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Review

Rural vulnerability to environmental change in the irrigated lowlands of Central Asia and options for policy-makers: A review

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ABSTRACT

Climate change, land degradation and drought affect millions of people living in drylands worldwide. With its food security depending almost entirely on irrigated agriculture, Central Asia is one of the arid regions highly vulnerable to water scarcity. Previous research of land and water use in the region has focused on improving water-use efficiency, soil management and identifying technical, institutional and agricultural innovations. However, vulnerability to climate change has rarely been considered, in spite of the imminent risks due to a higher-than-average warming perspective and the predicted melting of glaciers, which will greatly affect the availability of irrigation water. Using the Khorezm region in the irrigated lowlands of northwest Uzbekistan as an example, we identify the local patterns of vulnerability to climate variability and extremes. We look at on-going environmental degradation, water-use inefficiency, and barriers to climate change adaptation and mitigation, and based on an extensive review of research evidence from the region, we present concrete examples of initiatives for building resilience and improving climate risk management. These include improving water use efficiency and changing the cropping patterns that have a high potential to decrease the exposure and sensitivity of rural communities to climate risks. In addition, changes in land use such as the afforestation of degraded croplands, and introducing resource-smart cultivation practices such as conservation agriculture, may strengthen the capacity of farmers and institutions to respond to climate challenges. As these can be out-scaled to similar environments, i.e. the irrigated cotton and wheat growing lowland regions in Central Asia and the Caucasus, these findings may be relevant for regions beyond the immediate geographic area from which it draws its examples.

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1. Introduction

Today, over 2 billion people are living in drylands (FAO, 2011). Furthermore, the economic impacts of regular droughts in these drylands during the past two decades exceed 60 billion USD (EM-DAT, 2009), while the costs of on-going land degradation has amounted to 40 billion USD annually (FAO, 2013). Droughts and land degradation are increasingly being associated with the worldwide climate change, which is expected to aggravate the situation in Central Asia above global averages and to reduce snow and glaciers reserves in the mountains (Parry et al., 2007). The glacier and snow reserves are virtually the only source of water for most of the irrigated croplands in the Aral Sea basin. Given that future climate projections indicate increasing water supply–demand gaps, crop production is endangered, accompanied by decay of socio-ecosystems (Chub, 2000; Christmann et al., 2009).

A vulnerability approach is often applied in the context of climate change analysis. It relates to the concepts of resilience, exposure and susceptibility (Smit and Wandel, 2006; Adger, 2006; Parry et al., 2007) and accordingly, we adopt the following definitions of: (i) *vulnerability* as ''the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes''; (ii) *exposure* as ''the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social and cultural assets in places that could be adversely affected''; (iii) *susceptibility* as the predisposition of a system to be negatively affected (harmed) by climate variability or change; and (iv) *resilience* as ''the ability of a system and its components to absorb or recover from the effects of a hazardous event'' (Parry et al., 2007; Birkmann et al., 2013; IPCC, 2012b).

While evidence on climate risks in Central Asia has been reported (Sommer et al., 2013; Beek et al., 2011; Lioubimtseva et al., 2005; Mannig et al., 2013), few studies explore the determinants of vulnerability and provide policy-oriented synthesis of suitable risk reducing measures in the Central Asian context (e.g. Lioubimtseva and Henebry, 2009; Thomas, 2008). To reduce this gap, the objectives of this review are to examine the rural vulnerability to climate changes and extremes, basing the analysis on the case study of the Khorezm region of Uzbekistan. This region exemplifies many of the environmental, socio-economic and governance challenges of the 21st century in Central Asia and the Caucasus (summarized in Table 1).

Methodologically, this review is based on operationalizing a conceptual framework (Section 1.1), through a review of interdisciplinary scientific evidence. We rely strongly – but not solely – on evidence amassed through long-term research in Khorezm, where innovative concepts and technologies for improved and sustainable agricultural production and rural livelihood have been developed (Martius et al., 2012). The investigated practices could be applicable also to regions with similar conditions such as the traditionally cotton- and wheat-dominated irrigated lowland regions of Central Asia and the Caucasus.

The policy-relevant research findings are grouped into adaptation[1]/mitigation[2] measures, while underlining their potential effects on the vulnerability components (summarized in Table 2). The prospects of implementation are assessed while considering the expected benefits, and existing constraints (based on scientific evidence). The discussion suggests further practical options derived from global experience.

1.1. *Conceptual framework of the analysis*

Various vulnerability frameworks (e.g. Birkmann et al., 2013; Ostrom, 2011) provide guidance for a holistic vulnerability analysis in the field of natural hazards and climate change. Yet, they need to be adapted to the case-specific context (i.e. region, sector, hazard) (Birkmann et al., 2013). Considering the Central Asian environmental, socio-economic and governance specifics, an integrated vulnerability–resilience–climate risk management analytical framework is suggested (Fig. 1). Nonetheless, while recognizing the multidimensional nature of ''vulnerability'', which includes for instance cultural aspects (Birkmann et al., 2013), only those elements have been included that are relevant to identify how to counter climate change and extremes and environmental degradation with feasible options for action in irrigated areas.

Since the rural population makes up 60–70% of the total people in Central Asia and a high share is employed in irrigated agriculture (Christmann et al., 2009), the rural livelihoods (social systems), the ecological components (agro-ecosystems) and their interactions provide the key to resilience. These have therefore been emphasized here. Human activities in Central Asia, such as agricultural intensification (resource utilization arrow), may exacerbate the environmental degradation (impacts arrow) and consequently increase climate vulnerability (Fig. 1). The social susceptibility factors include for instance rural livelihoods reliance on irrigated agriculture. Resilience per se is comprised of ecosystems resilience and social systems capacity[3] to cope with (e.g. access to information) and adapt to (e.g. land tenure) changes and shocks (Birkmann et al., 2013). This has barely been analyzed previously.

A major climate change risk[4] in a rural area dominated by irrigated agriculture is water scarcity,[5] which is considered in the analytical framework and elaborated as a function of

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[1] *Adaptation* is defined as ''adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'' (Parry et al., 2007).

[2] *Mitigation* with respect to climate change, means implementing policies to reduce greenhouse gas emissions and enhance sinks.

[3] *Coping capacity* is ''the ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome adverse conditions'' (IPCC, 2012a); and *adaptive capacity* is the combination of capabilities, resources and institutions to implement adaptation actions.

[4] *Risk* refers to the probability of harmful consequences.

[5] *Water scarcity* refers to a situation where the absolute quantity of water availability is insufficient to meet the demand.

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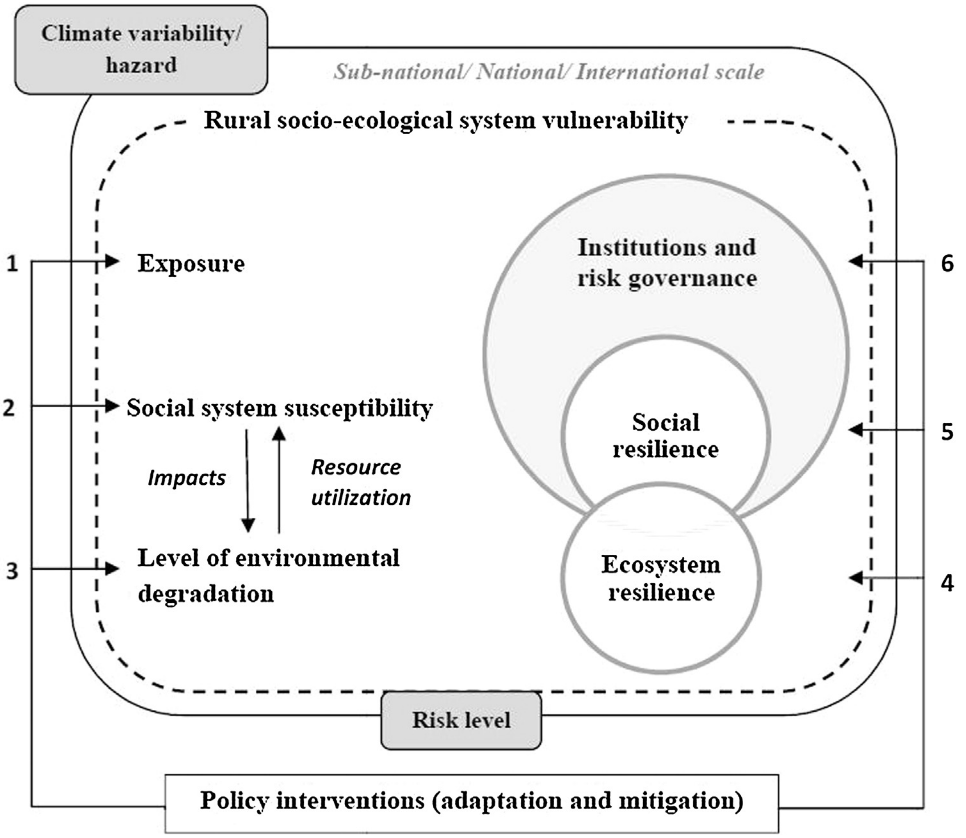

Fig. 1 – Integrated vulnerability–resilience–climate risk management framework, highlighting the relationship between climate pressures, social and ecological systems and the role of adaptation/mitigation and institutions.
***Source*: Developed by the lead-author based on concepts of Birkmann et al. (2013), Ostrom (2011) and Parry et al. (2007).**

climate change/hazard and vulnerability (Birkmann et al., 2013). Further, it was assumed that through adaptation and mitigation measures the vulnerability could be reduced while concurrently the resilience of the rural socio-ecological systems could be increased. The combination thereof could decrease the overall climate risks in the region.

The proposed framework suggests furthermore that a single adaptation/mitigation measure (shown by the arrows 1–6, Fig. 1) could address more than one vulnerability component. For instance, practices which preserve ecosystem functions (i.e. build resilience shown by arrow 4) could bring social benefits such as income diversification (i.e. reduced social susceptibility).

Due to the strong grip of the state on irrigated crop production, evidenced by state order quotas for cotton and wheat (Rudenko et al., 2012), it is particularly important that institutional and governance[6] aspects are included in the analysis. These regional characteristics are crucial for mainstreaming climate change policies into local and national development plans. Moreover, an integration of sub-national, national and international perspectives is needed given the present trans-boundary water conflicts on one side (Martius et al., 2009; Sehring and Giese, 2011) and the existing international climate change programmes and funds on the other (e.g. Clean Development Mechanism (CDM)). Both however, create opportunities for risk reduction and development.

2. Climate change, water scarcity and land degradation in Khorezm: a vulnerability perspective

2.1. *Climate risks and exposure*

The Khorezm region of Uzbekistan is situated in the downstream part of the Amu Darya river basin. It is part of the inner Aral Sea Basin. Annual precipitation is ca. 100 mm (Conrad et al., 2012) and the Amu Darya river, the only water source for irrigated agriculture, is fed by meltwater from the snow and glacier reserves in the Pamir and Tien Shan mountains. These are therefore vital for the livelihoods in Central Asia. The decrease in surface and volume of these reserves, and consequently changes in quantity and timing of Amu Darya discharges, have often been attributed to climate change (Siderius and Schoumans, 2009). Even though glacier-melt runoff is predicted to increase the water volume in the

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[6] *Governance* is comprising of mechanisms, processes and institutions involved in climate risk management at a local, national and regional level (UNDP, 2004); and *institutions* refer to existing formal and informal structures.

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Table 1 – Prime determinants of risk and vulnerability in the Khorezm region of Uzbekistan, categorized in line with Fig. 1 and described in detail in Section 2.

Climate change, hazards	Glacier-melt in Central Asia due to climate change
	Changes in quantity and timing of Amu Darya discharges
	Change in growing-degree days (temperature, precipitation)
	Extreme drought events
Exposure	Irrigated agriculture (crops, gross production) dominance
	Uncertainty over water availability (irrigation)
	High share of rural population
Socio-ecological systems' susceptibility	High socio-economic dependence on irrigated agriculture
	Low income diversification
	High water demanding crops (*cotton*, *wheat*, *rice*) dominance
	Irrigation system inefficiency
	Land/soil/water deterioration (salinization)
Resilience, governance/institutions	Coping capacity of the social system to deal with climate shocks (water scarcity) – concerns over:
	Information availability, access and trust
	Water management response during droughts
	Adaptive capacity of the social system:
	Restrictive water management with poor capacity
	Frequent land reforms and state tenure, farm restructuring
	Low diversification of cropping patterns
	Weak agricultural extension services
	Ecological system resilience:
	Land typology of non-irrigated areas: desert land, forests, pastures
	Poor state of the irrigation and drainage system
	Unsustainable natural resources utilization

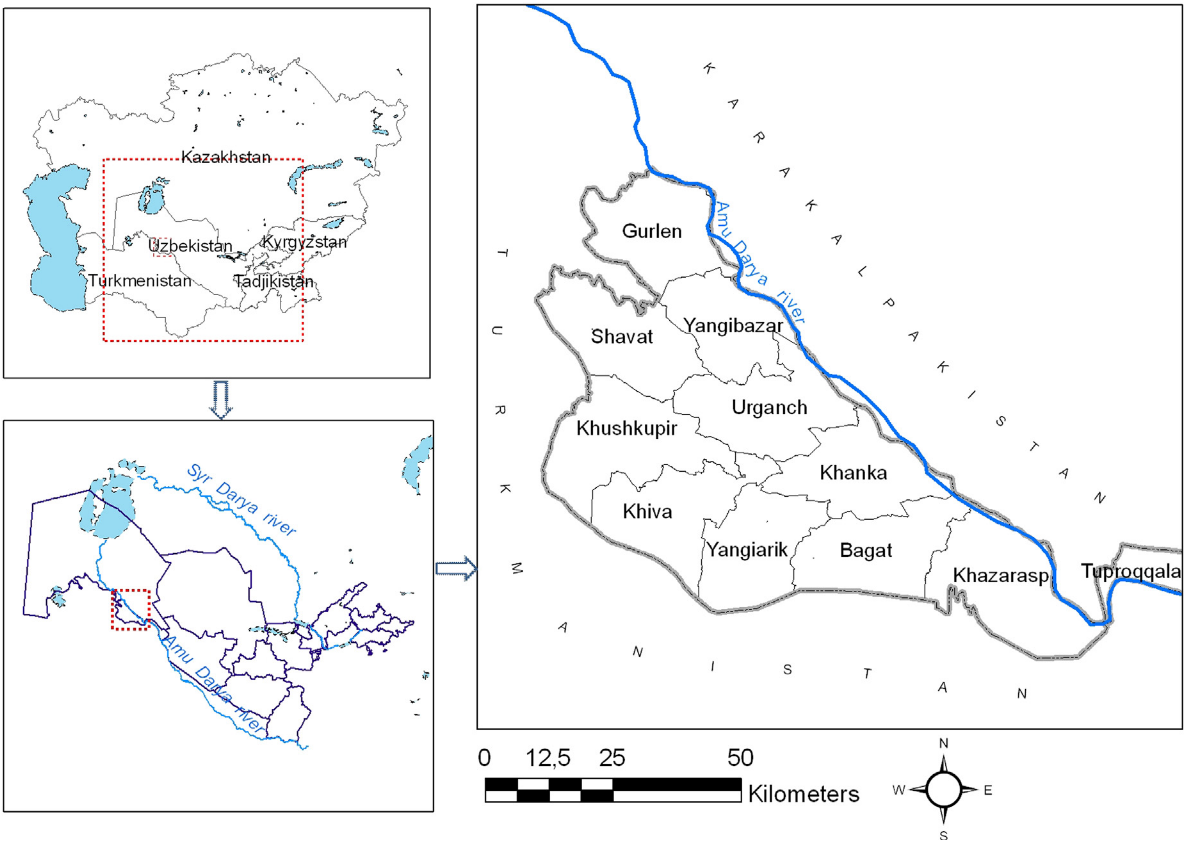

Fig. 2 – The Khorezm region in Uzbekistan. Top left: regional map. Bottom left: map of Uzbekistan. Right side: map of Khorezm with its political districts.
***Source*: ZEF/UNESCO GIS Lab (2013).**

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short and perhaps even mid-term (Cruz et al., 2007), the reserves are ultimately limited and water scarcity is likely to occur more frequently sooner or later (Trenberth et al., 2007).

Conflicts over water between upstream and downstream countries and within country water allocation, could further reduce downstream water availability (Martius et al., 2009), adding an international and national dimension that needs to be analyzed (Fig. 1). Also water quality is of concern, e.g. the average water salinity in the Tuyamuyun reservoir, upstream of Khorezm, has about doubled in 30 years as a result of diminishing flows from the Pamir and Tien Shan mountains and saline drainage water return flows (Siderius and Schoumans, 2009).

Changing climate has various risk-mitigating effects: the number of growing degree days is comparatively stable and suitable for cultivating the typical crops for the region (cotton, wheat, rice, maize, sorghum); high temperatures indicate increasing suitability for growing wheat; and climate-related crop water demands (i.e. the potential evapotranspiration) have only been slightly decreasing when analysing weather data of the past three decades (Conrad et al., 2012). But the arid climate, the high share of agricultural water use, the low water use efficiency and low irrigation water quality (salinity) all expose agriculture to risks from climate change.

Alternative water sources that potentially could be explored for agricultural purposes such as tapping local lakes (fed by groundwater and drainage system flows) have been examined, yet turned out to be insufficient in size (Shanafield et al., 2010). Also ground and drainage water resources have been considered, however groundwater recharge ultimately depends on the Amu Darya river flow (Ibrakhimov et al., 2007; Tischbein et al., 2012). Hence, while realizing now that such obvious options turned out to be not viable, the negative effect of climate change on water availability is much stronger than presently accounted for.

2.2. *Socio-ecological systems' susceptibility*

Land degradation in Uzbekistan is associated with the enormous expansion of irrigated croplands due to the intensive development of large-scale irrigation systems since the 1960s (e.g. Saiko and Zonn, 2000; Beek et al., 2011). The soil organic matter (SOM), estimated at an average of only 7.5 g kg^{-1} in the topsoil (Akramkhanov et al., 2012) is reportedly falling since the 1950s, due to intensive soil tillage, high temperatures and intensive (over-) irrigation. Furthermore, the on-going soil degradation caused by secondary soil salinization is alarming (Tischbein et al., 2012). The share of highly saline soils increased from 6% in 1960 to 21% in 1990 whilst the total share of saline croplands in Khorezm has reached 40–60% (Akramkhanov et al., 2012).

An analysis of the government' extensive groundwater monitoring datasets from 1990, 1994 and 2000 shows that during the irrigation cropping season about two thirds of the land in Khorezm had groundwater tables above the critical threshold level meaning levels triggering further soil salinization (Ibrakhimov et al., 2007). Remote sensing analysis based on the decline of NDVI over time shows that in the period 2000–2010 alone, about 33% of the Khorezm irrigated croplands experienced already various levels of degradation (Dubovyk et al., 2012).

Human activities impact the level of land degradation and consequently the overall vulnerability of the system (Fig. 1). Apart from climate change and variability, main drivers of land deterioration in Khorezm are: (i) the tight governmental control of which agricultural crops are to be produced and with which methods (Djanibekov et al., 2012a); (ii) a government policy abiding by production maximization, rather than seeking sustainable agriculture through resource use optimization; (iii) the land tenure status (all land is owned by the state and only leased to farmers) combined with frequent land reforms, which both discourage long-term planning of land use and investments in resource-conserving measures amongst the farmers (Djanibekov et al., 2012a), and (iv) the lack of access to agricultural service providers which is indispensable for modernizing irrigated agriculture in the region (Niyazmetov et al., 2012).

Socio-environmental determinants of water scarcity. The agricultural sector in Khorezm utilizes up to 95% of the total water intake in the region (Schieder, 2011). The typical irrigation practices include furrow and basin irrigation – both characterized by low efficiency (approx. 40% according to field estimations) (Bekchanov et al., 2010b). A high share of the delivered water (25% in 2004–2005) is used for pre-seasonal leaching in spring (Tischbein et al., 2012).

The risk of water scarcity is determined not only by insufficient water availability due to climate change (exposure), but also by the factors of susceptibility, i.e. socio-environmental conditions (Fig. 1). Khorezm, similar to other regions in Central Asia and the Caucasus, experiences water scarcity which is caused by: (i) the location along and the distance from the canal, for instance land located at the tail-end of the irrigation system suffers more frequent water shortages (Bekchanov et al., 2010a; Oberkircher, 2010); (ii) climate change, such as the observed more frequently occurring drought periods over the last decade; (iii) land elevation, insufficient levelling of croplands and low soil storage characteristics. However, the region also is exposed to economic/institutional water shortage that originates from: (i) maladaptive irrigation infrastructures after post-Soviet land reforms (Tischbein et al., 2012; Bekchanov et al., 2010a); (ii) insufficient and unequal water distribution amongst users, due to poor organizational structures and state policies (Abdullayev et al., 2008), and (iii) deteriorated infrastructure such as broken pumps or lack of electricity (Conliffe, 2009).

2.3. *Social and ecological resilience*

Coping with "drought" extremes. Khorezm experienced four major "droughts" since 2000, during which irrigation water inflow from the Amu Darya river amounted to not more than 40–60% of the long-term average (Abdullayev et al., 2008; Cawater-INFO, 2012). In particular water delivery to the tail-end users had been insufficient during these periods of water scarcity. The 2000–2001 droughts are considered the one with the most adverse impacts on agricultural sector, affecting concurrently the environment and rural livelihoods. The large scale of those impacts has been partly attributed to the insufficient drought preparedness of the national and local institutions (World Bank, 2005) including: (i) failure of drought early warning systems (such as inaccurate observations, poor

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data forecasting), and (ii) lack of *ex-ante* preparedness and adaptation planning. In addition, the farmers' lack of access to and/or trust in the provided information further exacerbated the negative drought effects (Conliffe, 2009).

The adaptive capacity in Khorezm is framed by the local and national socio-economic and institutional settings. About 70% of the population is rural, out of which 38% is directly employed in agriculture (OBLSTAT, 2013). Approximately 46% of the total agricultural land is annually used for cotton cultivation, followed by winter wheat and rice (Bekchanov et al., 2010a). Despite the growth of the agricultural sector in the past two decades, its share to GDP has gradually curbed from about 45% in the mid-90s to about 35% in 2012 (OBLSTAT, 2013) mainly owing to a faster growth of industry and services. At the end of 2008, after a series of intensive land reforms the share of private farms accounted for 82% with 24 ha as the average farm size (Djanibekov et al., 2012c). These frequent land reforms over the last two decades have affected the local adaptive capacity in several ways. Djanibekov et al. (2012c), but also Bobojonov et al. (2012), argued for instance that the present policy of state interventions disincentivizes efficient water use, distorts farming practices, hinders technical renovation and disfavours crop diversification and crop rotations.

Since 2000, the irrigation water management is organized through non-governmental Water Consumer Associations (WCAs), initially introduced to fill the gaps left after the reforms of state and collective farms which reduced the irrigation performance and sustainability. Mandated to regulate water distribution to the users and to maintain the infrastructure (Niyazmetov et al., 2012), the irrigation water limits for each WCAs are still allocated by the State, based on criteria such as irrigated area, planted crops, and the respective static irrigation norms (Manschadi et al., 2010). However, the low human capacity, experience, skills and funds led to decreasing water use efficiencies and low water fee collection rates (Veldwisch et al., 2012).

Ecosystems resilience. The capacity to maintain ecosystem functions in the aftermath of external shocks is considerably determined by a human component (Fig. 1), for instance through natural resource utilization, such as land and water use. Irrigated land resources (42% of the total land area) in Khorezm are used predominantly for cropping, with a small share for livestock rearing, horticulture and gardens. The non-irrigated areas consist mainly of desert land, riparian forests (Tugai) and pastures (Akramkhanov et al., 2012; Khamzina et al., 2012). Given the prioritized production of cotton and wheat, irrigated fields suffer from increasing soil deterioration (Tischbein et al., 2012). The capacity to cope with climate hazards is further reduced by the current status and management of the irrigation and drainage system, which does not allow for controlling the groundwater table and soil salinity adequately, and in turn limits the options for improved irrigation and groundwater management (Tischbein et al., 2012).

3. Policy-oriented review of promising adaptation and mitigation practices

Suitable policy interventions for climate risk management should be implemented at national and local scale and benefit from the international climate regime (Fig. 1). Uzbekistan is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and has initiated the establishment of institutional capacities for assessing climate change impact and developing national plans for adaptation and mitigation. The prime institutions involved in drought risk management in agriculture at national level are: (i) the Ministry of Agriculture and Water Resources of Uzbekistan, responsible for planning, regulating and monitoring the agricultural activities, including distribution of water and the dissemination of information; (ii) the Centre of Hydro-meteorological Service at the Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet), which is in charge of risk assessment, monitoring and forecasting; (iii) agricultural insurance companies. Following the severe droughts in 2000–2001, the Government has undertaken strategic actions to reduce future drought risks through: (i) large-scale introduction of water-saving technologies (e.g. a programme to implement drip irrigation over 2013–2017); (ii) institutional development for better water control; and (iii) improvement of runoff forecasting (Government of and Uzbekistan, 2008). Yet, climate risk management remains a challenge ahead also because up-to-date findings on feasible measures are not available to policy and decision-makers.

3.1. *Improved water resources management*

Promising strategies for improving water-use efficiency (arrow 2, Fig. 1) include tackling the demand side via (a) reducing the gross water requirements by more targeted and efficient irrigation without reducing yield, and (b) in case of severe under-supply, minimizing the impact of non-avoidable water stress on the yield production by controlled deficit irrigation. With improved irrigation scheduling, fulfilling the site-specific and time-depending needs of the crops (strategy a), water distribution can be optimized (Pereira, 1999) and this could raise the water productivity during drought seasons in Khorezm (Bekchanov et al., 2010a). Especially, replacing the existing static irrigation norms by an approach based on flexible modelling of surface and groundwater processes has a high potential to meet crop water requirements with lower water input (Awan et al., 2012). This can be supported by relatively simple measures for technical rehabilitation of the irrigation system (laser-guided levelling, introduction of equipment for water dosage at field level, lining of canals in reaches with high percolation) and by introducing modern irrigation techniques. The latter however, would require substantial investments (Rudenko and Lamers, 2010) and given the low capitalization levels of most farmers (Wehrheim et al., 2008), mainly low-cost methods seem currently appreciated. The latter include double-side irrigation on flat fields, short and alternate dry furrow techniques, optimizing application discharge under given field conditions, surge flow approach (Tischbein et al., 2012), although these are much less water-efficient (Bekchanov et al., 2010b).

The current irrigation practices based on static norms do not allow reacting adequately to severe supply–demand gaps (as was seen in the years 2000 and 2001). Adapting to severely reduced supply consists of controlled deficit irrigation (strategy b) which enables minimizing the impact of non-avoidable water

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stress on yield. Akhtar et al. (2013) combined the AquaCrop (Steduto et al., 2009) and the HYDRUS 1-D (Simunek et al., 2008) models to elaborate a tool to deal with deficit irrigation strategies. Considering the capillary rise from shallow groundwater, it was estimated that raising water productivity is feasible even under diminished water supply. Taking cotton as an example, simulations show that even up to a 20% reduction in water supply, a loss of (harvested) yield can be nearly avoided in case of optimized irrigation timing and amount. Furthermore, the impact of a 40% reduction in water supply on yield could be kept in the range of 14–29% in terms of yield loss (Akhtar et al., 2013).

Finding alternatives to increasing the storage capacity of the irrigation and drainage system (arrow 4, Fig. 1) would be a desirable option influencing the supply side mainly in terms of timing, including: (i) conjunctive use of surface and groundwater utilizing the buffer function of the groundwater; (ii) integrating the lakes, which are abundant in the region, into water management planning; and (iii) construction of small decentralized reservoirs to store canal water in case of oversupply and to use it during deficit periods (Tischbein et al., 2012). Currently, the farmers' preferences in response to water scarcity follow a certain sequence: first, tapping the groundwater reservoirs by partly blocking drainage discharge when possible and using them as a fall-back option during periods with water shortage; and second, cultivating alternative crops and/or abandoning part of the cropland. However, filling groundwater resources and maintaining shallow groundwater has the unwanted side effect of increasing secondary soil salinity. Since option (iii) requires huge investments and is not feasible in a short-run, options (i) and (ii) need to be further explored.

Studies on water use demonstrated that the poor performance of irrigation water management is not only a technical matter, but has an institutional dimension as well. Therefore, technical approaches for restructuring irrigation water supply must be flanked with institutional re-arrangements creating better management conditions and economic incentive-disincentive systems (arrow 6, Fig. 1). For instance, water pricing schemes aiming at economically efficient allocation of the water resources have been suggested. However, several practical difficulties remain, such as ''demand uncertainty'' (uncertainty over the willingness to pay) and need of infrastructural modifications (Saleth et al., 2011). Djanibekov et al. (2012b) investigated the prospects of introducing irrigation water service fees and concluded that while this measure has the potential to generate sufficient funds to support the management of the irrigation network, positive effects can be expected only if additional policies aiming at water use reduction and farms income increase are introduced as well.

3.2. *Considering alternative cropping patterns*

Bekchanov et al. (2012) argued that the long-term sustainability of the Uzbek economy, which is among others exposed to environmental degradation, water security risk and uncertain world commodity prices, requires switching to less water-intensive agricultural production procedures. For example, a change in the cropping patterns (arrow 2, Fig. 1) as an adaptation measure could have multiple benefits, such as improving soil quality while offering new opportunities for income generation. Relying on the combined information from field experiments, modelling and secondary sources, Bobojonov et al. (2012) show that higher water use efficiency combined with secured farm income is feasible through diversifying the crop portfolio.

3.3. *Considering perennial crops and afforestation*

Including perennial crops in the agro-ecological landscape has been practiced in Uzbekistan for wind erosion control, wood production and horticulture (Tupitsa, 2009). Although fruit trees have been part of the production systems as practiced over the Soviet Union era, their further promotion has been part of the reforms during the past decade (Djanibekov, 2008). Concurrently, an assessment through aerial photographs illustrated an average annual deforestation rate of almost 1.5% and an even higher rate of conversion of the natural *tugai* forests (natural floodplain forests along the Amu Darya river) to cropland with only sparse tree cover. This change in land use impacted significantly soil greenhouse gas emissions which turned out to be much lower from different forest-based land uses compared to agricultural land uses (Scheer et al., 2012).

Afforesting marginal, salt-affected croplands (arrow 4, Fig. 1) is a well-known strategy for re-vegetation, land reclamation, income generation and diversification of the land use while capturing atmospheric carbon dioxide (CO_2) (FAO, 2001). For instance, after five years of afforestation, the amount of Carbon (C) sequestered in the above-ground woody biomass was in the order of *Ulmus pumila* (11 t C ha^{-1}) < *Echinacea angustifolia* (17 t C ha^{-1}) < *Populus euphratica* Olivier (23 t ha^{-1}) (Khamzina et al., 2012). Afforestation of such marginal cropland patches turned out to be an economically viable alternative compared to a series of crop cultivations including cotton (Djanibekov et al., 2012d), provided that land users will be ensured with long-term tenure security and access to knowledgeable people for establishing tree plantations on marginal cropland. It was argued therefore, that afforesting degraded croplands may open new financial opportunities in Central Asia through CDM projects. With reference to the framework used (Fig. 1), global initiatives can thus support the social–ecological resilience at a local scale as well.

On the other hand, the research outcomes indicated that the current global average price for CDM payments of 4.76 USD per temporary Certified Emission Reductions (tCER) is insufficient to induce farmers to participate in short-term afforestation projects (Djanibekov et al., 2012d). However, the overall findings illustrated that afforesting degraded cropland has the potential of reducing the rural vulnerability to droughts through several pathways: (i) diversify income and relax food and energy insecurity (fruits, firewood, fodder and timber); (ii) provide amenities (shadow and shelter) for well-being; and (iii) provide ecosystems services and thereby build resilience of the environment (e.g. microclimate, biodrainage, water efficiency) (Khamzina et al., 2012). Although, a periodic leaching (for instance once during 10–15 years) may be needed to counterbalance the slowly rising soil salinity under afforested areas. Given the high timber prices, such plantations could be

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Table 2 – Summary of reviewed policy options, their potential effects on the components of vulnerability and prime constraints to implementation.

Climate change adaptation/ mitigation opportunities	Potential effect on the components of vulnerability					Constraints
	E	ED	SS	CAC	ER	
Improving water-use efficiency						
Improvement of the irrigation scheduling (arrow 2, Fig. 1) (Bekchanov et al., 2010b)			–	+		Need of substantial investments (Rudenko and Lamers, 2010) Poor performance of irrigation water management institutions (Abdullayev et al., 2008)
Replacement of the existing static with flexible, adaptive irrigation norms (arrow 2, Fig. 1) (Awan et al., 2012)			–	+		Need to improve storage capacity demands substantial infrastructural modifications (Tischbein et al., 2012)
Increase in the storage capacity of the irrigation and drainage system (arrow 4, Fig. 1) (Tischbein et al., 2012)	–	–		+	+	Current centralized water management (Djanibekov et al., 2012c, Manschadi et al., 2010) Ongoing land reforms and state land-tenure (Trevisani, 2009 cited in, Djanibekov et al., 2012a)
Water pricing schemes/ water user fees and consequently prospects for economy efficient allocation of water (arrows 2 and 6, Fig. 1) (Djanibekov et al., 2012b)			–	+		Water pricing "demand uncertainty" (Saleth et al., 2011)
Considering alternative cropping & processing patterns						
Crop diversification, change to less water-intensive production (arrow 2, Fig. 1) (Bobojonov et al., 2012, Bekchanov et al., 2012)	–	–	–	+	+	Fixed state production quotas on cotton and wheat (Bobojonov et al., 2012) Poor linkages of farmers with markets for fruits, vegetables (Bobojonov et al., 2012) Under-developed, in-country cotton and wheat value chains (Rudenko, 2008)
Perennial crops and afforesting degraded croplands						
Re-vegetation and land reclamation, capturing atmospheric carbon dioxide (arrow 4, Fig. 1) (Khamzina et al., 2012); CDM financial opportunities (Djanibekov et al., 2012d)	–	–	–	+	+	Lack of knowledge (Kan et al., 2008) Poor markets for tree products, insecure land tenure (Khamzina et al., 2012, Djanibekov et al., 2012d)
Conservation agriculture (arrows 3 and 4, Fig. 1) (Kienzler et al., 2012)	–	–	–	+	+	Lack of farmer knowledge State production quotas on cotton and wheat Ongoing land-reforms and state land-tenure Insufficient legal framework (Djanibekov et al., 2012a, Kienzler et al., 2012)
Adapting agricultural production and trade						
Improved market conditions (arrow 5, Fig. 1) (Mirzabaev and Tsegai, 2012)			–	+		Need of improved storage facilities and investments in the processing and refinement sectors (Bobojonov et al., 2012, Rudenko et al., 2012)
Development of the processing and refinement sectors (e.g. cotton value chain) (arrow 2, Fig. 1) (Bobojonov et al., 2012, Rudenko et al., 2012, Rudenko, 2008)	–	–	–	+	+	

Note: E = exposure, ED = environmental degradation, SS = social system susceptibility, CAC = coping and adaptive capacity, ER = ecosystem resilience. (–)/(+) refers to decreasing/increasing potential effect on the vulnerability components of each adaptation/mitigation option. The references in the table include only experience from Khorezm (global good practices described in Section 3 are excluded).

transferred to timber production, yet financial benefits can be reaped only after longer periods (Khamzina et al., 2012). Additional benefits from a change from annual to perennial vegetation include a reduced average daily outflux of CO_2 equivalents (Scheer et al., 2012) and an increased C sequestration in soils (Hbirkou et al., 2011).

3.4. *Considering conservation agriculture*

Conservation agricultural (CA) practices are highly potential means to build resilience of the ecosystems in relation to the human component (arrows 3 and 4, Fig. 1). CA consists of a basket of measures that are applied adaptively, but must follow three principles: (i) minimizing soil disturbance (e.g. direct seeding, decreased/no tillage); (ii) maintaining a permanent soil cover (e.g. use of cover crops, crop residues); and (iii) providing adaptive crop rotations (Milder et al., 2011; FAO, 2002). In this way, CA contributes to preserving soil moisture and sequester and maintain C; protects and enhances the biological functioning of the soil; decelerates salt accumulation due to a lowered evaporation; reduces soil erosion; maintains and improves crop yields and increases the

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resilience against droughts, salinization and other hazards (Derpsch and Friedrich, 2009).

Worldwide, CA practices have been introduced considerably in the rain-fed agricultural areas of South and North America, whilst recently they have been found promising under the irrigated conditions in Central Asia, although demanding various adaptations and improvements of legal frame-conditions (Kienzler et al., 2012). Yet, the combined benefits from CA practices that require much lower energy input per unit area (energy, machinery, labour, seeds, fertilizers) do not only cut on production costs (Kassama et al., 2012), which improves rural income, but also decrease greenhouse gas emissions.Adapting agricultural production and trade.

The entire cotton value chain plays a significant role in the national and regional economy of Uzbekistan, while wheat production was greatly promoted to support national food self-sufficiency (Rudenko et al., 2012). Therefore options which increase resource use efficiency and favour the processing industry must be explored (arrow 2, Fig. 1). Rudenko (2008) argued that in the cotton value chain, an increase in the in-country processing of cotton fibre and Khorezm regional production of textile products with higher value-added followed by their export, could double or maintain the present regional export revenues. Meanwhile, the lower water demand would decrease the vulnerability to droughts and reduce the present environmental burden provoked through cotton cultivation (Rudenko, 2008).

Although the diversification of agricultural commodity trade and the promotion of market participation could potentially make rural livelihoods more resilient to climate extremes (Sections 3.2 and 3.3), presently poor markets exist for fruits, vegetables and tree products (e.g. Bobojonov et al., 2012; Khamzina et al., 2012). Good economic practices for improving the market conditions (arrows 5 and 6, Fig. 1) should be adapted to the Central Asian context, including regional free trade as a measure against price volatility (Mirzabaev and Tsegai, 2012), better functioning of the processing sector, improved storage facilities and facilitation of export (Bobojonov et al., 2012; Rudenko et al., 2012) (Table 2).

4. Outlook

Within the proposed vulnerability–resilience–climate risk management framework, institutional support and political awareness on climate risks are prerequisites for effective risk governance (highlighted by arrow 6, Fig. 1). The national administration of Uzbekistan plays a central and active role in the water and agriculture sectors. The current differential crop policies prioritizing cotton for export and wheat to support national food security through elevated levels of subsidies are nevertheless inconsistent with climate change mitigation and adaptation measures. This consequently reduces the resilience of the agricultural sector (at a local and national level) to the changing environment. To take advantage from all opportunities, Uzbekistan should reflect on discarding differential crop schemes altogether or give equal importance to all crops and sectors. This in particular would decrease the vulnerability of areas with poorer access to markets, storage and processing facilities (Bobojonov et al., 2012).

Furthermore, incentives should be orchestrated to facilitate sustainable resource management, social equity and environmental preservation. The highly needed decentralization of the water management in the country was only half-heartedly pursued. Combined with the on-going reversing of previous land reforms towards larger farms (Djanibekov et al., 2012a), the capacity of the rural population to take adaptation initiatives relevant to their needs and capabilities is restricted. Insecurity about land ownership could also explain the low incentives for investment in adaptation measures as frequently argued (e.g. Djanibekov et al., 2012a). Similar challenges need to be overcome before introducing adaptation measures such as farm-forestry (Khamzina et al., 2012) and conservation agriculture (Kienzler et al., 2012). Further obstacles identified for the implementation of adaptation and mitigation measures are the lack of farmers' knowledge about the environmental benefits from measures such as afforestation (Kan et al., 2008), and cultural and religious aspects that affect water management at a local level (Oberkircher, 2010). Therefore, climate change adaptation and mitigation planning could benefit from a shift in governmental policies towards more equitable and participatory distribution of decision power among the involved stakeholders in agriculture and water management, together with social capacity building, such as awareness rising.

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