provision of ecosystem services leads to their transboundary flow. Such flows need to be identified and assessed to ensure regional and global sustainability of agricultural land use (Liu et. al., 2013, Wang et.al., 2021, Xie & Ibrahim, 2021).

Altogether, for the land use systems in Central Asia, sustainable solutions are urgently required for managing the landscapes, in particular those parts intensively used for agriculture on the mid and long run. On the way to identify applicable solutions for sustainable agricultural land management in the region, recent studies substantiated the demand to understand the existing interrelations between influencing factors (Qi et. al., 2012, Reyer et.al., 2017, Hamidov et. al., 2022). For example, the problem of clearly differentiating land use and climate effects for the impairment of ecosystem functions has not been solved. The same applies to the spatial effects of the use of ecosystem functions. Here, the range of land use effects beyond their immediate location for neighboring and distant systems is known only exemplary (Hamidov et. al., 2022).

In this white paper / contribution we aim to identify, review, and analyze research on conflict burden key topics in the agricultural land use systems of Central Asia. We start from the idea that there are real conflicts over land use directly, but also those where agricultural practices potentially draw off other important uses or functions of ecosystems that are important to humans on a larger scale or simply to nature itself. The real conflicts involve, for example, the introduction of alternative crops to secure food supplies at the expense of cotton production in the Aral Sea basin (Abdullaev et al., 2009). An example of the second group of conflicts is caused by the reduction of carbon sequestration and thus deteriorated climate regulation due to intensive use of machinery for the arable use of steppe soils (Bischoff et. al., 2016, Guggenberger et. al., 2020) or by the destruction of ecosystems at the expense of biodiversity (Schlueter et al., 2013, Silanteva et. al., 2020a). Solutions to such conflicts are rarely just a choice of one option or the other, rather than using the existing land use option more sustainably, i.e. with less consumption of ecosystem services (Liao & Brown, 2018). Thus, we further analyze existing challenges to sustainability in agricultural land use, identify obstacles and potential additional demand for ecosystem services and outline ongoing alterations of ecosystem service supply that is beside overutilization mainly due to climate change .

With regard to the spatial definition, we follow the concept of terrestrial ecozones developed by Schultz (2005). To analyze the trade-offs in the context of climate adaptation and sustainable land use and ecosystem services, we choose the scale level of subregions or subzones within the arid mid-latitudes. Accordingly, the contribution is structured as follows: After outlining the environmental and socioeconomic settings (Chapter 2) the historical development of the agricultural land use in the different ecozones of Central Asia is presented (Chapter 3). The analytical part focuses on the elaboration of characteristics of conflict potential caused by agricultural land use in the region utilizing the concept of ecosystem service (Chapter 4). The presentation of major challenges and future conflict areas (Chapter 5) is followed by the conclusions section (Chapter 6).

## 2. Terrestrial ecozones in Central Asia

Central Asia is characterized by an extremely continental and dry climate, mainly influenced by the West Wind Zone and the Siberian Anticyclone, with minor effects of the Monsoon in the south (Gerlitz et al., 2016). In the geoecological classification of the world by Schultz (2005), the countries of Central Asia are located in the dry mid-latitude zone, where plant growth is limited for at least 5 months of the year due to aridity (Schultz, 2005). Environmental gradients such as the NS increase of air temperature and decline of precipitation and the orographic WE contrast divide the region in three terrestrial ecozones (sub-zones), i.e. steppe ecosystems in the north, semi-deserts and deserts in the south and southwest, and mountains in the southeast (see Fig.1). Soil types and vegetation composition follows these trends (Schultz, 2005). In accordance with these gradients of natural conditions, the supply of ecosystem services varies (Chen et al., 2013a; Li & He, 2022; Thevs et al., 2017), which in turn is the reason for remarkably differing (agricultural) land use systems in these ecozones. This section provides an overview on the physical geography of the three sub-zones.


**Figure 1.** Map of ecoregions in Central Asia (Central Asian Atlas of Natural Resources, ADB, 2010).

## *2.1. Eurasian Steppe Belt – forest steppes, typical and dry steppes*

The steppe zone extends mainly over large parts of northern Kazakhstan. In addition, steppes are common to a lesser extent in southern Kazakhstan, and in southeastern Uzbekistan. Steppes are also found in the intramountain basins of Kyrgyzstan and southwestern Turkmenistan. The climate is defined as highly continental and is characterized by a high temperature amplitude. The average annual precipitation ranges from 250mm (short grass steppe) to 700 mm (forest steppe). Climatically, the steppes have a high biomass production, with 2 t/ha/a to 15 t/ha/a (Schultz, 2005). However, from the forest steppe to the dry steppe, this decreases due to precipitation and water availability. Temperate grasslands play a significant role as global carbon reservoirs. Due to the high biomass production and the highly continental climatic conditions, the average carbon storage in the Eurasian steppes is 12.86 $g/m^2/a$ (Chen et. al., 2017). Thus, steppe soils are characterized by a high organic carbon content and a high nutrient and water storage capacity. The typical soils of the forest steppe are Phaeozems. In the long and short grass steppes dominate Chernozems and Kastanozems. Thus, they are good plant sites and are well suited for arable and pastoral use. Because of their high production potential and rich grain yields, the steppe areas, which belong to the temperate grasslands, are also called the breadbaskets of the world (Swinnen et. al., 2017).

### *2.2. Deserts and semi deserts of the dry midlatitudes*

The major part of Central Asia is characterized by desert and semi desert landscapes. These arid landscapes occur south of the Eurasian Steppe Belt and cover the southern Ust-Urt Plateau, Kazakh Upland and the Turanian Lowland. The Kopet-Dag Range, and the Tien Shan, Pamir, and Alay mountains demarcate this zone in the South and East with their steppes, forest steppes and mountain ecoregions. The two Turanian lowland deserts encompass a number of hills up to 1.000 meter a.s.l. and several depressions below sea level. The Karakum (red sand) covers extensive parts of the territory of Turkmenistan whilst the Kyzylkum is predominantly shared by Uzbekistan and Kazakhstan (Létolle and Mainguet, 1993). High seasonal temperature amplitudes characterize the continental climate in the region. Following a latitudinal gradient, cold winters and hot summers occurring in the north and central parts of this zone transition into very hot summers and cool winters in its south. Aridity is extreme with an average annual precipitation below 200 mm (Gessner et al., 2013).

The mid and lower courses of the Syr Darya and Amu Darya traverse the region. Both streams are endorheic, as all rivers in this zone, and drain into the Aral Sea. Vegetation in the midlatitude semi deserts and deserts is sparse and consists of xerophytic (drought-resistant) scrubs and short grasses. The floodplains along the rivers and delta regions are naturally covered by Tugai vegetation, i.e. the riparian vegetation along the Central Asian rivers (Thevs et al., 2012). Above ground NPP is extremely low and amount to 3 t C ha-1 y-1 for deserts, semi-deserts and desert steppes (Schultz, 2005). Remote sensing-based measures recently returned < 0.8 t C ha-1 y-1 in the Turan lowland deserts (Li & He, 2022). With the exception of the floodplains, where Fluvisols dominate, the soils can be classified as Calcisols, i.e. with very low humus content, but very high calcium carbonate, gypsum, sodium salts, and pH values (>7) (Schultz, 2005). In locations with stagnant water or high groundwater tables, halomorphic soils such as Solonchaks and Solonetz occur also widely throughout the deserts.

### *2.3. Mountain and Alpine Areas - Pamir, Tian Shan Mountains and foothills*

The mountain regions of Tien Shan, Pamir and Altai cover more than 10% of the total area of Central Asia and are among the highest mountains in the world. Due to their geographical location and the extreme differences in altitude, they are characterized by a great variety of landscapes and high biodiversity.

Climatic conditions in Central Asian mountain ecosystems are characterized by high continentality and strong spatial differentiation due to altitude and exposure effects. It is essentially determined by the Siberian anticyclone. The transport of water vapor is driven by the westerly wind circulation. This results in low mean precipitation and large intra annual temperature amplitudes (Xu et al., 2018). Large parts of the Central Asian mountains are covered by glaciers and thus form the headwaters of major rivers, e.g. Amu Darya and Syr Darya. Meltwater forms about 80% of the total runoff of the Central Asian river systems. Thus, the mountains are also of great ecological importance for the rivers of the steppes and desert region they flow through (CEPF, 2017).

In addition, the mountain regions are home to the most important forest ecosystems in Central Asia. The mountain forests play an important role as water and carbon reservoirs, as oxygen producers and for relief stability. They are the habitat of a highly specialized and diverse fauna. Mountain forests in Central Asia play a key role in regional hydrology by helping maintain a steady river discharge from the high mountains to the irrigated lowlands (Yin, 2017). Besides timber and wood for energy purposes, the mountain forests provide fruits, berries and medicinal plants for human use (Tian et al., 2022).

## 3. Conflict-bearing large-scale developments of agricultural land use in Central Asia

The previous section showed that due to the individual natural conditions, the three ecoregions in Central Asia provide very different ecosystem services. They provide diverse land use potential, even though they are impacted by severe aridity especially in the steppe, semi-desert and desert ecosystems. By human utilization of these potentials distinct patterns of rural population distribution and agrarian land use arose (Gupta et al., 2009). These nowadays called social-ecological systems (Ostrom, 2009) have exhibited some constancy with numerous highs and lows over the past three thousand years, e.g. with severe collapses through overutilization or mismanagement of the scarce land and water resources and climate change (e.g., Brite, 2016). In addition, through economic systems, trade, value chains, uneven distribution of natural resources these systems have always been interconnected and interdependent in different ways across regions.

This section initially outlines population distribution and typical agricultural land use referring to the three ecoregions in Central Asia. Further it points at nineteenth/twentieth-century political decisions and agricultural land use developments related to the Czarist Russian expansion (1730-1895) and especially the Soviet era (1924-1991), which tremendously increased the pressure on land and water resources and largely neglected sustainability aspects (Létolle & Mainguet, 1993; White, 2013): The Virgin Land Program for wheat production in the Eurasian steppe belt in the 1950s, the intensification of irrigated agriculture in the Aral Sea Basin during the 1930s and especially in the 1960-70s (Abdullaev & Rakhmatullaev, 2013). Consequently, the Kazakh steppe and major river systems in the semi-deserts and deserts, in particular the Aral Sea Basin, became seriously affected by syndromes of global change (Lüdeke, Petschel-Held & Schellnhuber, 2004). Beside agricultural land use, and the overexploitation of raw materials such as uranium in the Tien-Shan and Pamir Mountains and the use of Kazakhstan's drylands for nuclear weapons testing are worth mentioning here (Giese, Bahro & Betke, 1998) albeit they are not the focus of this contribution. Those management, or avoidance of renewed collapses, are major challenges for the entire region as they bear high conflict potential for the future of Central Asia.

The third part of this section focuses on the current situation. Since the collapse of the Soviet Union, the states of Central Asia have again undergone serious land use and land cover change (Chen et al., 2013b; Hu & Hu, 2019; Klein, Gessner, & Kuenzer, 2012). For example, societal transformations in the former Central Asian Soviet Republics led to, among other things, disintegration, de-industrialisation and changes in ownership. These transformations were mainly reflected in farm closures, abandonment of agricultural land and increased migration (Saiko, 1995, Kraemer et. al., 2015, Hu & Hu, 2019). The globally increasing demand for raw materials, energy and food has for some time been a major driving force for the intensification of raw material extraction and agricultural production in the countries of Central Asia. This exacerbates the conflicting goals of land use interests, especially with a view on the water-energy-food nexus challenge in the region, protection of natural resources and biodiversity as well as requirements for adaptation to climate change.

### *3.1. Agricultural land use (potential) in the different ecoregions*

The long and short grass steppes are relatively sparsely populated areas in which intensive agriculture farming is practiced. High soil fertility and water storage capacity, high irradiation and relatively flat relief are favorable factors for agriculture (Schultz, 2005). The forms of agricultural use are essentially determined by the precipitation gradient from the forest steppe to the dry steppe. Thus, arable farming dominates in the rainier forest steppe and long grass steppe regions. With decreasing precipitation, the share of grazing increases and becomes dominant in the dry steppe regions. The productive forest and long grass steppe regions are dominated by farms that emerged from the collective farms of the socialist era. These are characterized by structures with several thousand to several tens of thousands of hectares of farm size and intensive farming methods. Grain farming is dominant. In addition, animal husbandry in the form of grazing and dairy farming takes place there. The steppe regions are characterized by individual grazing for subsistence purposes.

With the exception of the oases along the rivers mining areas, parts with comparably high grazing potential, and other special sites like Baikonur, the deserts and semi-deserts in Central Asia are almost unpopulated. Throughout history the oases have been hotspots for settlement and population growth, e.g. the Fergana Valley became the most densely populated rural part of Central Asia (Reddy et al., 2016). In Uzbekistan that entirely belongs to the Aral Sea Basin, the overwhelming majority of the rural settlements are located within these large-scale irrigation systems in these oases (Conrad et al., 2015). The agricultural landscapes of the desert zone, including both irrigation cultivation and pastoralism, have frequently altered during their history (Brite, 2016). Due to the availability of surface water, the upstream valleys and oases flanking the Amu Darya and Syr Darya in the Kyzyl Kum and Kara Kum Deserts have always been used for irrigated agriculture. High crop diversity is reported for the 19th century, with cereal crops (including rice), sorghum, lucerne, cotton, vines, fruits, and oil-seeds (Dingelstedt, 1888).

The mountain ecosystems of Central Asia are sparsely populated with a decreasing trend in remote areas of Tajikistan and Kyrgyzstan. They have quasi inexhaustible water sources, humus-rich soils and comprise extensive natural agricultural areas such as pastures and natural hayfields. Agricultural land use is characterized by the cultivation of fodder crops for livestock production (Gupta et al. 2009). Pasture farming is the only form of land use that extends over several altitudinal levels. At lower altitudes, e.g. river valleys, lower slopes and areas with longer vegetation period, a mixture of diverse forms of land use is characteristic (orchards, nut forests, forests, arable farming, pasture farming), with different degrees of irrigation. In the mountainous regions, pastoralism is a dominant form of land use. Neudert (2021) distinguishes between nomadic, transhumant and stationary forms of pastoralism. Due to its different forms of operation, pastoralism is present at almost all altitudes of the mountain regions.

### *3.2. The Soviet period: Large-scale expansion, intensification and two syndromes of global change*

The Soviet Union reorganized the entire economic system and hence agricultural land use in all ecoregions of Central Asia through collectivization and change of farming system to the rules of planning and state-order. In the steppe and forest steppe ecosystems, large-scale agricultural development took place mainly in the context of land reclamation during the 1950s and 60s in the former Soviet Union (Frühauf et. al., 2020). With the virgin land campaign, 42 million hectares of steppe and fallow land were converted into arable land. This can be considered the largest global ecosystem conversion of the 20th century. This valorization for food production was accompanied by an ecosystem degradation comparable to the Dust Bowl of the 1920s and 1930s in the Great Plains (Frühauf et al., 2020). In addition to the negative effects on biodiversity, the destruction of the carbon sink function is one of the most significant negative effects of intensive crop production. This was accompanied by a decrease in soil stability and fertility, resulting in yield depression and the occurrence of extreme erosion events (Frühauf & Meinel, 2007; Kurganova & Gerenyuk, 2012). The consequences for the environment, biodiversity and humans in Central Asia are well known and documented.

The former Soviet Union also initiated an enormous expansion and intensification of irrigated agriculture already in the 1930s (Abdullaev and Rakhmatullaev, 2013). Yet, it gained another momentum through land reclamation programs of the 1960ies and 1970ies (Gupta et al., 2009). Hence, in less than seven decades, irrigated cropland areas in the Aral Sea Basin expanded from 0.725 Million ha (Mha) in 1915 to 7.6 Mha in 1990 (Létolle and Mainguet, 1993). The centrally planned development included the installation of new farms and associated construction of (rural) settlements, roads and railways, the provision of energy, water, education, medical care, administration, etc., in the domesticated agricultural landscapes, as well as a considerable resettlement of people (Komilov, 2016; Rahmonova-Schwarz, 2010). To achieve timely and adequate irrigation, the river system was regularized, and one of the world-wide biggest irrigation and drainage (I&D) infrastructure was established. Since the water for irrigation is generated mainly from the mountain regions, a ring of water reservoirs now lines the edges of the mountains (Rakhmatullaev et al., 2010). However, this immense intervention in nature destroyed valuable ecosystems typical for the region such as Tugai forests, wetlands, and lakes particularly in the downstream parts of the river systems.. In addition, still before the collapse of the Soviet Union, in particular limited investments in maintenance of the I&D systems and mismanagement led to severe land degradation. followed by numerous consequences for man, animal, wildlife, and environment (Schlüter et al., 2013; Zonn, 2010; White, 2013). The developments and impacts on the agricultural sector, the causes and consequences of this so-called Aral Sea Syndrome or ARal Sea Crisis (Micklin, Aladin, & Plotnikov, 2014; Varis, 2014) from an ecological, economic, and social point of view have been chronicled by numerous authors (Giese, Bahro, and Betke, 1998; Létolle and Mainguet, 1993; Micklin, 2007).

### *3.3 Situation today*

As a result of the dissolution of the Soviet Union and the establishment of the Central Asian republics, there was an increased abandonment of cultivated arable land in the 1990s (Schierhorn et. al., 2013, Kraemer et. al., 2015). This development was accompanied by the migration of large parts of the population from rural areas. In the steppe the area under cultivation has been increasing again since the beginning of the 2000s (Chen et al., 2013, Hu & Hu, 2019). Similar observations have been observed for the irrigation systems in the Aral Sea Basin, where re-use of agricultural land has been observed (Degtyareva et al., 2019) as well as intensification of crop production especially in the last decade (Rufin et al., 2022).

The organizational forms of agriculture in all regions have changed considerably after the collapse of the Soviet Union (Neudert, 2021). During the socialist period, collective forms of economy were dominant. Since the formation of the Central Asian national states in the 1990s, the organizational forms of farming have diversified due to legal regulations and economic development.

Economic development in the region is rather slow. Irrigation agriculture remains of paramount importance for income generation in Central Asia, in particular the inner Aral Sea Basin (FAO, 2012).

The mountain regions with their glaciers and relief conditions together with the ring of dams originally constructed for the regulation of irrigation water offer ideal conditions for generating energy from hydropower. The large hydropower plants in Kyrgyzstan and Tajikistan were built in the course of industrialisation in the former Soviet Union and supply not only the Central Asian countries with energy (Giese, 2004).

From a global perspective, the social-ecological systems of these ecoregions are subject to different challenges of Global Change. The most prominent of these are the increasing demand for natural resources (water, food, energy) and the need for climate protection measures and adaptation to climate change. Inevitably, conflicts of interests and conflicting goals arise in overcoming these challenges, which require interdisciplinary and supraregional approaches to solving them.

## 4. Competitions for ecosystem services utilized for agricultural land use (potential for conflicts and solutions)

Ecosystem services are defined as benefits that people derive from ecosystem functions (Costanza et.al., 1997, Costanza et.al., 2017). Usually they are divided into 4 categories: provision, regulation, cultural and supporting services (Quillérou et al., 2016). Individual services are to be assigned to these categories. In current research, different classifications are presented for these categories. The attributions of individual ecosystem services are not universal and are subject to regional, thematic and ecosystem-specific modifications (Costanza et.al., 1997, Costanza et.al., 2017, Quillérou, E. et al., 2016, Hamidov, A. et al., 2016).

We use the concept of ecosystem services for this exercise, because the case of conflict is exactly about the fact that different users have an interest in the same ecosystem functions (Lee & Lautenbach, 2016, Lautenbach et. al., 2019). The concept of ecosystem services reveals at the same time the trade-offs arising from the provision of these services. These trade-offs are expressed spatially and transboundary. Thus, this section first provides an overview of the ecosystem services provided to and demanded by agricultural activities. Focus is set on the two ecozones that are intensively used for agricultural production (i) the Eaurasian steppe belt with its enormous grain production and (ii) the irrigated oases along the rivers in the deserts and semi-deserts of the dry mid-latitudes, which include the Aral Sea basin. Second, based on current land management practices that limit ecological sustainability, i.e., heavily use and deplete ecosystem services (Foley et al., 2005), the requirements and barriers to increasing the sustainability of agricultural production in the two ecozones are described in general terms. Overcoming these challenges means a potential supply of ecosystem services for improved implementation of other land uses (including environmental protection) or other activities. The result is shown in Table I and II.

**Table I**. Overview on ecosystem services utilized and affected in the forest steppe and steppe ecoregion that is characterized by intensive agricultural production (columns 1-3). The fourth to seventh column indicate the challenges, potentials, and obstacles to increase the sustainability of agricultural land use in these ecosystems, and the actual or potential demands by other users for the same ecosystem services, including requirements by ecosystems. The users are given in bold.

| **Highly demanded provision services** | **Heavily utilized supporting services and consequences** | **Negatively affected regulating services and effects** | **Practices challenging sustainability of agricultural production** | **Potential to increase sustainability in the agricultural sector** | **Obstacles** | **Land use alternatives and potential competitions** (some changes have been emerging in the past decade) | **Further reading** |
|---|---|---|---|---|---|---|---|
| **Food: Grain, Sunflower seeds,**<br><br>Fiber: Lin, Hemp,<br><br>Fodder: silage corn;<br><br>Fuel: linseed, sunflower<br><br>Fresh Water | **Nutrient cycling:**<br><br>soil fertility (-)<br><br>Primary production (+)<br><br>**Habitat provision:** natural, diverse steppe ecosystems (-) | **Climate regulation:** carbon sequestration/ storage (-)<br><br>**Erosion regulation:** wind and water erosion (+) | Increasing mineralization of soil organic matter due to land management practice (intensive tillage, Biomass removal by yields)<br><br>Reduction of natural vegetation cover and increase soil treatment (machinery) increases soil erosion by water and wind<br><br>Verringerung der Biodiversität durch intensive Pflanzenproduktion mit dominanten Anbaukulturen | Conservation agriculture<br>-minimizing soil erosion by wider application of minimum and no till<br>-improving carbon sequestration function of soils (keep crop residues at fields, mulch seeding)<br>-increasing biodiversity and soil health by less mechanical disturbance (ground burrower microorganisms) | -limited financial resources to invest in new machinery<br>-knowledge gaps at stakeholders<br>-lacking measures of advanced professional training<br>-weak institutions | -Livestock production (extensive grazing)<br>-diversification of production - new crops (hemp, canola, soybean)<br>-Intensification and taking marginal sites out of production<br>-steppe restoration by converting marginal sites | Frühauf et al. (2020); Meinel et al. (2020); Müller et al. (2021); Silanteva et. al. (2020b), Pazur et al. (2021)<br>.<br>.<br>.<br>.<br>.<br>. |

**Table II**. Overview on ecosystem services utilized and affected in the ecoregion of semi-desert and deserts that is characterized by intensive irrigated crop production (columns 1-3). The fourth to seventh column indicate the challenges, potentials, and obstacles to increase the sustainability of agricultural land use in these ecosystems, and the actual or potential demands by other users for the same ecosystem services, including requirements by ecosystems. The users are given in bold.

| **Highly demanded provision services** | **Heavily utilized supporting services and consequences** | **Negatively affected regulating services and effects** | **Practices challenging sustainability of agricultural production** | **Potential to increase sustainability in the agricultural sector** | **Obstacles** | **Land use alternatives and potential competitions** (some changes have been emerging in the past decade) | **Further reading** |
|---|---|---|---|---|---|---|---|
| **Food: Rice, wheat,** maize, fruit tree plantations;<br><br>**Fiber: Cotton;**<br><br>Fodder: Alfalfa;<br><br>Fuel: Plant oil (sunflower), fruit tree plantations;<br><br>**Fresh Water** | **Nutrient cycling and soil formation:** soil fertility (-), soil salinity (+)<br><br>Primary production (?)<br><br>**Habitat provision:** natural, diverse wetland ecosystems (-), diverse agrarian landscape (-) | **Water purification:** salinity of irrigation and drainage water, capillary rice (+)<br><br>**Climate regulation:** methane emission (+)<br><br>**Flood regulation** | Low application efficiency of flood and furrow **irrigation practice**<br><br>Negligence of non-functioning and partly missing drainage infrastructure | **Increase application efficiency** of irrigation water, e.g. by laser leveling, sprinkler or drip irrigation<br><br>Regular maintenance of **I&D infrastructure** | Limited financial resources of governments and all other stakeholder | Protect and increase **biodiversity** and diverse landscapes<br><br>Increase **landscape diversity** and protect **natural ecosystems** (lakes and wetlands) for **national and international tourism**<br><br>Increase of diversified food production to ensure food security for **population**<br><br>Clean drinking water and energy supply for **cities and rural development**<br><br>Energy and secure fresh water supply for **food value chains and industry**<br><br>Afforestation of degraded cropland | Schlueter et al. 2010, Tischbein et al. 2013, White 2013, Qadir et al. 2009, Varis, 2014 Conrad et al. 2015, Zonn, 2010 |
| | | | Unreliable and untimely **water distribution**<br><br>**Excessive water use** and reduced incentives for water saving<br><br>**Monocultures,** partly due to mis-dimensioned irrigation infrastructure<br><br>Area-demanding production at **low productivity levels** | **Demand oriented water distribution**<br><br>International **water cooperation**<br><br>**Digitalization:** Monitoring of water distribution and crop production<br><br>**Conservation Agriculture**<br><br>**Crop diversification,** including alternative, water saving and salt tolerant crop types<br><br>Focus shift from high quantity towards **high quality production**<br><br>**Release unproductive land** | Weak institutions<br><br>Empowerment of women in irrigation water management<br><br>Limited international cooperation in the Aral Sea Basin<br><br>Low practical agricultural knowledge of stakeholders<br><br>Missing cooling opportunities and value chains for alternative crops<br><br>High need for energy and food security | | |

## 5. Major challenges and future conflict areas

The challenges posed by increasing resource demands and climate adaptation, and sectoral approaches to addressing them, lead to specific conflicts of interest in the ecoregions of Central Asia. These conflicts do not only affect individual ecoregions or ecosystem services, but are multicausal and transregional. In the following, outstanding areas of conflict will be highlighted by way of example.

A) Increasing demand for natural resources

● Food production versus renewable energy resources

Meeting the growing demand for renewable energies leads to changes in agricultural production and to more land being used for the cultivation of energy raw materials. This creates direct competition for land. Meeting the growing demand for renewable energies leads to changes in agricultural production and to more land being used for the cultivation of energy raw materials. This creates direct competition for land. The reduction of land resources for food production requires intensification of production as demand increases. This in turn has a negative impact on regulatory services such as carbon storage or erosion regulation. The steppes and forest-steppe regions will be particularly affected by this area of conflict.

● Water use versus riparian forests, wetland and lake ecosystems and biodiversity

Floodplain ecosystems are adapted to the specific conditions of the hydrological amplitude of high and low water. They provide valuable habitats and refuges for a variety of plants and animals. With flow regulation for energy production or irrigation, the runoff pattern is leveled. The seasonal alternation of flooding and drought no longer takes place and the habitat conditions of many species are permanently impaired.

● Grazing vs. forests in mountainous ecosystems

Mountain forests fulfill a variety of ecosystem services. They provide water storage, have a protective function against erosion and avalanches, supply fuel and offer unique refuges for mountain fauna. Overuse through grazing leads to forest decline and thus impairs the ecologically important functions for mountain ecosystems as a whole.

B) Adaptation to Climate Change

● Hydropower generation versus water supply

Increasing use of water resources for energy production in the mountain regions will lead to a shortage of water supply in the ecoregion of semi-deserts and deserts. This affects both the drinking water supply and irrigated agriculture. In addition to the effects on the provisioning services, this energetic water use also affects regulatory services (biodiversity). This affects both the mountain regions and the waters of the semi-desert and desert regions.

● Green hydrogen production versus food production and water supply

For the production of green hydrogen on a significant scale, there is a high demand for both electricity from renewable energy sources and water. With regard to renewable energies, besides hydropower, there is considerable potential for energy production from wind and solar energy. This creates a demand for land for the installation of solar and wind farms. This is associated with potential conflicts with land requirements for agricultural production (arable farming, pasture farming).

C) Transboundary challenges (telecoupling)

Water storage in the headwaters of major Central Asian rivers is a prime example of the spatial complexity of interdependencies and trade-offs of ecosystem services. Large dams are being built with the aim of generating electricity and supplying drinking water. These interventions in the headwaters not only affect the ecosystem services (biodiversity) there, but also the provisioning, support and regulation services in the entire river system. The overuse of water resources (irrigation) in one part of the catchment leads to devastating effects elsewhere (Aral Sea).

## 6. Conclusions

The overview presented in this contribution aimed at highlighting current and potential conflicts over ecosystem services in Central Asia triggered by agricultural land use with a view to possible solutions. As worldwide, agricultural land use in the different ecoregions of Central Asia places special demands on and influences various landscape functions (e.g., water storage, nutrient provision, erosion control). Thus, agricultural land use always triggers and is affected by trade off that can be increased by unsustainable land management practice, as demonstrated at the examples of steppe cultivation for grain production and crop irrigation in the oases along the rivers in the desert ecosystem.

The diversity of Central Asia's landscapes and their abundance of resources leads to significant pressures regarding the use of ecosystem services and thus to multiple impacts on them. With regard to the application of the concept of ecosystem services, the spatial effects of sustainable agricultural land use measures must be taken into account in impact analyses in addition to the resolution of trade offs.

The example of the Aral Sea Basin underpinned the necessity to think of land and water management together, because the links between the respective ecosystem services demanded for the water intensive irrigation are strong. Solutions to reduce soil salinity and mitigate land degradation, or to increase biodiversity in natural wetlands along the rivers always require the identification of improved water management, i.e. more efficient utilization of supporting services.

The ongoing and future conflicts between the protection of natural functions (e.g. climate regulation) and resources (e.g. saving of fresh water) and their utilization, e.g. water in the context of the water-energy-food nexus in the region, or between different land use targets induced by agricultural land use, and the attempts to their solution have both local and supraregional effects. Examples include dust movements through wind erosion in the steppe ecosystems affecting health e.g. in surrounding urban areas, or downstream consumption of water that originates from the mountains. They underscore the connectivity of the ecoregions at the one hand, and among different sectors within an ecoregion.

The elaborations made in this contribution are certainly not exhaustive, nor do they represent the actual diversity of ecosystem services or conflict areas of land use in Central Asia. They should raise awareness for central conflict areas of agricultural land use in Central Asia. Against the background of different concepts of sustainable development (ESS, SDG, Global Environmental Syndromes) integrative approaches for sustainable use and design of landscapes are necessary to develop practicable measures for their implementation.

Compromise solutions in the sense of optimisation are necessary for the implementation of sustainable land use activities. These compromises have to be found not only in terms of conflicting goals between individual ecosystem services, but also across landscapes and countries. In our opinion, this poses greater challenges than resolving trade-offs between competing interests in ecosystem services.

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