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Human Dimensions of Climate Change in Arid and Semi-arid Environments: A Case Study of Post-Soviet Central Asia

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Abstract: Arid and semi-arid regions are expected to undergo significant environmental changes caused by the global climate change. Social, political and economic factors and processes, such as globalization, institutional and land-use changes, are likely to be determinant factors of human vulnerability and adaptations to impacts of climate change. This paper explores human dimensions of climate and environmental changes in arid and semi-arid zones of the Central Asian countries of the former USSR. Political, economic, and institutional changes in this region during the past decades have affected its sensitivity and adaptive capacity to climate change and climate variability in many ways. Various non-climatic factors, such as land-use changes, agricultural and economy-wide reforms, crisis of the national health care systems, forced migrations of the population, the general economic decline, and increase of poverty and inequality currently overwhelm the impacts of the global climate change. The same factors, however, are likely to exacerbate the projected impacts of climate change, such as the increasing climate aridity and variability, projected by the climate change scenarios.

Key words: Human dimensions of climate change, Central Asia, arid environments, adaptations

The history of human-environment interactions in arid and semi-arid zones of Central Asia is long and rich. For millennia, different approaches to land use (rangelands, rain-fed agriculture, irrigation) have been acting both as drivers of environmental changes and key factors of human vulnerability, resilience and adaptations to climate variability and change. Climate change and variability affect arid and semi-arid ecosystems and their productivity through the changing patterns in temperature and precipitation, droughts, frosts, floods, heavy winds, and other extreme events, representing both new threats for some regions and opportunities for others. Likewise, examples all around the world suggest that depending on the role of the existing local socio-economic condition, policies and institutions, the internationalization of the global economy might alleviate stresses associated with climate change in some cases and, contrary, to exacerbate them (Leichenko and O'Brien, 2002; Ramankutty *et al.*, 2006).

Projections of climate change impacts on natural resources, ecosystem services, food security, human health and many other aspects of human development are largely based on climate modelling scenarios (IPCC, 2001; Solomon *et al.*, 2007; Parry *et al.*, 2007). Yet, vulnerability, resilience and adaptive capacity of the population to climate change impacts are primarily determined by the human factors, such as the level of economic development, wealth, access to technology and information, institutional changes (agricultural reforms, management practices, policies, legislation), and more recently, responses to globalization (Handmer *et al.*, 1999; Yohe, 2000; Leichenko and O'Brien, 2002; Adger, 2006; Janssen *et al.*, 2006). The same human dimensions also determine the causes and impacts of the local environmental processes and changes, such as rangeland degradation, salinization of arable lands, deforestation, depletion of water resources, and many others.

The purpose of this paper is to review the recent scholarly work on human dimensions of climate changes in arid and semi-arid environments and to illustrate some concepts and theoretical frameworks emerging in the integrative climate change research by examples from the post-Soviet countries of Central Asia. Among many other arid and semi-arid regions of the world, transitional economies of Central Asia are particularly vulnerable to impacts of climate change because of combination of multiple geopolitical, social, cultural, and economic internal and external stressors already present in the region.

Climate change, seen from a human-centred perspective, involves many dimensions and variables, such as; (a) impacts of climate change on food security, water resources, health, security and other aspects of human life; (b) regional development factors contributing to the global climate change (through green-house emissions and the interactions between landcover and the boundary layer of the atmosphere), and (c) human vulnerability, resilience and adaptation to the impacts of climate change at various spatial and temporal scales. While there are strong conceptual connections among these three perspectives, the later group of variables has been increasingly prominent within the research on the human dimensions of global environmental change (Janssen *et al.*, 2006; Adger, 2006; Füssel and Klein, 2006).

Existence of multiple schools and traditions within human vulnerability, resilience, and adaptation research involving scientists from various disciplinary backgrounds has created a new interdisciplinary area of study with rich, but sometimes competing conceptualizations, terminologies and methodological frameworks. Detailed reviews of conceptual frameworks and methodological development of vulnerability and adaptation research have been published in the recent years by Moss *et al.* (2001); Turner II *et al.* (2003); Downing *et al.* (2005); O'Brien *et al.* (2004); Kasperson and Kasperson (2005); Schröter and Patty. (2005); Janssen *et al.* (2006); Füssel and Klein (2006); Smit and Wandel (2006); Adger (2006); Folke (2006); Gallopin (2006); Adger *et al.* (2007); Metzger and Schroter (2006); Füssel (2007); Polsky *et al.* (2007). They build on the earlier studies by Liverman (1990); Bohle *et al.* (1994); Handmer *et al.* (1999); Burton (1997); Downing (1996); Adger and Kelly (1999); Kelly and Adger (2000) and others.

The motivation for this paper grew from the International Workshop on Human Dimensions of Climate and Environmental Change in Central Asia (HDCECCA) organized by the author in May 2004 at Grand Valley State University in Michigan (http://www4.gvsu.edu/lioubime/CentralA_files/HDCECCA.htm). The workshop brought together geographers, biologists, soil scientists, hydrologists, economists, and political scientists from the United States, Russia, India, Uzbekistan, Kazakhstan, Mongolia, Turkey, and Germany, and initiated the interdisciplinary network for collaborative research on human-environmental interactions in Central Asia. Discussions about human dimensions of climate change in Central Asia have continued through the international research projects, such as Evaluating the Effects of Institutional Changes on Regional Hydrometeorology: Assessing the Vulnerability of the Eurasian Semi-arid Grain Belt, sponsored by the National Aeronautics and Space Administration, and through the author's involvement in the USDA-ARS, ICARDA and CIMMYT workshop on Carbon Sequestration in Central Asia held at Ohio State University in November 2005 that discussed the prospects for carbon trading in Central Asia. My motivation for this paper has been reinforced by conversations with scientists, decision-makers and lay people in Central Asia about the potential implications of climate change on water resources, food security, and human health in Central Asia.

This paper includes five sections including the introduction. Section two provides a brief discussion of terminology related to human dimensions of climate and environmental change and provides the key references to the seminal publications in this field. Section three defines the study area and describes the climate change and variability in Central Asia and is based on our analysis of historical meteorological records and climate change scenarios for this region generated by the numerical climate models. Section four provides a discussion of the key areas of potential impacts of and human vulnerability to climate change in arid and semi-arid zones of Central Asia. Finally, section five offers some thoughts on development of mitigation and adaptation policies.

Key Concepts and Definitions

This section is necessary to clarify several key terms used in this paper: human dimensions of climate and environmental change, climate change impact, human vulnerability, resilience, mitigation, and adaptations.

The concept of the human dimensions of climate and environmental change (HDCEC) is quite broad as it brings together human causes, impacts, consequences and responses to environmental changes at a variety of scales. Research on the human dimensions of global change concerns human activities that alter the Earth's environment, the driving forces of those activities, the consequences of environmental change for societies and economies, and human responses to the experience or expectation of global change. Such research is essential both to understand global change and to inform public policy (Committee on the Human Dimensions of Global Change and Committee on Global Change Research, 1999). The HDGCC research community emphasises the need for broadly interdisciplinary approach to the interactions between human activity and global environmental change and brings the social science perspectives and methodological approaches into the global climate change studies traditionally dominated by biophysical science.

Theoretical and methodological frameworks of the HDCEC stem from the seminal publications on social and economic dimensions and impact assessments of climate and land-use/landcover change by Liverman (1990); Liverman *et al.* (1998); Ostrom (1990); Turner II *et al.* (1990); Rosenzweig and Parry (1994), Patz (2001); Patz *et al.* (2005), Parry *et al.* (1999, 2004); Lambin *et al.* (2001) and have been advanced by such organizations as the International Social Science Council (ISSC) of UNESCO, National Research Council (US.) Committee on the Human Dimensions of Global Change, the International Human Dimensions Program on Global Environmental Change (IHDP). As the mission statement of the IHDP points this "international, interdisciplinary science program, dedicated to promoting, catalyzing and coordinating research, capacity-development and networking on the human dimensions of global environmental change. It takes a social science perspective on global change and works on the interface between science and practice." Another key international organization advancing the body of knowledge on HDGECC is the Intergovernmental Panel on Climate Change (IPCC). Its Working Group II: Impacts, Adaptation examines the scientific, technical, environmental, economic and social aspects of the vulnerability (sensitivity and adaptability) to climate change and its consequences for ecological systems, socio-economic sectors and human health, with an emphasis on regional sectoral and cross-sectoral issues. The IPCC Working Group III: Mitigation of Climate Change is dedicated to analyses of mitigation options for the main economic sectors and relationship between mitigation and sustainable development (IPCC, 2007).

During the past decade there was an increasing interest in the HDCEC research in the methodological development related to assessment of *climate change impacts*, *human vulnerability* and *resilience*, *mitigation* and *adaptations* (Janssen *et al.*, 2006; Füssel and Klein, 2006). *Vulnerability* is typically defined as the extent to which an environmental or social system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes (McCarthy *et al.*, 2001; IPCC, 2007). Although many definitions of human vulnerability have been proposed by different authors it is usually understood as a function of the character, magnitude, and rate of climate change and the exposure, sensitivity and adaptive capacity of the human-environmental system (Turner II *et al.*, 2003, Schröter *et al.*, 2005; Parry, 2007; Adger, 2006; Polsky *et al.*, 2007, Adger *et al.*, 2007). One of the key dimensions of human vulnerability to climate change is exposure – a degree to which a system is exposed to a hazard, perturbation or stress caused by the changing climatic conditions. *Sensitivity* can be defined as a degree to which a system is affected by, or responsive to, climate change stimuli (Smit *et al.*, 2001; Turner II *et al.*, 2003). Adaptive capacity or adaptability is understood as the potential or capability of a system to adapt to climatic stimuli (Smit *et al.*, 2001; Schröter *et al.*, 2005; Polsky *et al.*, 2007). The capacity of a sector or region to adapt to climatic changes depends on many non-climatic factors, such as level of economic development and investments, access to markets and insurance, social and economic policies, access to education and technology, cultural and political considerations, the rule of law regarding private and public properties, including natural resources, etc. Adaptation is not a synonym of *mitigation*, a term that describes an action that prevents, limits, delays, or slows the rate of undesired impacts by acting on either the environmental system, the human proximate forces, or the human systems that drive environmental change.

Vulnerability can be also regarded as a function of *potential impact* of climate or other environmental change that can be in turn defined as all implications of the projected environmental change, without considering adaptations (Metzger and Schröter, 2006; Schröter and Patt, 2005). Therefore, impact depends on exposure and sensitivity of a system.

Resilience is generally defined as a tendency of a system to maintain integrity when subject to disturbance (Holling, 1973) or in other words how quickly a variable that has been displaced from equilibrium can return to it (Moss *et al.*, 2001). This term originates from ecology, but similar to vulnerability, this concept is based on combination of physico-environmental attributes, socio-cultural, political, and economic factors that amplify or mitigate the consequences of environmental change or hazards.

Another term that requires some clarification is "post-Soviet Central Asia", defined here as a part of Central Asia including Kazakhstan, Turkmenistan, Uzbekistan, Tajikistan and Kyrgyzstan, five members of the CIS (Commonwealth of Independent States). In the Russian-speaking literature this region is typically defined as "Middle Asia", but excludes Kazakhstan, while the term "Central Asia" includes Kazakhstan, as well as parts of China and Mongolia (Cowan, 2007). In the western literature (and partly the Russian literature of the past decade) the term "Central Asia" sometimes refers to the five Asian republics of the former Soviet Union, but also occasionally is used to describe the larger area, including Dzhungaria, the Takla-Makan, and Gobi (Merzlyakova, 2002; Lioubimtseva, 2002, 2004; Lioubimtseva *et al.*, 2005; Micklin, 1991). A detailed discussion of geographic usage of these terms can be found in Cowan (2007). Further in this paper I use the term "Central Asia" as a synonym of "post-Soviet Central Asia" referring to five Asian republics of the former Soviet Union.

Climate Change in Arid and Semi-arid Zones of Central Asia

Study area and the present climatic conditions

Based on the UNEP classification (UNEP, 1992), roughly half of Kazakhstan, Uzbekistan and Turkmenistan located west from 68-70°E are classified as an arid zone, with aridity index (P/PET) ranging between 0.05 and 0.20 and the rainfall between 25 and 200 mm. The rest of the region is semi-arid, with aridity index varying between 0.2 and 0.5 and the annual rainfall within 200-500 mm range (Fig. 1).

Arid and semi-arid zones of Central Asia feature continental climate with hot and dry summers and moist, relatively warm winters in Turkmenistan and south-eastern Uzbekistan, but cold winters with severe frosts in the rest of the region. Temporal variability of precipitation is very high, but throughout most of the region precipitation has a distinctive spring maximum. Very high daily temperature variance is recorded with frequent sand storms and intense sunshine. As in many other arid and semi-arid regions, climate of Central Asian deserts and semi-deserts is highly variable. The North Atlantic Oscillation (NAO) exerts an important control over the pattern of winter time atmospheric circulation variability over arid and semi-arid zones of Central Asia. Over the past four decades, the pattern captured in the NAO index has altered gradually from the most extreme and persistent negative phase in the 1960s to the most extreme positive phase during the late 1980s and early 1990s. The detailed description of the region's physical geography and climate can be found in Lioubimtseva (2002) and Lioubimtseva *et al.* (2005).

Palaeoclimatic and archaeological data indicate that climate of arid and semi-arid Central Asia has experienced many natural fluctuations in the past that might be comparable with future climate change. Based on the early-to-mid-Holocene pollen and archaeological data, some arid parts of Central Asia may become moister as a result of global warming due to an expected southward shift and probable intensification of the westerly cyclones (Lioubimtseva *et al.*, 2005), while others may become drier.

Historical records available from the weather stations show a steady increase of annual and winter temperatures in this region since the middle of the 20th century. On the other hand, the precipitation trends are highly variable across the region, both spatially and temporally, reflecting the great natural rainfall variability and landform diversity. Precipitation records available in this region since the end of the 19th century show a slight decrease during the past 50-60 years in the western part of the region, little or no changes throughout most of the region, and relatively significant increase in precipitation recorded by the stations surrounded by irrigated lands. This precipitation decrease in the area between the Caspian and Aral Sea mainly occurred since 1960 and it coincides with the Aral Sea desiccation. Both the degradation of the Aral Sea and the dramatic fluctuations of the Kara-Bogaz-Gol Bay, have caused significant changes in albedo, hydrological cycle, and mesoclimatic changes throughout western parts of Kazakhstan, Uzbekistan, and Turkmenistan (Varushchenko *et al.*, 1987). While the overall regional trend indicates a small decrease in rainfall throughout the region, data series from the stations located in the quasi-pristine ecosystems significantly differ from those reported by the stations located on irrigated lands (Neronov, 1997; Small *et al.*, 1999; Lioubimtseva *et al.*, 2005; Lioubimtseva, 2007). Despite the general decrease of precipitation in Central Asia during the past decades the opposite trends have occurred in vicinity of the major oases of Kazakstan, Uzbekistan, and Turkmenistan, such as Urganch, Bokhora, Toshkent, Murgab, Tedjen, and Ashgabat (Lioubimtseva, 2005). This phenomenon is likely to be caused by the human-induced local climatic change caused by the expansion of irrigated lands (Neronov, 1997; Lioubimtseva, 2005; Pielke *et al.*, 2007).

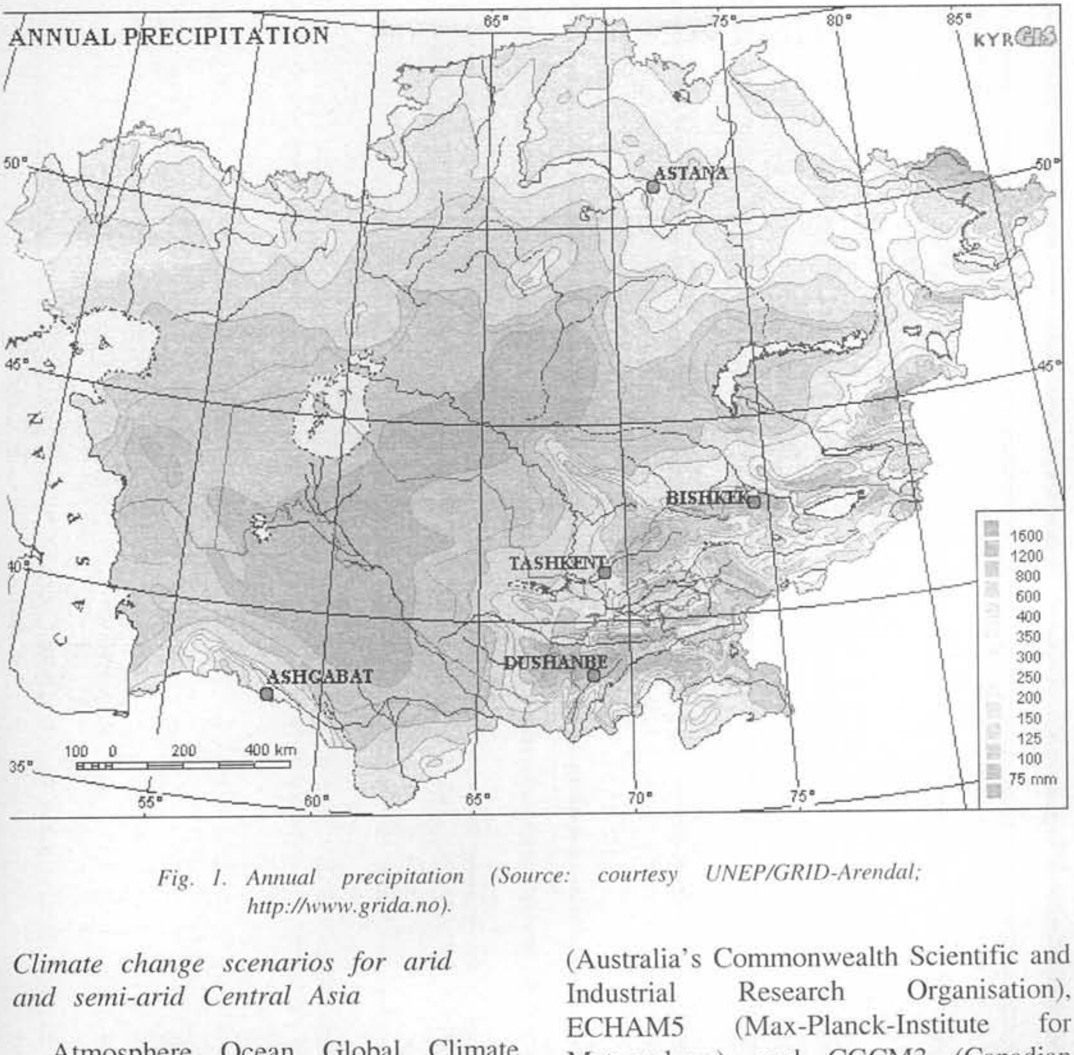

Fig. 1. Annual precipitation (Source: courtesy UNEP/GRID-Arendal; http://www.grida.no).

Climate change scenarios for arid and semi-arid Central Asia

Atmosphere Ocean Global Climate Models (AOGCMs) representing physical processes in the atmosphere, ocean, cryosphere and land surface are the most advanced tools currently available for simulating the responses of the global climate system to increasing greenhouse gas concentrations. Lioubimtseva (2007) has examined the annual and seasonal temperature and precipitation scenarios for Central Asia produced by the HadCM3 (UK Meteorological Office), CSIRO-Mk3 (Australia's Commonwealth Scientific and Industrial Research Organisation), ECHAM5 (Max-Planck-Institute for Meteorology), and CGCM3 (Canadian Centre for Climate Modelling and Analysis) global climate models under A2 and B2 IPCC SRES policy scenarios (Nakicenovic *et al.*, 2000). The SRES IPCC policy scenario families follow narrative storylines, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different

Table 1. Annual temperature and precipitation scenarios for 2050 and 2080 (baseline 1961-1990)

SRES family scenario	Temperature and precipitation			
	Annual temperature scenarios for 2050, °C			
	HadCM3	ECHAM4	CSIRO-Mk3	CGCM3
A2a	2.68-3.61	2.87-3.61	2.87-3.99	2.12-4.55
B2a	1.93-2.87	2.12-3.24	2.12-3.80	1.93-3.24
	Annual temperature scenarios for 2080, °C			
	HadCM3	ECHAM4, 5	CSIRO-Mk3	CGCM3
A2a	2.87-3.80	5.11-6.05	3.80-5.30	4.36-6.42
B2a	2.87-3.99	2.87-3.99	3.80-3.99	2.68-4.18
	Annual precipitation scenarios for 2050, mm per day			
	HadCM3	ECHAM4, 5	CSIRO-Mk3	CGCM3
A2a	(-0.49)-0.42	(-0.09)-0.42	(-0.26)-0.08	(-0.26)-0.08
B2a	(-0.43)-0.08	(-0.09)-0.45	(-1)-1	(-0.09)-0.08
	Annual precipitation scenarios for 2080, mm per day			
	HadCM3	ECHAM4, 5	CSIRO-Mk3	CGCM3
A2a	(-0.43)-(-0.09)	(-0.26)-0.08	(-0.26)-(-0.09)	(-0.43)-(-0.09)
B2a	(-0.26)-(-0.09)	(-0.26)-0.08	(-0.26)-(-0.09)	(-0.26)-(-0.09)

demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways in future. The AOGCM scenarios have been downloaded from IPCC Data Distribution Centre (DDC) website (http://www.ipcc-data.org/).

AOGCM scenarios of the mean annual temperature and precipitation changes in Central Asia are summarized the Table 1. Annual temperature is predicted to increase in the range between 2.1 and 4.5°C by around 2050 and by 2.8 to 6.2°C by around 2080 under A2 scenarios. Under B2 scenarios the warming would range from 1.9 to 3.8°C by 2050, and from 2.8 to 4.2°C by 2080. The rates of the predicted changes significantly differ across seasons, with much higher temperature changes generally expected during the winter months in all scenarios. Under both A2 and B2 scenarios the warmest scenarios are produced by the Canadian Climate Center model and the coolest by the Hadley Center model. These also apply to the seasonal and monthly scenarios that are not presented in the table. More detailed analysis of AOGCM scenarios for Central Asia is available in Lioubimtseva (2007).

The majority of the AOGCM-generated scenarios agree that the warming will be accompanied by further increase of aridity, especially in the western part of the region. The ECHAM and CSIRO models suggest a possibility of insignificant precipitation increase over the eastern part of Central Asia (east from 70°E), while the Hadley and Canadian models suggest that the precipitation will decrease throughout the entire region, particularly in spring and summer, under all policy scenarios. The trend towards higher aridity is predicted to be more significant west from 70°E by all models. The recently published IPCC AR4 supports these findings, pointing that Central Asia, particularly its western parts, is very likely to become drier during the coming decades (Christenseen *et al.*, 2007). The magnitude of the precipitation changes, however, is far below the short-term natural variability of precipitation in this region (Table 1), so it is very likely that the temperature changes would be a more determinative factor of increasing aridity.

Overall, the AOGCM scenarios appear to be consistent with the observed temperature and precipitations trend over the past decades in most of the arid and semi-arid Central Asia. However, it is uncertain the extent to which the observed and projected trends result primarily from the global restructuring of atmospheric circulation and changes in the teleconnections controlling macroclimatic conditions versus meso-climate changes induced by regional land use change. These scenarios are based entirely on the projected changes in the global atmospheric circulation and do not incorporate the regional controls on climate. The regional climate changes caused by the degradation of the Aral Sea and Kara-Bogaz-Gol and extensive redirection of water resources to irrigated agriculture in this region are likely to continue exerting much stronger impact on the regional climate, ecosystems and land use of the Central Asian countries compared to the global trends during the next decades. Regional weather records show a significant increase of summer and annual air temperature and a decrease of winter-temperatures in the vicinity of the Aral Sea. The reduction of the sea surface area also caused a significant decrease of precipitation in this region since the 1960s and saline dust from the exposed lake bed has been implicated in climate and vegetation change, as well as health problems and economic disaster (Glantz, 1999; Middleton, 2002; Micklin, 2007).

Critical Areas of Climate Change Impact and Human Vulnerability

The projected impacts of climate change on arid and semi-arid lands are manifold and include changes in the regional hydrometeorology, increase in the interannual variability and more frequent catastrophic climate events, such as droughts and floods, intensification of the human induced desertification, reduction of biodiversity, and CO_2 fertilization effect (LeHouerou, 1996; Hamerlynk *et al.*, 2000; Lioubimtseva and Adams, 2004; Lioubimtseva, 2004, 2007; Fischlin *et al.*, 2007). These changes, in turn, are likely to have a significant impact on economic development, food and water security, quality and standards of life, and human health. Human society in Central Asia is particularly vulnerable to climate change impacts in the three following sectors: hydrology and water resources, agriculture and food security, and human health. Although they are relevant for the entire study area, the geographical distribution of these impacts and risks vary considerably at the regional and sub-national scales. Therefore, I will examine them using three regional case studies (arid areas adjacent to the Aral Sea area, semi-arid grain-growing belt Kazakhstan, and semi-arid mountainous areas of Tajikistan).

Hydrological changes in the Aral Sea area (Priaralye)

There is a growing agreement in the literature that potential impacts of the global climate change on the hydrometeorology of Central Asia will be massively overwhelmed by the regional environmental processes associated with the man-made land degradation, particularly degradation of the Aral Sea, and concerns over water quality and quantity caused by land-use and irrigation issues (Glantz, 1999, 2005; Small *et al.*, 2001; Saiko and Zonn, 2000; Middleton, 2002; Lioubimtseva *et al.*, 2005; Micklin, 2007). Water resources of Central Asia are already highly stressed and it is likely that increase of temperature and aridity projected by the global climate models would further exacerbate the existing tensions. The water crisis, however is nowhere in Central Asia is as deep as in parts of Kazakhstan and Uzbekistan surrounding the Aral Sea.

The reduction and fragmentation of the lake surface area have caused a significant decrease of precipitation and saline dust from the exposed lake bed has been implicated in rapid climate and vegetation change. A general trend towards a more continental climate has been suggested by an increase in summer and decrease in winter air temperatures at stations near the shore by 1.5-2.5°C and a decline in mean annual relative humidity of 2-3%, while the occurrence of drought days has increased by 300% (Middleton, 2002). Precipitation records also show a shift in seasonality. The Aral Sea desiccation caused significant climate change not only in the coastal area, but affected the entire system of atmospheric circulation in its basin. Summer and winter air temperatures at the stations near the sea shore increased by 1.5-2.5°C and diurnal temperatures increased by 0.5-3.3°C (Glazovsky, 1995; Chub, 2000). Near the coast the mean annual relative humidity decreased by 23% and recurrence of drought days increased by 300% (Glazovsky, 1995). The annual cycle of temperature and precipitation has also changed. A seven-fold rise in the albedo of the area previously occupied by the Aral Sea caused a three-fold increase in reflected solar radiation and increased overall continentality of the climate (Chichasov, 1990; Glazovsky, 1995). Some regional modelling scenarios suggest that rise of the air temperature in Central Asia should cause further 8-15% increase in evaporation (Chub, 2000; Miagkov, 2006).

In addition, the exposure of the former lakebed areas, especially on the eastern side of the Aral Sea, represents an enormous source of highly saline wind-blown material (up to 1.5% salt in the total mass of hard particles transported by the wind). According to Semenov (1990) the amount of aeolian redeposition from the former Aral seabed is exceeding 7.3×10^6 tons per year, comprised of between 5 and 7×10^4 tons of salt per year. Today the drying bed of the Aral Sea has become one of the biggest sources of dust aerosols in the world. Salty dust blown into the atmosphere is another important factor that needs to be considered in model simulations of both global and regional climates. Dust tends to cool the earth by reflecting sunlight back into space, and it decreases rainfall by suppressing atmospheric convection (Lioubimtseva *et al.*, 2005). This effect is not taken into account by the global models and therefore the increase of aridity in the western part of Central Asia is likely to be much higher than in most AOGCM scenarios.

For the period from 1961 to 1990, annual mean flow of Amu Darya River has decreased from 57.1 km^3 to 53.2 km^3, i.e., the annual decrease was of 0.13 km^3 (Tajikistan, 2003). As the Aral Sea states, Kazakhstan and Uzbekistan are immediately affected by the regional climate change caused by the reduction of water volume in the Aral Sea and impacts of salt and dust storms carrying particles from the former sea-bed for hundreds of kilometers around. The salinity of the Aral Sea has already reached 100-150 g L^{-1} (Small *et al.*, 2001; Aladin *et al.*, 2005; Micklin, 2007). The same processes that contributed to the Aral Sea degradation, excessive irrigation and mismanagement of water– have also resulted in the rise of groundwater table, which then became contaminated with high levels of salts and other minerals (Small *et al.*, 2001). Groundwater quality ranges in the region from a minimum of 1.5 g L^{-1} TDS (total dissolved solids) to 6 g L^{-1} TDS, which is 20 times higher than in the US (about 300 mg L^{-1}) and drinking water reaches levels of up to 3.5 g L^{-1} TDS. In Karakalpakstan (an autonomous republic of Uzbekistan adjacent to the Aral Sea) about 65% of drinking water samples tested did not meet national standards of 1 g L^{-1} TDS (AQUASTAT, 2008).

At the same time water consumption in the Central Asian countries of the former USSR has increased from 37 km^3 per year in 1950 to 102 km^3 per year in 2000 and is projected to reach 122 km^3 per year by 2025 (Shiklomanov, 2001). For the period from 1961 to 1990, annual mean flow of Amu Darya River has decreased from 57.1 km^3 to 53.2 km^3 per year, i.e., the annual decrease was of 0.13 km^3 (Tajikistan, 2003). There is a growing concern that water stress in Central Asia may lead to open water conflicts between the states and also weaken them to such an extent that they lose their capacity to address other threats to stability and development (Sievers, 2002; Glantz, 2005).

Agricultural production in semi-arid zones of Kazakhstan

Northern Kazakhstan has been playing a significant role in the regional and global grain supply for several decades. Production of spring wheat and barley in Kazakhstan strongly depends on summer precipitation, which is particularly important during the critical phases of wheat growth, such as bushing and earring (Muratova *et al.*, 2005). The second major climatic constraint for the grain production here is the temperature: high summer temperatures above 33°C can damage crops and reduce their productivity.

Climate change and increasing climate variability associated with continued emissions of greenhouse gases are likely to bring changes in grain production. The AOGCM scenarios tend to agree that summer precipitation is likely to decline all over the region and winter precipitation is projected to increase in north-eastern Kazakhstan and adjacent part of Russia (IPCC, 2001; Solomon *et al.*, 2007). Temperatures maxima are also projected to increase both in summer and in winter. Increase of the mean and maximum summer temperatures in combination with precipitation decrease potentially means more droughts and is likely to have adverse impact on agriculture of this region.

The results of modeling studies conducted by the IIASA (International

Institute for Applied Systems Analysis), however, suggest that grain production Kazakhstan will benefit from the increase in winter temperatures and a longer growing season and increase in the water-use efficiency by agricultural crops due to the CO_2 fertilization effect (Fischer *et al.*, 2002, 2005). The IIASA optimistic scenario largely reflects the assumption of the model that elevated atmospheric CO_2 would reduce the sensitivity of agricultural crops to aridity (Fischer *et al.*, 2005). However, the recent FACE (Free-Air CO_2 Enrichment) experiments suggest that the CO_2 fertilization effect might be largely overestimated in the models (Long *et al.*, 2005).

It has been well documented that extreme events are responsible for disproportionately large part of climate-related damages to agriculture and sensitivity of extremes to climate change may be greater than one would assume from simply shifting the location of the climatological distribution (Solomon, 2007). A study by Tebaldi *et al.* (2006) based on analysis of ten indicators of temperature and precipitation-related extremes computed by nine AOGCMs used in the IPCC-AR4 suggests that agricultural production in Kazakhstan and can benefit from the decrease of frosts and increase of the length of the growing season, but also will be negatively affected by the increasing variability of precipitation and number of dry days.

Agricultural productivity and food security depend on multiple environmental, social, and economic factors and reflect the sensitivities of agricultural sector not only to climate change, but also to the global market variations, country-scale political and economic changes, local policies and other factors. Analyses of economic and agricultural statistics (EBRD, 2008; OECD-FAO, 2008; World Bank, 2008) and landcover changes estimated from the satellite imagery (de Beurs and Henebry, 2004; Spivak *et al.*, 2005; Muratova *et al.*, 2005) indicate that in the near future effects of the global climate change are likely to be overwhelmed by such factors as socio-economic transformation, institutional changes, and effects of economic globalization.

Between 1988-90 and 1998-2001 the grain production in Kazakhstan fell by 35% and total grain area of Kazakhstan was contracting at the rate of nearly 2 million hectares per year during this period (Meng *et al.*, 2000). Fields that consistently failed to meet the threshold established by the government were taken out of grain production and converted to permanent pasture. However, the demand in pastures was also falling leading to a widespread undergrazing and abandonment of agricultural lands. For example, 33.9 million sheep were in stock in Kazakhstan in 1992 but by 1999 that number had dropped by 74% to 8.6 million (FAOSTAT, 2008). This land conversion trend has occurred in many semi-arid areas of the former USSR with extensive herding, not only in northern Kazakhstan.

Landcover changes caused by this drastic institutional transformation following collapse of the USSR has also been confirmed by remote sensing data. (deBeurs and Henebry, 2004, 2005; Lioubimtseva, 2007). Analysis of the NOAA AVHRR imagery indicates a "greening" trend throughout the region (measured as an increase of the Normalized Difference Vegetation Index) between 1991 and 2002, resulting from a contraction of agricultural lands, decline of pressure on rangelands, spread of mosses and weeds due to undergrazing, declining productivity and overall "deintensification" of agriculture (deBeurs and Henebry, 2005). The most recent NDVI series from MODIS suggest some increase of agricultural crop productivity in 2002-2004 (Spivak *et al.*, 2005), but given a short period of MODIS observations, it is too early to predict further trends in the agricultural sector of this region.

The massive land-use changes in semi-arid grain-growing zone of Kazakhstan and its neighbourhood are likely to have profound impact on multiple interactions between climate and the surface vegetation, including changes in albedo, evaporation, runoff, carbon fluxes, heat exchange, etc., but vegetation-climate feedbacks and their role in global and regional climate change are still relatively poorly understood. It is difficult to predict multiple feedbacks caused by land-use. On the other hand, the recent decline of agriculture caused by the general economic decline and transformation of the entire land-use system is very likely to be further exacerbated by the increasing aridity and variability of precipitation predicted by the climate models.

The recent resurgence of malaria in Tajikistan and Kyrgyzstan

Changes in the regional climate and ecosystems might both increase or reduce the risk of some infectious diseases (particularly water-borne and vector-borne infections very sensitive to mesoclimatic conditions). Temperature rise and climate variability can also increase the exposure of populations to heat stress, extreme weather events, such as droughts, dust-storms and floods, contribute to the already existing water stress, and also stress the existing institutional systems of public health (Confalonieri *et al.*, 2007).

After many decades with virtually no locally transmitted cases, epidemic malaria, including the tropical form of malaria, caused by *Plasmodium falciparum*, has returned to Uzbekistan, Kyrgyzstan, Turkmenistan, and Tajikistan in the 1990s (World Health Statistics, 2008). In 1994, the number of malaria cases reported in Tajikistan quadrupled compare to 1993 and peaked in 1997, when nearly 30,000 cases were registered (World Health Statistics, 2008). In 1996, the first case of autochthonous malaria was registered in the Panfilov district of Kyrgyzstan and since then, there has been a rise in the number of autochthonous malaria cases (Abdikarimov, 2001). In 2002, the explosive resumption of malaria transmission produced an epidemic situation with an incidence much greater than that reported in the past years in Kyrgyzstan, and a total of 2,267 autochthonous cases were reported in the south-western regions of the country, including Batken, Osh, and Jalal-Abad. The explosive resumption of malaria transmission in Kyrgyzstan started as a result of immigration of a number of infected people from Tajikistan into the Batken region where the *Anopheles* vector exists and conditions for malaria transmission are very favorable (Abdikarimov, 2001). In 2004-2005, as a result of the application of epidemic control measures, there was a significant decrease in the reported number of autochthonous malaria cases. However, in 2004 the first autochthonous case of *P. falciparum* malaria was reported in the Aravan district of the southern part of Kyrgyzstan, in an area bordering Uzbekistan, and in 2005 the number of autochthonous cases of *P. vivax* malaria increased in the outskirts of the capital city Bishkek. The resumption of *P. falciparum* cases in Tajikistan and Kyrgyzstan and the expansion of the territory in which this type of malaria is spread is a matter of particular concern. Endemic malaria has now returned to the southern part of Tajikistan (Sabatinelli, 2000). Surveys recently conducted by the WHO personnel in the southern part of Tajikistan bordering Afghanistan have shown that the presence of malaria in the Khatlon Region, with its total population of nearly 2.2 million people, may be estimated at 50,000-100,000 malaria-infected carriers (World Health Statistics, 2008).

The observed and predicted climate changes in Central Asia, such as the temperature rise, changes in climatic variability, and seasonal shifts might be responsible for creating more favorable mesoclimatic conditions for vectors and parasites. The last decade of the 20th century was marked by a series of particularly warm years. Combination of high summer temperature, extended transmission period, and abundance of mosquito breeding grounds had created particularly favorable conditions for malaria transmission in 1995, 1997, 2000, and 2003, when the summer temperatures had exceeded the average, while the levels of precipitations were relatively high. Climate change has a direct impact on mosquito reproduction, development rate and longevity, and the rate of development of a parasite, as the parasites develop in the vector within a certain temperature range, where the minimum temperature for parasite development lies between 14.5°C and 15.0°C in the case of *P. vivax* and between 16°C and 19°C for *P. falciparum* (Martens *et al.*, 1999; Razakov and Shaghunova, 2001). According to the study by Kayumov and Mahmadaliev (2002), the zone of potential malaria development in Tajikistan is likely to increase during the coming years up to an elevation of more than 2,000 meters due to the continuous temperature rise.

In addition, climate change might affect malaria transmission indirectly through such factors as changes in vegetation, agricultural practices, desertification, migration of populations from areas in which vector-borne diseases are endemic into receptive areas (Kovats *et al.*, 2001; van Lieshout, 2004). Large irrigated areas and river valleys within these mainly arid and semi-arid countries provide perfect habitats for mosquitoes. Increasing climate aridity and variability and increasing summer temperatures can increase the reliance of the local agriculture on irrigation and create the areas suitable for vector development.

Although global climate change is likely to impact the patterns of malaria transmission in this region, human factors, such as land-use practices, health care systems, institutional and political systems, economic development, wealth and equity distribution, can significantly modify these impacts.

Many non-environmental factors, such as political instability in Tajikistan and massive migrations caused by civil unrest in Afghanistan and Tajikistan, deterioration of the national health system, economic decline, reduction of the use of pesticides, and land use change have all contributed to the regional health crisis (Abdikarimov, 2001, Razakov and Shakhgunova, 2001; Small *et al.*, 2001, Dittmann *et al.*, 2000). The number of malaria cases in Central Asia has declined in the recent years as a result of governmental programs involving widespread application of insecticides, but the crisis that has recently occurred in this region clearly indicates the potential risk of the future malaria outbreaks.

Adaptation Options and Strategies

Examples examined in the previous section suggest that development of adaptation strategies to climate change is only possible if we examine the impacts of climate change in the context of many other processes, such as political and institutional changes, economic development and globalization, changes in the land-use practices and livelihoods, etc. Capacity of countries, regions, and communities to implement potentially useful adaptation strategies depend on a variety of geographic, historical, political, and economic factors. There is compelling evidence from many other parts of the world that there is a strong relationship between vulnerability to climate change and sustainable development. As the Fourth Report of the IPCC Working Group II states, "sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways" (Parry *et al.*, 2007).

During the past decade all countries of Central Asia have developed national environmental action plans that provide some assessment of vulnerability and adaptations to climate impacts and risks (State of the Environment of Turkmenistan, 2000, Kyrgyzstan State of the Environment, 2001, Tajikistan State of the Environment, 2002, State of the Environment in Kazakhstan, 2004; National Environmental Action Plan of the Republic Uzbekistan, 2001, National Action Plan of the Republic Kazakhstan for Climate Change Mitigation, 2003, National Action Plan for Climate Change Mitigation of the Republic Tajikistan, 2003). These assessments, however, are typically limited to sector-specific responses to the biophysical components to climate change, but little attention is given to socio-economic aspects of vulnerability. Factors such as social inequality, uneven access to health care and education, poverty, crisis in the land tenure system, population migrations, and ethnic conflicts are not considered by the national and local decision makers as factors of human vulnerability to climate change. Another serious problem is the lack of inter-governmental co-operation for integrating some adaptations at the macro-regional scale. Due to their common environmental, political and economic legacy, arid and semi-arid zones of post-Soviet Central Asian states have inherited multiple geographic connections and represent together a complex macro-regional system. Development of effective and realistic adaptation strategies would benefit from an integrated macro-regional approach reaching beyond the national borders, especially because adaptation measures are rarely undertaken in consideration of the impacts of climate change alone and are typically imbedded within other initiatives such as land-use planning, water resource management, drought warning, desertification control, health care programs, diversification of agriculture.

Non-climatic stresses are likely to increase vulnerability of arid and semi-arid regions of Central Asia to climate change and reduce their adaptive capacity because of resource deployment to competing needs. For example, increases in surface temperature and frequency of droughts in the Aral Sea basin, decline of precipitation and the length of the growing season due to the microclimatic changes caused by the Aral Sea degradation, soil salinization and degradation, degradation of vegetation cover, water loss due to inadequate irrigation practices, chemical runoff from agriculture, coupled with declined in living standards, malnutrition and limited access to drinking water and sanitation, health care collapse and outbreaks of many chronic and infectious diseases, and many other regional stresses would require unprecedented amount of resources to alleviate just some of them. In the context of arid climate of Central Asia short-term, unplanned reactive coping strategies aiming to address separately some of these stresses usually provide only an immediate solution for a limited areas or group of the population, but in the long-term they only exacerbate the problem. Focusing on effects, but not on the causes of the problem they can only further aggravate the ongoing adverse environmental changes in the long term. For example, there is a continuous migration of the population from Karakalpakstan, an autonomous republic within Uzbekistan, adjacent to the Aral Sea, to eastern Uzbekistan and Kazakhstan. During the first year after collapse of the USSR the estimated number of environmental migrants from the Aral Sea area was more than 100,000 people and in the recent decade the net emigration from the areas adjacent to the Aral Sea has doubled from over 3,000 to over 6,000 persons per year (Akiner, 2000; Kolb, 2003). About 10% of the working-age population of this region is leaving home to work every year (Elpiner, 2003). Many studies suggest that migration is a feasible climate adaptation strategy (Adger *et al.*, 2003; Patz *et al.*, 2005). Considering, however, that these environmental refugees are usually individuals who had the skills, opportunity, and psychological aptitude to migrate and adjust to different lifestyles in other regions or countries, there is a concern that the population left behind would have even lower capacity, skills and potential to adapt to the regional environmental crisis.

To cope with the multiple regional stresses in the context of multiple increasing stresses, both related and unrelated to climate change, it is important to consider such adaptive strategies that could place equal importance on environmental, social, and economic considerations. Development of such adaptation strategy involves inevitable trade-offs between environmental, economic, and socio-cultural and political considerations and priorities. There is a compelling evidence from around the world that development and implementation of adaptation strategies and policies are successful only when they are driven by the interests of stakeholders

– groups of individuals and communities vulnerable to the risks of climate change (Turner II *et al.*, 2003; Adger *et al.*, 2003; Schroter *et al.*, 2005; Polsky *et al.*, 2007). At the national and regional scale adaptations are usually undertaken by the governments on behalf of the entire society or particular groups, but regardless of the geographic scale, these decisions, policies and projects must be driven by the "place-based" initiatives and integrate the needs of various communities at multiple scales. Communities rarely face only one effect or risk of climate change at a time and the interaction of multiple vulnerabilities often can lead to amplification of risks (Schröter *et al.*, 2005; O'Brien *et al.*, 2000). Climate change impacts are interconnected with land-use changes, socio-economic changes, and many other processes that interact in the human-environmental system. Therefore, adaptations can be sustainable only if they target multiple processes and risks in the integrated manner, reaching across various aspects of human life (food security, water resources, health, quality of life, etc.) at multiple geographic and temporal scales. For example, reduction of cotton monoculture in Turkmenistan and Uzbekistan, diversification of crops, and application of no-tillage techniques in agriculture could not only help to increase food security but also would decrease the use of water, improve soils through the nitrogen fixation in soil, and at the same time would be useful as a climate change mitigation measure (carbon sequestration). The renovation of the existing irrigation network, and introduction of more advanced irrigation techniques, such as drip irrigation could significantly reduce the loss of water resources, but also would improve crop productivity, reduce the soil losses due to salinization, and help to reduce the risks of water contamination and transmission of many vector-borne and water-borne diseases.

Conclusions

Arid and semi-arid zone of Central Asia represent an area with diverse and overlapping environmental, social and economic stresses. The well-being and security of this vast region depends on interplay of several groups of internal and external factors, such as institutional changes (agricultural reforms, management practices, policies, legislation, etc.) and the subsequent regional land-use changes, climate variability and change, and globalization of economy.

Central Asia is projected to become warmer and probably drier during the coming decades. Aridity is expected to increase across the entire region, but especially in the western part of Turkmenistan, Uzbekistan, and Kazakhstan. The temperature increases are predicted to be particularly high in summer and fall, but lower in winter. Especially significant decrease in precipitation is predicted in summer and fall, while a modest increase or no change in precipitation is expected in winter months, particularly in the eastern part of Kazakhstan and in adjacent Kyrgyzstan and Tajikistan. These seasonal climatic shifts are likely to have profound implications for agriculture when some parts of the region can be winners (cereal production in northern and eastern Kazakhstan can benefit from the longer growing season, warmer winters and slight increase in winter precipitation), while others can be losers (particularly western Turkmenistan and Uzbekistan, where frequent droughts will negatively affect cotton production, increase already extremely high water demands for irrigation, and exacerbate the already existing water crisis and human-induced desertification). The recent and ongoing severe drought, particularly during 2001-2003, has already resulted in multiple water disputes and increased tensions among the states of the Aral Sea basin. Knowing that the aridity and water stress are likely to increase, new political and economic mechanisms are necessary to ease such tensions in future.

The ability of this western subregion of Central Asia to adapt to hotter and drier climate is limited by the already existing water stress and the regional land degradation and poor irrigation practices. Central Asia inherited many environmental problems from the Soviet times, but many years after independence, the key land and water-use related problems remain the same. Deintensification of agriculture after independence, documented by agricultural statistics, was significant enough to produce a signal in the temporal series of remote sensing data, but its impact on vegetation and boundary layer of the atmosphere are still unknowm. Agricultural transformation had extremely high social cost but to date agricultural reforms and transition to market remain problematic in most of the region. Increasing rural poverty and unemployment, particularly among females, growing economic inequality, and shortage of adequate living conditions, medical care and water management infrastructure have significantly increased human vulnerability of the majority of population in the region.

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References

Abdikarimov, S.T. 2001. Current epidemiological malaria situation in Kyrgyzstan (1995-1999). *Medizinskaya Parazitologia* 1: 33-40.

Adger, W.N. 2006. Vulnerability. *Global Environmental Change* 16(3): 268.

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and Takahaashi, K. 2007. *Assessment of Adaptation Practices, Options, Constraints and Capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC,* (Eds. M.L. Parry, O.F.Canziani, J.P.Palutikof, P.J. van der Linden and C.E. Hanson), pp. 717-743. Cambridge University Press, Cambridge, UK.

Adger, W.N., Huq, S., Brown, K., Conwaya, D. and Hulme, M. 2003. Adaptation to climate change in the developing world. *Progress in Development Studies* 3(3): 179-195.

Adger, W.N. and Kelly, P.M. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change* 4 (3/4): 253-266.

Akiner, S. 2000. Central Asia: *A Survey of the Region and the Five Republics. UNHCR Centre* *for Documentation and Research*, WRITENET Paper No.22/1999, United Nations High Commissioner for Refugees, Geneva, 50 p.

Aladin, N., Cretaux, J.F., Plotnikov, I.S., Kouraev, A.V., Smurov, A.O., Cazenave, A., Egorov, A.N. and Papa, F. 2005. Modern hydro-biological state of the Small Aral sea. *Environmetrics* 16 :375-392.

AQUASTAT 2008. Food and Agriculture Organization, http://www.fao.org/nr/water/aquastat/main/index.stm, last access September 2008.

Bohle, H.G., Downing, T.E. and Watts, M.J. 1994. Climate change and social vulnerability. Toward a sociology and geography of food insecurity. *Global Environmental Change* 4(1): 37-48.

Bryant, C.R., Smit, B., Brklacich, M., Johnston, T.R., Smithers, J., Chiotti, Q. and Singh, B. 2000. Adaptation in Canadian agriculture to climatic variability and change. *Climatic Change* 45(1): 181-201.

Burton, I. 1997. Vulnerability and adaptive response in the context of climate and climate change. *Climate Change* 36: 185-196.

Chichasov G.N. (editor) 1990. *Hydrometeorological problems of the Aral Sea area* (Gidrometeorologicheskije Problemi Priaralya). Gidrometeoizdat, Leningrad, 274 p. (in Russian)

Christenseen, J.H., Hewtson, B., Busioc, A., Chen, A., Held, J., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T. Lapriee, R., Magana Rueda, V., Meame, L., Menendez, C.G., Raleanen, J., Rinke, A., Sarr, A. and Whetton, P. 2007. *Regional Climate Projections, In: Climate Change 2007: The physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, and H.L. Miller), pp. 849-940. Cambridge University Pres, Cambridge, UK and New York, NY, USA.

Confalonieri, U., Menne, B., Akhtar, R., Ebi, K.L., Hauengue, M., Kovats, R.S., Revich, B. and Woodward, A. 2007. Human health. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* (Eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson), pp. 391-431. Cambridge University Press, Cambridge, UK.

Committee on Global Change Research, National Research Council, 1999. *Global Environmental Change: Research Pathways for the Next Decades.* The National Academic Press, 616 p.

Chub, V.E. 2000. *Climate Change and its Impact on the Natural Resources Potential of the Republic of Uzbekistan* (Izmenenija klimata I ego vlijanije na prirodno-resursnij potensial respubliki Uzbekistan), Gimet, Tashkent, 253 p. (in Russian)

Cowan, P.J. 2007. Geographic usage of the terms Middle Asia and Central Asia. *Journal of Arid Environments* 62(2): 359-363.

de Beurs, K.M. and Henebry, G.M. 2004. Land surface phenology, climatic variation, and institutional change: Analyzing agricultural land cover change in Kazakhstan. *Remote Sensing of Environment* 89: 497-509.

de Beurs, K.M. and Henebry, G.M. 2005. A statistical framework for the analysis of long image time series. *International Journal of Remote Sensing* 26(8): 1551-1573.

Dittmann S., Wharton, M., Vitek, C., Ciotti, M., Galazka, A., Guichard, S., Hardy, I., Kartoglu, U., Koyama, S., Kreysler, J., Martin, B., Mercer, D., Ronne, T., Roure, C., Steinglass, R., Strebel, P., Sutter, R. and Trostle, M.2000. Successful control of epidemic diphtheria in the states of the Former Union of Soviet Socialist Republics: lessons learned. *The Journal of Infectious Diseases*, 181:S10-S22.

Downing, T.E. (Ed.) 1996. Climate Change and World Food Security. Springer-Verlag, Berlin, Germany, pp. 662.

Downing T., Patwardhan, A., Klien, R., Mukhala, E., Stephen, L.,Winograd, M., Ziervogel, G. 2005. Vulnerability assessment for climate adaptation, Chapter 3 in Lim B. and E. Spanger-Siegfired (Editors), *Adaptation Policy Framework for Climate Change: Developing Strategies, Policies and Measures,* UNDP and GEF, Cambridge University Press: Cambridge, UK.

European Bank for Reconstruction and Development, 2008. Grain production and export potential in CIS countries. In *Fighting Food Inflation* *through Sustainable Investment*. London, March 10, 2008.

Elpiner, L.I. 2003. A scenario of possible effect of changes in the hydrological conditions on the medical and environmental situation: on the problem of global hydroclimatic changes. *Water Resources* 30(4): 434-444.

FAOSTAT 2008. Faostat.fao.org. Last access September 2008.

Fisher, G., Shah, M. and van Velthuizen, H. 2002. *Climate Change and Agricultural Vulnerability*. International Institute for Applied Systems Analysis, Vienna, 152 p.

Fischer, G.M., Shah, M., Tubiello, F.N. and van Velhuizen, H. 2005. Socio-economic and climate change impact on agriculture: an integrated assessment, 1990-2080. *Philosophical Transactions of Royal Society* B 360, 2067-2083.

Fischlin, A., Midgley, G.F., Price, J.T., Leemans, R., Gopal, B., Turley, C., Rounsevell, M.D.A., Dube, O.P., Tarazona, J. and Velichko, A.A. 2007. Ecosystems, their properties, goods, and services. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson), pp. 211-272. Cambridge University Press, Cambridge.

Folke, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16: 253-267

Füssel, H.M. 2007. Vulnerability: A general applicable conceptual framework for climate change research. *Global Environmental Change* 17(2): 155-167.

Füssel, H.M. and Klein, R.J.T. 2006. Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic Change* 75(3): 301-329.

Gallopin, G. 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change* 16: 293-303.

Glantz, M.H. (Ed.) 1999. *Creeping Environmental problems and Sustainable Development in the Aral Sea Basin*. Cambridge University Press, Cambridge, UK.

Glantz, M.H. 2005. Water, climate, and development issues in the Amu Darya basin. *Mitigation and Adaptation Strategies for Global Change* 10(1): 1381-2386.

Glazovsky, N.F. 1995. The Aral Sea basin. In: *Regions at risk: comparisons of threatened environments.* (Eds. J.X. Kasperson, R.E. Kasperson and B.L. Turner II), pp. 92-139. United Nations University Press, on-line edition, Tokyo, New York, Paris

Hamerlynck, E.P., Huxman, T.E., Nowak, R.S., Redar, S., Loik, M.E., Jordan, D.N., Zitzer, S.F., Coleman, J.S., Seeman, J.R. and Smith, S.D. 2000. Photosynthetic responses of Larrea tridentata to a step-increase in atmospheric CO_2 at the Nevada Desert FACE Facility. *Journal of Arid Environments* 44: 425-436.

Handmer, J.W., Dovers, S. and Downing, T.E. 1999. Societal vulnerability to climate change and variability. *Mitigation and Adaptation Strategies for Global Climate Change* 4: 2677-281.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1-23.

IFAS/UNEP, 2000. *State of Environment of the Aral Sea Basin. Regional report of the Central Asian States.* International Fund on the Aral Sea and United Nations Environmental Program, Bishkek, http://enrin.grida.no/aral/aralsea/index.htm (last access September 2008).

IPCC 2001. *Climate Change: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Eds. J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu), Cambridge University Press, UK. pp 944

IPCC Data Distribution Center, http://www.ipcc-data.org/,last access September 2007.

IPCC 2007. Climate Change 2007: Mitigation, *Contribution of Working Group III to the Fourth Assessment Report of the IPCC* (Eds. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meye), Cambridge University Press, Cambridge, UK and New York, NY, USA.

Janssen, M.A., Michael, L., Schoon, Weimao, Ke, and Katy, Börner 2006. Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. *Global Environmental Change* 16: 240-252.

Kasperson, J.X. and Kasperson, R.E. 2005. *The Social Contours of Risk.* Earthscan, London, 578 pages.

Kayumov, A.K. and Mahmadaliev, B.U. 2002. *Climate Change and its Impacts on Climate Change.* Avesto, Dushanbe, 174 p. (in Russian)

Kelly, P.M. and Adger, W.N. 2000. Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation. *Climate Change* 47: 325-352.

Kolb, A. 2003. An ominous flip side: population dynamics in an environmental disaster zone. *A Population, Environmental Change, and Security Newsletter* 8: 6-9.

Kovats, R.S., Campbell-Lendrum, D.H., McMichael, A.J., Woodward, A. and St H. Cox, J. 2001. Early effects of climate change: Do they include changes in vector-borne disease? *Philosophical Transactions of the Royal Society* 356:1057-1068.

Kyrgyzstan State of the Environment 2001. National Report of the Ministry of Environmental Protection, Bishkek, Kyrgyzstan, 157 pages (in Russian)

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.l B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Steffen, W., Stone, G. D., Svedin, U., Veldkamp, T. A., Vogel, C. and Xu, J. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11: 261-269.

Le, Houerou 1996. Climate change, drought and desertification *Journal of Arid Environments* 34(2): 133-185.

Leichenko, R.M. and O'Brien, K.L. 2002. The dynamics of rural vulnerability to global change: the case of southern Africa. *Mitigation and Adaptation Strategies for Global Climate Change* 7: 1-18.

Lioubimtseva, E. 2002. Arid environments. In *Physical Geography of Northern Eurasia* (Ed. M. Shahgedanova), pp. 267-283. Oxford University Press, Oxford, 571 p.

Lioubimtseva, E. 2004. Climate change in arid environments: Revisiting the past to understand the future. *Progress in Physical Geography* 28(4): 502-530.

Lioubimtseva, E. 2005. Environmental changes in arid Central Asia inferred from remote sensing data and ground observations. *Arid Ecosystems* 11(26-27): 64-72.

Lioubimtseva, E. 2007. Possible changes in the carbon budget of arid and semi-arid central Asia inferred from landuse/landcover analyses during 1981 to 2001. In *Climate Change and Terrestrial Carbon Sequestration* (Eds. R. Lal, M. Suleimenov, B.A. Stewart, D.O. Hanson and P. Doraiswamy), pp. 441-452. Central Asia, New York: Taylor and Francis.

Lioubimtseva, E. and Adams, J.M. 2004. Possible implications of increased carbon dioxide levels and climate change for desert ecosystems. *Environmental Management* 33(4): S388-S404.

Lioubimtseva, E., Cole, R., Adams, J.M. and Kapustin, G. 2005. Impacts of climate and land-cover changes in arid lands of Central Asia. *Journal of Arid Environments* 62(2): 285-308.

Liverman, D. 1990. Drought Impacts in Mexico: Climate, Agriculture, Technology, and Land Tenure in Sonora and Puebla. *Annals of the Association of American Geographers* 80(1): 49-72.

Liverman, D., Moran, E.F., Rinfuss, R.R. and Stern, P.C. (Eds.) 1998. People and Pixels: Linking Remote Sensing and Social Science. DC National Academy Press, Washington.

Long, S.P., Ainsworth, E.A., Leakey, A.D.B. and Morgan, P.B. 2005. Global food insecurity. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields. *Philosphical Transactions Royal Society* 360: 2011-2020.

Martens, P., Kovats, R.S., Nijhof, S., de Vries, P., Livermore, M.T.J., Bradley, D.J., Cox, J. and McMichael, A.J. 1999. Climate change and future population at risk of malaria. *Global Environmental Change* 9S: 89-S107.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. 2001. *Climate Change 2001: Impacts, Adaptations, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPCC.* Cambridge University Press, Cambridge, UK.

Meng, E., Longmire, Jim and Moldashev, Al. 2000. Kazakhstan's wheat system: Priorities, constraints, and future prospects. *Food Policy* 25(6): 701-717.

Merzlyakova, I. 2002. The mountains of Central Asia and Kazakhstan. In *The Physical Geography of Northern Eurasia* (Ed. M. Shahgedanova), pp. 377-402. Oxford University Press, Oxford.

Metzger, M.J. and Schröter, D. 2006. Towards a spatially explicit and quantitative vulnerability assessment of environmental change in Europe. Regional *Environmental Change* 6 (4): 201-216.

Miagkov, S. 2006. Climate change impact on the river runoff in Central Asia: risks of water management. *Proceedings of Asia Capacity Building Workshop Earth Observation in the Service of Water Management*, 26-28th September 2006, Bangkok, Thailand.

Micklin, P.P. 1991. The water management crisis in Soviet Central Asia. The Carl Beck Papers in Russian and East European Studies No. 905. University of Pittsburg, Center for Russian and East European Studies. 124 pp.

Micklin, P.P. 2007. The Aral Sea disaster. *Annual Review of Earth and Planetary Sciences*, 35:47-72. DOI:10.1146/annurev.earth.35.031306.140120.

Middleton, N.J. 2002. The Aral Sea. In *Physical Geography of Northern Eurasia* (Ed. M. Shangedanova), pp. 497-510. Oxford University Press, Oxford.

Moss, R.H., Brenkert, A.L. and Malone, E.L. 2001. *Vulnerability to Climate Change. A Quantitative Approach.* Pacific Northwest National Laboratory and US Department of energy, Springfield, VA, 70 p.

Muratova, N., Terekhov, A. and Mamykina, S. 2005. Spring Wheat Quality Estimation in Northern Kazakhstan using MODIS, IEEE, 0-7803-9050-4/05

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N. and Dadi , Z. 2000. *IPCC Special Report on Emissions Scenarios*, IPCC Special Reports, Cambridge University press, Cambridge, 599 p.

National Action Plan for Climate Change Mitigation 2003. Ministry for Nature Protection of the Republic Tajikistan, Dushanbe (in Russian).

National Action Plan of the Republic Kazakhstan for Climate Change Mitigation 2003. The main Administration for Hydrometeorology, Republic of Kazakhstan (in Russian), 53 pages.

National Environmental Action Plan of the Republic Uzbekistan 2001. Ministry of Environmental protection, Tashkent (in Russian), 190 pages.

Neronov, V.V. 1997. Landshaftnije osobennosti vekovih izmenenij uvlaznennosti v yugo-vostochnom Turkmenistane (Landscape features of century changes in wetting of south-eastern Turkmenistan), *Arid Ecosystems* 3(6-7): 141-150.

O'Brien, K.L., Sygna, L. and Haugen, J.E. 2004. Resilient of vulnerable? A multi-scale assessment of climate impacts and vulnerability in Norway. *Climatic Change* 64: 193-225.

OECD-FAO 2008. OECD-FAO Agricultural Outlook 2008-2017. OECD-FAO, OECD Publications, Paris July 2008.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge University Press.

Parry, M.L., Arnell, N.W., Hulme, M., Martens, P., Nicholls, R.J. and White, A., 1999. The global impact of climate change: A new assessment. *Global Environmental Change* 9: S1-S2.

Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J. and Hansen, C.E. (Eds.) 2007. Climate Change 2007: *Impacts, Adaptations and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC*, Cambridge University Press, Cambridge, 1000 pages.

Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, V. and Fischer, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14: 53-67.

Patz, J.A. 2001. Public Health Risk Assessment Linked to Climatic and Ecological Change. *Human and Ecological Risk Assessment* 7(5): 1317-1327.

Patz, J.A., Campbell-Lendrum, D., Holloway, T. and Foley, J.A. 2005. Impact of regional climate change on human health. *Nature* 438(17): 310-317.

Pielke Sr., R.A., Adegoke, J., Beltran-Przeukurat, A., Hiemstra, C., Lin, J., Nair, U.S., Niyogi, D. and Nobis, T.E. 2007. An overview of regional land-use and land-cover impacts on rainfall. *Tellus* DOI: 10.1111/j.1600-0889.2007.00251.x.

Polsky, C., Neff, R. and Yarnal, B. 2007. Building comparable global change assessments: The vulnerability scoping diagram. *Global Environmental Change* 17(3-4): 472-485.

Ramankutty, N., Delire, C. and Snyder, P. 2006. Feedbacks between agriculture and climate: An illustration of the potential unintended consequences of human land use activities. *Global and Planetary Change* 54 (1-2): 79-93.

Razakov Sh. A. and Sh. Shakhgunova, G. 2001. Current malaria situation in the Republic of Uzbekistan. *Medizinskaya Parazitologia* 1: 39-41 (in Russian).

Rosenzweig, C. and Parry, M. 1994. Potential impacts of climate change on World agriculture. *Nature* 367: 133.

Sabatinelli, G. 2000. The malaria situation in the WHO European region. *Medizinskaya Parazitologia* 2: 4-8.

Saiko, T. and Zonn, I. 2000. Irrigation expansion and dynamics of desertification in the Circum-Aral region of Central Asia, *Geographical Magazine* 20(4): 349-367.

Schröter, C. Polsky and A. G.Patt, 2005. Assessing vulnerability to the effects of global climate change: an eight step approach. Mitigation *and Adaptation Strategies for Global Change* 10: 573-596

Shiklomanov, I.A. and Rodda, J.C. (Eds.) 2001. *World Water Resources at the Beginning of the Twenty-First Century*, Cambridge University press, Cambridge, UK, 449 p.

Sievers, E.W. 2003. *The Post-Soviet Decline of Central Asia: Sustainable Development and Comprehensive Capital*. Taylor & Francis: London, New York, 264 p.

Small, E., Giorgi, F. and Sloan, 1999. Regional climate model simulation of precipitation in central Asia: Mean and interannual variability. *Journal of Geophysical Research* 104: 6563-6582.

Small, I., van der Meer, J. and Upshur, R.E.G. 2001. Acting on an environmental disaster: the case of the Aral Sea. *Environmental Health Perspectives* 109(6): 547-549.

Smit, B., Pilifosova, O., Burton, I., Challenger, B., Huq, S., Klein, R.J.T. and Yohe, G. 2001. Adaptation to climate change in the context of sustainable development and equity. In *Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the IPCC* (Eds. J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White), pp. 877-912. University Press, Cambridge, Cambridge.

Smit, B. and Wandel, J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(2006): 282-292.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averit, K.B., Tingor, M. and Miller, H. L. 2007. *The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the IPCC*, Cambridge University Press, Cambridge, 1000 p.

Spivak, L.F., Archipkin, O.P., Vitkovskaya, I.S. and Sagatdinova, G.N. 2005. Land use space monitoring in Kazakhstan. *IEEE International Geoscience and Remote Sensing Symposium (IGARSS '05)* 4: 2398-2401.

State of the Environment in Kazakhstan 2004. Ministry of the Environment of Kazakhstan (in Russian), http://www.nature.kz/obsuzhdenie/national_doklad/doklad_2.htm, last access September 2008.

State of the Environment of Turkmenistan 2000. The Ministry of Environment, Republic of Turkmenistan, UNEP/GRID http://enrin.grida.no/htmls/turkmen/soe2/index.htm, last access September 2008.

Tajikistan. National Action Plan for Climate Change Mitigation 2003. Ministry for Nature Protection of the Republic Tajikistan, Dushanbe http://unfccc.int/resource/docs/nap/tainap01e.pdf last access October 2008.

Tajikistan State of the Environment, 2002. Research Laboratory for Nature protection for UNEP/GRID-Arendale, http://enrin.grida.no/htmls/tadjik/soe2001/eng/, last access November 2007.

Tebaldi, C., Hayhoe, K., Arblaster, J.M. and Meehl, G.A. 2006. Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. *Climatic Change* 79: 185-211.

Turner, II, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T. and Meyer, W.B. (Eds.) 1990. *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 years*. Cambridge University Press, Amsterdam.

Turner II, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J. X. Luers, A., Martello, M.L., Polsky, C., Pulsipher, A. and Schiller, A. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America* 100(14): 8074-8079.

UNEP 1992. World Atlas of Desertification (Eds. N. Middleton and D. Thomas). Edward Arnold for the United Nations Environmental Program, London, 69 pp.

van Lieshout, M., Kovats, R.S., Livermore, M.T.J. and Martens, P. 2004. Climate change and malaria: Analysis of the SRES climate and socio-economic scenarios. *Global Environmental Change* 14: 87-99.

Varuschenko S.I., Varuschenko, A.N. and Klige, R.K. 1987. Izmenenija rezima Kaspijskogo morja i besstochnih vodoemov v paleovremeni (Variations of the Caspian sea regime and of closed lakes in palaeotimes). Moscow: Nauka, 239 pp. (in Russian).

World Bank 2008. *The World Development Indicators*. The World Bank Publications.

World Health Statistics 2008. Computerized Information System for infectious Diseases (CISID), http://data.euro.who.int/cisid/, last access September 2008.

Yohe, G. 2000. Assessing the role of adaptation in evaluating vulnerability to climate change. *Climate Change* 46: 371-390.