Climate Change and Terrestrial Carbon Sequestration in Central Asia

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CHAPTER 9

Soil and environmental degradation in Central Asia

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1 INTRODUCTION

Five countries in Central Asia have a total land area of about 400 million hectare (Mha), population of about 60 million, arable land area of 32.6 Mha, and average per capita arable land area of 0.55 ha (Table 1). The population growth rate ranges from 1.2% yr^{-1} to 3.0% yr^{-1} of the total land area of 400 Mha, about 148 Mha or 37.0% is desert (Table 2). Desert area, as a percent of total land area, is 27.5% in Kazakhstan, 35.4% in Kyrgyzstan 17.5% in Tajikistan, 79.3% in Turkmenistan and 55.7% in Uzbekistan.

Despite the low population, Central Asia is an important region historically, strategically and environmentally. Historically, the region comprises ancient civilization which strongly influenced South Asia and Southwestern Europe. Being on a silk route, the region was the trade link between China and Middle East and Europe. As newly independent states, all five countries are strategically important in global economy, especially for trading carbon (C) credits. Environmentally, the region can be a major terrestrial sink for sequestering atmospheric CO_2 in trees and soil thereby off-setting

Table 1. Land resources and population of Central Asia (World Bank, 2000; FAO, 2004).

Country	Total area (Mha)	Arable land (Mha)	Total population (10^6)	Per capita arable land (ha)
Kazakhstan	272.5	24.0	16.8	1.43
Kyrgyzstan	20.0	1.4	5.2	0.27
Tajikistan	14.3	0.8	6.2	0.13
Turkmenistan	48.8	1.4	5.2	0.27
Uzbekistan	44.7	5.0	26.1	0.19
Total	400.3	32.6	59.5	0.55

Table 2. Land area covered by deserts in Central Asia (Adapted from Jumashov, 1999).

Country	Desert area (Mha)	% of total area
Kazakhstan	74.7	27.5
Kyrgyzstan	7.0	35.4
Tajikistan	2.5	17.5
Turkmenistan	38.7	79.3
Uzbekistan	25.0	55.7
Total	147.9	37.0

Table 3. Land use in Central Asia (FAO, 2004).

Country	Agricultural land	Cropland	Rangeland	Forest	Other land	Irrigated land
	Mha					
Kazakhstan	206.6	21.5	185.1	9.6	35.7	2.35
Kyrgyzstan	10.7	1.3	9.4	0.7	3.0	1.10
Tajikistan	4.1	0.4	3.2	0.5	9.1	0.72
Turkmenistan	32.6	1.9	30.7	4.0	11.5	1.80
Uzbekistan	26.7	4.5	22.2	1.3	14.8	4.28
Total	280.7	30.1	250.6	16.1	79.1	10.35

Table 4. Land area under irrigation (Adapted from Babaev and Zonn, 1999; Macklin, 2000; Glantz, 2000).

Country	1950	1960	1965	1970	1975	1980	1985	1986	1995
	Mha								
Kazakhstan	–	–	–	–	–	–	–	–	0.76
Kyrgyzstan	–	–	–	–	–	–	–	–	0.46
Tajikistan	2.28	2.57	2.64	2.75	3.00	3.53	3.91	4.17	4.28
Turkmenistan	0.36	0.43	0.44	0.52	0.57	0.63	0.66	0.70	0.72
Uzbekistan	0.45	0.50	0.51	0.67	0.86	0.96	1.16	1.35	1.74
Total	3.09	3.50	3.59	3.94	4.43	5.12	5.73	6.22	7.94

the industrial emission. In addition, degradation of the Aral Sea and its Basin has been a major concern which must be addressed.

Human–induced soil and environmental degradation are widespread problems in the region. These problems are exacerbated by the predominantly arid climate of the region. The climatic aridity, characterized by low precipitation and high evaporative demand, reduces ecological resilience and renders soils and ecosystems highly prone to degradation. Thus, the objective of this chapter is to discuss predominant land uses, and the impact of land use and soil/water/vegetation management practices on the extent and severity of soil and environmental degradation in Central Asia.

2 LAND USE

Agricultural lands, comprising cropland and rangeland, are the predominant land use covering 281 Mha or 70% of the total land area (Table 3). Being an arid climate, rangelands occupy 63% of the land area compared with only 7% under cropland. Of the 30.1 Mha of cropland, 10.3 Mha or 34.0% is irrigated. Forested area is only 16.1 Mha or 4.0% of the total land area.

Land area under irrigation expanded drastically between 1950 and 1990. The increase in irrigated land area between 1950 and 1986 occurred from 2.3 Mha to 4.2 Mha (83% increase) in Uzbekistan, 0.36 Mha to 0.70 Mha (94% increase) in Tajikistan, and from 0.45 Mha to 1.35 Mha (300% increase) in Turkmenistan (Table 4). This rapid increase in irrigation strongly affected the water balance of the region, especially that of the Aral Sea and the two rivers feeding it: Amu Darya and Syr Darya.

3 THE ARAL SEA

Prior to the implementation of large scale irrigation schemes by the Soviet authorities during the 1950's and 1960's, the Aral Sea was the World's fourth largest lake with a surface area of 6.7 Mha,

Table 5. Temporal changes in the Aral Sea over a 40 year period from 1960 to 2000 (Adapted from Macklin and Williams, 1996; Micklin, 2000).

Year	Level (m)	Area (Mha)	Volume (Km^3)	Salinity g l^{-1}
1960	53.4	6.70	1090	10
1991	51.1	6.02	925	11
1976	48.3	5.57	763	14
1989				
(i) Large lake	39.4	3.69	341	30
(ii) Small lake	40.2	0.28	23	30
1994				
(i) Large lake	36.8	2.89	298	35
(ii) Small lake	40.8	0.31	273	25
2000				
(i) Large lake	33.4	2.18	186	60
(ii) Small lake	41.6	0.34	26	20
2010				
(i) Large lake	30.9	1.84	128	>60
(ii) Small lake	42.6	0.35	29	15–20

Table 6. Water use for agricultural production in Amu Darya and Syr Darya Basins during the late 1980s (Adapted from Tsutsu, 1991).

	Water use (%)	
Crop	Amu Darya ($44.8\,km^3$)	Syr Darya ($33.6\,km^3$)
Cotton	51.5	34.2
Fodder	18.5	28.7
Rice	12.1	18.6
Orchard	4.3	6.0
Vineyard	2.8	1.9
Maize	2.2	4.0
Wheat	3.0	2.5
Potatoes	0.8	0.9
Vegetables	2.4	2.3
Melons	1.6	0.8
Other cereals	0.8	1.0

water level of 53.4 m, total volume of 1090 $Km^3$from the Amu Darya and 37–40 Km^3 from the Syr Darya (Center for International Projects, 1991; Micklin, 1994; Tanton and Heaven, 1999). Developments of hydropower generation and irrigation schemes in early 1960's, increased the irrigation area in the Basin from 3.5 Mha in 1960 to 6.2 Mha in 1986 (Table 4) and to 7.5 Mha by 1994 (Tanton and Heaven, 1999; TACIS, 1995). Between 1950 and 1986, the irrigated land area increased from 2.28 Mha to 4.17 Mha in Uzbekistan, 0.36 Mha to 0.70 Mha in Tajikistan, and 0.45 Mha to 1.35 Mha in Turkmenistan. Consequently, the Aral Sea progressively shrunk (Table 5) with strong adverse environmental impacts. The large irrigation canal built under the project was the Karakum Canal: a 1,100 km long canal completed in 1965. A large fraction of the total flow of Amu Darya and Sry Darya was used for the production of cotton, fodder and rice (Table 6). With increase in irrigation, land area under cotton production increased by 122% in Uzbekistan, 196% in Tajikistan and 330% in Turkmenistan (Table 7). The unlined irrigation canal caused severe seepage losses through highly permeable desert sand, with the overall water use efficiency of about 30%.

Table 7. Temporal changes in land area under cotton production in Central Asian countries (Adapted from Critchlow, 1991).

Country	1940	1971–75	1976–80	1981–85	1985	1986	Increase from 1940–86 (%)
	Mha						
Tajikistan	0.11	0.26	0.30	0.31	0.31	0.31	182
Turkmenistan	0.15	0.44	0.50	0.53	0.56	0.65	330
Uzbekistan	0.92	1.72	1.82	1.93	1.99	2.05	122
Total	1.18	2.42	2.62	2.77	2.86	3.01	155

Table 8. The extent of salinization of irrigated land in Central Asia (Adapted from Pankova and Solovjev, 1995).

Country	Irrigated land (Mha)	Saline soils (Mha)
Kyrgyzstan	1.0	0.1
Tadijkstan	0.7	0.1
Turkmenistan	1.2	1.1
Uzbekistan	4.1	2.1
Total	7.0	3.4

Table 9. Salt affected soils in Central Asia (Adapted from Essenov and Redgephaev, 1999 and Funakawa et al., 2000).

Country	Salt affected soils (Mha)
Kazakhstan	1.40
Kyrgyzstan	0.01
Tajikistan	0.12
Turkmenistan	1.09
Uzbekistan	2.13
Total	4.75

Because of the diversion of flow, the annual inflow into the Aral Sea decreased to 7 km^3 yr^{-1}. By 1996, the Aral Sea had become saline and devoid of fish. The shrinkage and drying of Aral Sea led to the drying of extensive marginal swamp ponds and flood plains of the deltas, decline in domestic water supply of towns in the region, and the loss of agronomic productivity due to salinization of croplands, and a drastic decline in biodiversity (Frederick, 1991; Glantz, 2000).

4 SOIL SALINIZATION

With increase in area under irrigation, there has also been a problem of secondary salinization of irrigated cropland. Of the total irrigated land use of 7.0 Mha, almost half (3.4 Mha) had been salinized by mid 1990's (Table 8). The problem of salinization is especially severe in Turkmenistan and Uzbekistan where 92% and 51% of the irrigated land, respectively, had been salinized by 1995 (Pankova and Salovjev, 1995, Table 8). Along with 1.4 Mha of salt affected soils in Kazakhstan, total area of salt affected soil in Central Asia is 4.75 Mha (Table 9) or 68% of the total irrigated land area of 7.0 Mha. Salinization of the irrigated land in the Aral Sea Basin is rather high both

Table 10. The extent and severity at desertification in the Aral Sea Basin (Modified from Babaev and Muradov, 1999).

Degradation process	Total degraded area (Mha)	Degraded area as % total area
Vegetation degradation	108	77
Sand deflation	2	2
Water erosion	8	6
Salinization of irrigated land	13	9
Salinization due to shrinkage of sea	5	3
Desertification	3	2
Water logging	1	1
Total	140	100

Table 11. Estimates of desertification in Central Asia (Modified from Dregne and Chou, 1992).

Severity	Irrigated land	Rainfed cropland	Rangeland
	Mha		
Slight	10	29	130
Moderate	9	21	160
Severe	1	4	135
Very severe	0.2	–	5
Total area	20	54	430
% Desertified	51	45	70

due to secondary salinization and shrinkage of the Sea which has been source of salt through wind transport to the adjacent land (Table 10).

5 SOIL DEGRADATION AND DESERTIFICATION

Water mismanagement, excessive irrigation and monocropping caused severe problems of soil and environmental degradation, especially, in the Aral Sea Basin. Water logging and soil salinization affected 2.8 Mha of land area in the Aral Sea Basin. In addition, vast areas were affected by development of salt pans from irrigation seepage water especially in shallow depressions. Salt/dust storms arising from the exposed sea bed adversely affected soil and vegetation of the adjacent areas, leading to destruction/desertification of the ecosystems. The problem was exacerbated by degradation of the deltas of Amu Darya and Syr Darya by severe diminution of their flow (Frederice, 1991). The data in Table 10 show the extent and severity of soil and vegetation degradation.

Desertification of soil and vegetation are severe problems throughout Central Asia (Table 11). Dregne and Chou (1992) estimated that land area prone to desertification in Central Asia comprises 51% of irrigated land, 45% of the rainfed cropland and 70% of the range land. Soil and environmental degradation were caused by poor water management, and collapsing irrigation systems especially in the Karakum Canal. The causative factors are complex and driven by the interactive effects of biophysical, socio-economic and political drivers. Uncontrolled and excessive grazing were responsible for degradation of range lands. Vladychensky et al. (1995) observed that soils of the grazed pasture in Kyrgyzstan were severely degraded.

6 SOIL ORGANIC CARBON POOL

In general, soils of the arid and semi-arid regions have low soil organic carbon (SOC) pool. The SOC pool is depleted by land misuse and soil mismanagement, including practices such as excessive grazing, plowing, and residue removal. In Kyrgyzstan, Vladychensky et al. (1995) assessed the impact of grazing on the SOC pool in 0–15 cm depth. In the protected/ungrazed area, the SOC pool was 36.4, 49.7 and 43.9 Mg ha^{-1}. In contrast, adoption of soil restorative measures can enhance SOC concentration and restore the depleted pool.

Afforestation of degraded soils can enhance the SOC pool (Lalymenko and Shadzhikov, 1996; Kuliev, 1996; Faituri, 2002; Zayed, 2000). Similarly, restoration of degraded pastures and range lands enhances SOC pool. Establishment of grasses in pastures can improve soil fertility (Mirzaev, 1984), and increase addition of biomass-carbon to the soil. In Western Kazakhstan, Teryukov (1996) observed that improved pastures comprised a mixture of shrub species and perennial grasses. Restoring degraded soils and ecosystems in the Aral Sea Basin can also enhance the SOC pool (Baitulin, 2000; Dimeyova, 2000; Karibayeva, 2000; Meirman et al., 2000; Muradov, 2000). Martius et al. (2004) outlined several strategies for developing sustainable land and water management options for the Aral Sea Basin through an inter-disciplinary approach. These strategies include mapping of ground water and soil salinity, afforestration and assessing performance of tree growth, enhancing irrigation efficiency through improved methods, and soil fertility management.

Conversion of Steppe and natural ecosystems into cropland can deplete the SOC pool. In this regard, recycling of drainage water can be a useful strategy (Koloden and Robachev, 1999). The rate of SOC depletion can be severe with extractive farming practices (e.g., no fertilizer use, crop residue removal) and monoculture. Use of manure can maintain and even enhance the SOC pool (Table 12). Improved systems of soil and crop management in arable land can also enhance the SOC pool. Use of crop residue mulch is one option of enhancing the SOC pool. The data in Table 13

Table 12. Cropping systems and fertility effects on soil organic carbon pool (Recalculated from Nasyrov et al., 2004).

Treatment	Soil organic carbon pool[1] (Mg ha^{-1}) 1930	1976	Rate of change (Mg ha^{-1} yr^{-1})
Cotton monoculture, no fertilizers	30.8	20.3	−0.23
Cotton monoculture, with fertilizers	32.3	25.1	−0.16
Cotton monoculture, with manure	37.9	37.9	0
Crop rotation[2] with fertilizers	28.9	15.8	−0.28

[1] Assuming 30 cm depth and bulk density of 1.25 Mg m^{-3}.
[2] Rotation involved 3 years of alfalfa and 7 years of cotton.

Table 13. Mulching effects on soil organic carbon pool in Sierozems (Calculated from Sanginov et al., 2004).

	Soil organic carbon pool (Mg ha^{-1})				Rate of change (Mg ha^{-1} yr^{-1})	
	Fallow		Mulching			
Depth (cm)	1986	2001	1986	2001	Fallow	Mulching
0–30	27.4	19.4	27.9	63.2	−0.56	2.69
30–50	10.4	10.6	14.0	32.9	0.01	1.26
0–50	37.8	30.5	41.9	101.1	−0.48	3.95

Values based on assuming 58% carbon in soil organic matter.

show that long-term application of crop residue mulch enhanced the SOC pool in a Sierozem soil at the rate of about 4.0 Mg C $ha^{-1}yr^{-1}$. Judicious use of irrigation, which increased biomass production with a high water use efficiency (Kg $ha^{-1}mm^{-1}$ of water) can also increase the SOC pool. In this regard, recycling of drainage water can be a useful strategy (Koloden and Robachev, 1999). The data in Table 14 show that irrigation enhanced the SOC pool of a Typical Sierozem and Light Sierozem but not that of a Meadow.

Reducing intensity and frequency of plowing in conjunction with the use of crop residue mulch through conservation farming enhances the SOC pool (Lal, 2004). Application of conservation farming, however, is rather site specific (Barajev and Suleimenov, 1974; Suleimenov and Lysenko, 1997; Hemmat and Oki, 2001). In addition, elimination of summer fallowing can be extremely useful to reducing risks of erosion by wind and water and enhancing the SOC pool (Suleimenov et al., 1994; 1997; 2003; Barajev and Suleimenov, 1979). Assessment of the rate of SOC sequestration, however, must be based on long-term experimentation. The SOC pools of those soils are highly variable (Yanai et al., 2005). The temporal variability in SOC pool can be marked by high spatial variability, which must be taken into consideration through geostatistics and other techniques based on sampling for variable soils.

7 OFF-SETTING INDUSTRIAL EMISSIONS OF CO_2 THROUGH SOIL CARBON SEQUESTRATION

Temperal changes in CO_2 emission for 5 Central Asian countries are shown in Table 15. It is apparent that the collapse of former Soviet Union led to disruption in the industrial production

Table 14. Irrigation effects on soil organic carbon pool in some soils of Uzbekistan (Calculated from Nasyrov et al., 2004).

	Depth (cm)	Soil bulk density ($Mg\,m^{-3}$)	Soil organic carbon pool ($Mg\,ha^{-1}$)		
			Virgin soil	Rainfed	Irrigated
Typical Sierozem	0–30	1.25	39.2–54.4	17.4–23.9	23.9–37.0
	30–60	1.30	–	11.3–15.8	13.6–20.4
Meadow	0–30	1.20	52.2–73.1	37.6–73.1	31.3–52.2
	30–60	1.25	–	26.1–73.1	2.2–39.2
Light Sierozem	0–30	1.25	32.6	13.1–17.4	19.6–36.8
	30–60	1.30	–	9.0–13.6	13.6–22.6

Values based on assuming 58% carbon in soil organic matter.

Table 15. Temporal changes in CO^2 emissions in Central Asia (Adapted from Marland et al., 2001).

Year	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan	Total
	Tg C yr^{-1}					
1992	69.0	3.0	5.6	7.7	30.9	116.2
1993	58.4	2.3	3.7	7.5	32.4	106.3
1994	53.7	1.8	1.4	9.1	30.5	96.5
1995	45.2	1.4	1.4	9.2	27.0	86.2
1996	38.3	1.7	1.6	8.3	27.7	77.6
1997	37.1	1.8	1.4	8.0	27.7	76.0
1998	33.5	1.8	1.4	7.6	29.8	76.1
1999	30.7	1.3	1.4	9.3	32.0	74.7
2000	33.1	1.3	1.1	9.4	32.4	77.3

with an attendant decline in CO_2 emission. The annual $CO_2 - C$ emission of 116 Tg C yr^{-1} in 1992 declined to 77 Tg C yr^{-1} in 1996, and has stabilized over the last decade ending in 2005.

The industrial emission of CO_2 can be off-set by terrestrial C sequestration in soil and biota. The potential of soil C sequestration in Central Asia is 10 to 22 Tg C yr^{-1} (16 ± 6 Tg C yr^{-1}) (Lal, 2004) which is about 20% of the total industrial emission. In addition, there is also a potential of C sequestration in the biomass through afforestation. While off-setting industrial emissions, terrestrial C sequestration is an essential strategy of restoring degraded soils and ecosystems.

8 CONCLUSION

Adoption of extensive farming systems, monoculture of irrigated cotton and expansion of livestock industry, caused the severe problem of soil and environmental degradation. Principal soil degradation processes are desertification, salinization, waterlogging, defoliation and degradation of vegetation. Degradation processes have been exacerbated by shrinkage of the Aral Sea and drying up of the deltas of Amu Darya and Syr Darya.

Restoring degraded/desertified ecosystems is important to enhancing productivity and improving the environment. Improving soils and environment of the Aral Sea Basin, increasing inflow into the Sea, afforestation of degraded soils and improvement of rangeland through establishment of better species and controlled grazing are important options.

Enhancing SOC pool in cropland soils is necessary to the sustainable management of soil and water resources. The SOC pool can be enhanced by mulch farming techniques, use of conservation farming, elimination of summer fallow, and maintenance of soil fertility. The rate of SOC sequestration can be high with mulch farming and manuring techniques. Conservation farming can be site specific. The potential of SOC sequestration, 22 Tg C yr^{-1} or 20% of the annual industrial emission, provides another income source for the farmer through trading of carbon credits regionally and internationally.

Soil quality can be enhanced by adoption of conservation farming with crop residue mulching, elimination of summer fallowing, manuring and judicious use of irrigation water. Afforestation and restoration of range lands also enhance the soil carbon pool. The potential of carbon C sequestration in soils of Central Asia is 10 to 22 Tg C yr^{-1}. In addition, there is also a potential of C sequestration in biomass through afforestation. Realizing the potential of soil C sequestration can offset 20% of the annual industrial emission of 77 Tg C yr^{-1} in 2002.

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