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Variations in ecosystem service value in response to land use/land cover changes in Central Asia over 1995-2035

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Acute farmland expansion and rapid urbanization in Central Asia have accelerated land use/land cover changes, which has significant effect on ecosystem service. However, the spatio-temporal changes in ecosystem service values in Central Asia are not well understood. Here, based on land use products with 300-m resolution for the years of 1995, 2005 and 2015 and transfer methodology, we predicted LUCC for 2025 and 2035 using CA-Markov, assessed changes in ecosystem service value in response to LUCC dynamics, and explored the elasticity for the response of ESV to LULC changes. We found significant expansions of cropland and urban and shrinking of water bodies and bare land during 1995-2035. Overall ESVs had an increasing trend from 1995-2035, which was mainly due to the increasing cropland and construction land. The combined value of ecosystem services of cropland, grassland, water bodies accounted for over 90% of the total ESVs. However, LULC analysis showed that the area of water body reduced by 21.80% from 1995 to 2015 and continued to decrease by 21.14% from 2015 to 2035, indicating that approximately 63.37 billion US\$ of ESVs lost in Central Asia. Biodiversity, food production and water regulation were major service functions, accounting for 80.52% of the total ESVs. Our results demonstrated that the effective land-use policies should be made to control farmland expansion and protect water bodies, grassland and forestland for better sustainable ecosystem services.

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Abstract

Acute farmland expansion and rapid urbanization in Central Asia have accelerated land use/land cover changes, which has significant effect on ecosystem service. However, the spatio-temporal changes in ecosystem service values in Central Asia are not well understood. Here, based on land use products with 300-m resolution for the years of 1995, 2005 and 2015 and transfer methodology, we predicted LUCC for 2025 and 2035 using CA-Markov, assessed changes in ecosystem service value in response to LUCC dynamics, and explored the elasticity for the response of ESV to LULC changes. We found significant expansions of cropland and urban and shrinking of water bodies and bare land during 1995-2035. Overall ESVs had an increasing trend from 1995-2035, which was mainly due to the increasing cropland and construction land. The combined value of ecosystem services of cropland, grassland, water bodies accounted for over 90% of the total ESVs. However, LULC analysis showed that the area of water body reduced by 21.80% from 1995 to 2015 and continued to decrease by 21.14% from 2015 to 2035, indicating that approximately 63.37 billion US\$ of ESVs lost in Central Asia. Biodiversity, food production and water regulation were major service functions, accounting for 80.52% of the total ESVs. Our results demonstrated that the effective land-use policies should be made to control farmland expansion and protect water bodies, grassland and forestland for better sustainable ecosystem services.

Introduction

Humans ecosystem services (ES) refer to the direct and indirect benefits that people obtain from ecosystems (Costanza et al., 1997), including provisioning services (food and raw material), regulating services (gas regulation, climate regulation and hydrological regulation), supporting services (waste treatment, soil formation and biodiversity) and cultural services (recreation, cultural and tourism) (Hassan et al., 2005). Quantifying the benefits obtained from ecosystems can be achieved through evaluation of the ecosystem services (Costanza et al., 2014; Metzger et al., 2006), the evaluation method plays an essential role in raising people's awareness of environment, providing references for decision makers, and promoting the sustainable development of ecosystems (De Groot et al., 2012; Wei et al., 2015).

Many researchers have made substantial efforts in evaluating the ecosystem services. The global biosphere first classified into 16 ecosystems and 17 service functions, and then, the value of each ecosystem service was evaluated by Costanza et al (1997). But some researchers have severely criticized their findings (e.g. (Serafy, 1998; Wilson & Howarth, 2002)) due to the limitations and uncertainties in its use locally (Kindu et al., 2016b; Li et al., 2007). Recently, the evaluation has been updated based on more than 300 case studies around the worldwide (Costanza et al., 2014; De Groot et al., 2012). Costanza et al (2014) claimed that the underlying data and models they use in the assessment can be applied at various scales to evaluate changes in ES.

Land Use and Land Cover Change (LUCC) alters ecosystem processes and patterns and even influences the supply of ecological services (Hu et al., 2008; Kreuter et al., 2001; Yirsaw et

al., 2017). Excessive utilization of land resources may lead to severe degradation or loss of local or regional ES (Collin & Melloul, 2001). Recent research has shown that cropland conversion, urbanization and deforestation have led to the loss of carbon storage, degradation of water quality, and reduction of biodiversity, resulting in significant decline in ESV (Maitre et al., 2007; Polasky et al., 2011). Numerous studies have evaluated the impact of LULC dynamics on ES worldwide by utilizing the valuation coefficients of Costanza et al. (Costanza et al., 1997; Costanza et al., 2014). For example, Aisha et al (2009) studied the land-use change and its impacts on ESV in Nigeria. Arowolo et al (2018) assessed effects of land-use change on ES in the San Antonio River Basin, Texas. These studies have provided valuable reference for land-use policy makers.

Sitting in the center of the Eurasian continent, Central Asia dryland has experienced major LULC changes since the collapse of Soviet Union in the early 1990s (Behnke & Mortimore, 2016; Hamidov et al., 2016). This change has profound effects regarding fragile ecological environment in Central Asia. For example, as a major supply of food resources, the animal husbandry heavily relies on grassland resources in study area (Han et al., 2016; Huang et al., 2018). The vast pastures of Central Asia constitute the largest continuous grazing area in the world (Gintzburger et al., 2003). Furthermore, grasslands also provide other important ecosystem services, such as material production, climate and gas regulation, soil and water conservation, carbon sequestration, and biodiversity preservation (Eichelmann et al., 2016; Grace, 2010; Huang et al., 2017). In recent years, water-stressed grassland ecosystems have been frequently disturbed by human activities (e.g. grazing and reclamation) and climate change, which leads to the decline of grassland ecosystem service quality (Chen et al., 2018; Han et al., 2018; Hobbs & Norton, 1996; Tanentzap & Coomes, 2012). Additionally, the Syrdarya and Amudarya Rivers are essential source of water used for agriculture in the study area (Kulmatov et al., 2017). In Amu River Basin, such as in Khorezm Provinces of Uzbekistan and the Fergana Valley, the efficiency of the irrigation and drainage system from agricultural fields is extremely low (Awan et al., 2016; Karimov et al., 2014). Excessive irrigation not only lead to waste large amount of water resource in Amu Darya Delta, but also results in fertilizer loss, soil salinization and salt storm (Devkota et al., 2015b). Because of irrational land use and improper managements, there are serious soil erosion and desertification and extensive land degradation in some basins. Therefore, it is urgent to assess the impacts of human disturbances on ecosystem services of Central Asia. Such study is important for ecological monitoring, sustainability management and disturbance regulation in this fragile dryland ecosystem. Except for a few qualitative estimates on ES change in response to LULC change (Chen et al., 2013; Chi et al., 2016), to date there has been no quantitative assessment of ESV in Central Asia.

Therefore, the aim of this study is to: (1) estimate and project the LULC changes in Central Asia during the period 1995–2035; (2) assess changes in ESV in response to LULC changes; and (3) explore the elasticity for the response of ESV to LULC change by 50% adjustment of value coefficients. Our findings could provide policy makers with important reference for ecological environment protection and sustainable development of Central Asia.

Materials & Methods

Study Area

The Our study area covering the five Central Asian countries (from 35°08'N, 55°25'N to 46°28'E, 87°29'E.), including Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan (Figure 1). With a land area of 4 million km², the Central Asia extends from Russia in the north to Afghanistan in the south and from the Caspian Sea in the west to western borders of China in the east (Ozturk et al., 2017). The terrain gradually increases from the western of the Caspian lowland to the Altai Mountains, Tianshan Mountains and Pamirs (Beurs et al., 2015). As this area is located in the hinterland of the Eurasian continent, far from the ocean, it has a distinctive continental arid and semi-arid climate with dry, low precipitation and intensive evaporation (Lioubimtseva & Henebry, 2009). In recent decades, potential evapotranspiration has increased in Central Asia, especially in the Aral Sea region and western Kazakhstan and, with an annual growth of 7.42 mm/year (Jiang et al., 2019). Central Asia has a heterogeneous landscape, including a diverse land-cover types such as temperate deserts (e.g. Kyzylkum, Karakum Desert), forests, lakes (e.g. the Aral Sea, Balkhash Lake) and vast grasslands. Major transboundary rivers, such as the Amu Darya, the Syr Darya, the Irtys River, and the Ili River are critical water sources for regional ecosystems as well as agriculture (Zhou et al., 2019). With the large-scale development of irrigated agriculture in the Aral Sea Basin in the early 1960s, the area of irrigated cultivated land increased by 60% and the area of cotton planted doubled between 1960s and 1990s. Now the irrigated land accounts for almost half of the total cultivated land area (Suo, 2009).

Data Collection and Land Use Classification

Social statistics come from the World Bank (<https://data.worldbank.org/>) and the United Nations Food and Agriculture Organization (<http://www.fao.org/>). Multi-scale Satellite observations are used to characterize LULC change (Song, 2018). In a preliminary study, we compared the multiple LULC datasets for the study area, including the GLC2000 (Corresponding & Belward, 2005), the GlobCover 2009 product (Arino et al., 2008) and MODIS land cover product (Friedl et al., 2010), and the newly released annual European Space Agency Climate Change Initiative land cover maps (CCI-LC) (<http://maps.elie.ucl.ac.be/CCI/viewer>) (Radoux et al., 2013). The comparison showed that the CCI LC has the highest spatial resolution and have better accuracy in the study area (Hartley et al., 2017; Wei et al., 2016). Therefore, the CCI-LC dataset was chosen to study the LULC change from 1995-2015. Details about the CCI-LC dataset including its accuracy and classification method can be found in Hartley et al. (Wei et al., 2016). In order to match up with Costanza's biomes, plant functional types were classified into major 7 LULC types, including cropland, forestland, grassland, wetland, urban, bare land and waterbodies (Table S1).

Model Projecting of future LULC Change

Future LULC change from 2015 to 2035 were projected by combining Geographic Information System (GIS) with CA-Markov Model, which is a robust effective approach for simulation of the

spatial and temporal change patterns of land use (e.g. (Fu et al., 2018; Hartley et al., 2017; Muller & Middleton, 1994). The CA-Markov model merges the cellular automata (CA) and theories of Markov chain (Ji et al., 2009). The Markov chain is constructed, which is based on the probability of change matrices. The CA model is used to predict the space-time dynamic change pattern by using a transition map of the LULC (Yang et al., 2012). By incorporate the advantages of these two methods, the CA–Markov model is able to accomplish a better simulation of LULC changes both in quantity and space (Yang et al., 2014). In this study, the transition probability matrix was performed for the time period between 1995 and 2005 to predict the LULC map of 2015, which would be used to verify model accuracy. Then, using the 2015 classified map as the LULC baseline and the 2005 and 2015 maps for transition probability matrix, we predicted the 2025 and 2035 LULC maps with the CA-Markov model.

Assessment of Ecosystem Service Values

The Benefit Transfer Method (BTM) based value coefficients from Costanza et al (2014) were applied to assessed the 7 major LULC categories in Central Asia. ESV were estimated based on the ecosystem service valuation model of Costanza et al (1997). Cultivated land, temperate forest, grasslands/shrubland, swamps/floodplains, urban areas, and desert/tundra/ice/bare-rocks in Central Asia were matched to cropland, forests, grassland, wetland, urban and bare land in Costanza et al.'s (2014) model, respectively (Table S1). the biomes that we used as proxies for the 7 LULC categories are evidently not perfectly matched Costanza et al.'s (1997) ESV model in some case (Table S1), but they are closely related (Kreuter, 2001). The equivalent value coefficient of each ES and functions (Table1), as follows:

$$ESV_k = \sum_f A_k \times VC_{kf}$$

$$ESV_f = \sum_k A_k \times VC_{kf}$$

$$ESV = \sum_f \sum_k A_k \times VC_{kf}$$

where ESV_k refers to the ecosystem service value of land cover category 'k', A_k represents the area (ha) for land cover category 'k', and VC_{fk} is the value coefficient (US \$ ha⁻¹ year⁻¹) of function f for the land cover category 'k' (Kreuter, 2001). ESV_f is the ecosystem service value of service function f and ESV is the total ecosystem service value. We use the following formula to evaluate changes in ESV:

$$ESV_{cr} = \frac{ESV_{t2} - ESV_{t1}}{ESV_{t1}} \times 100\%$$

In this expression, ESV_{cr} is the change rate of ESV from the initial year to the final year, ESV_{t1} and ESV_{t2} refer to the total ESV at the start and end of the study period, respectively.

Elasticity for the Response of ESV to LULC change

As the biomes that we used as proxies for the 7 LULC categories are evidently not perfectly matched Costanza et al.'s (1997) ESV model in some case (Table S1), which results uncertainties in assessment of the ESV. Thus, sensitivity analysis was introduced to evaluate the changes in ESV in response to 50% adjustments of the ESV coefficients for each LULC type (Kindu et al., 2016a). In our study, the coefficient of sensitivity (CS) was calculated using the standard economic concept of elasticity as follows (Kreuter, 2001):

$$CS = \frac{(ESV_j - ESV_i) / ESV_i}{(ESV_{jk} - ESV_{ik}) / ESV_{ik}}$$

where *ESV* refers to the estimated total value of ecosystem services, *VC* represents the value coefficient, '*i*', '*j*' and '*k*' represent the initial, adjusted values, and land cover categories, respectively. If $CS > 1$, then the estimated *ESV* is elastic with respect to that coefficient; if $CS \leq 1$, the estimated *ESV* is inelastic. Thus, when $CS < 1$, even if the accuracy of *VC* values used as proxy biomes is low, the results of estimation in *ESV* are credible. (Kreuter, 2001).

Results

Analysis of LULC dynamics

Combining the GIS technology with CA-Markov Model, we use the LULC base map from the year 2005 and transition probabilities from 1995 to 2005 to simulate the LULC for the year 2015. The kappa statistic of 0.93 indicates that there is a good consistency with the actual value of the LULC types and the predicted result for the base year. Then, the future LULC in 2025 was predicted with the CA-Markov model in IDRISI using the LULC base map from the year 2015 and transition probabilities from 2005 to 2015. Following the above process, the future LULC in 2035 was predicted.

Figure 2 presents the patterns of spatial distribution of LULC in Central Asia from 1995 to 2035 and Table 2 reveals the magnitude of changes for the same periods. In 1995, grassland occupied about 51.39% of the study area, followed by the bare land and cropland which occupied 23.90% and 18.98% of the study area, respectively (Figure 3). During 1995-2015, cropland and construction land has increased remarkably. The cropland expanded at a rate of 0.76% per annum, increasing 1219.56×10^4 ha by the year of 2015 (Table 2). Rapid urbanization also caused the proportion of urban built-up increasing from 27.57×10^4 ha in 1995 to 60.21×10^4 ha in 2005 and then to 89.19×10^4 ha in 2015, with an average growth rate of 10.64% per year (Table 2). Cropland and urban were expected to continue to increase in 2025 and 2035 periods. However, the coverage of bare land, mainly concentrated in Kyzylkum Desert and Karakum Desert, decreased from 23.90% to 22.95% during 1995-2015, and was projected to further decrease to 21.65% by the year of 2035.

The wetland and water bodies only account for 3% of the total study area. Wetland increased from 121.14×10^4 ha in 1995 to 125.25×10^4 ha in 2015 and 128.41×10^4 ha in 2035 (Table 2), mainly nearby the Balkhash Lake (Figure 2). The area of water bodies decreased 292.59×10^4 ha from 1995 to 2015 and is expected to further decrease 221.90×10^4 ha by the year of 2035. Among water bodies in Central Asia, the Aral Sea has shrunk most dramatically. Its surface area decreased from 3.8×10^6 ha in 1995 to 0.88×10^6 ha in 2015 and is projected to be 0.43×10^6 ha in 2035 with a total loss of 3.37×10^6 ha.

Changes in the total ecosystem service values

According to our estimation the total *ESV* in Central Asia was about 1505.31 billion US\$ in 1995 (Table 3). Grassland had the highest contribution of 56.90%, followed by cropland and water bodies (28.09% and 11.15%, respectively) (Figure 3). Due to LULC change, the regional

ESV increased 5.68 billion US\$ during 1995-2015, mainly due to the increased ESV in cropland and urban built-up, which overcompensated the ESV loss in grassland and water bodies. The regional ESV further increased 5.23 billion US\$ from 2005-2015. Overall, the ESV in Central Asia increased 10.91 billion US\$ during 1995-2015. It is noteworthy that the proportion of water bodies decreased sharply by 21.80% from 1995-2015 causing a loss of 36.61 billion US\$. These trends will continue to occur in 2025 and 2035 (Table 3).

We further analyzed the ESV for administrative units in 1995 (Figure S1). The highest ESV was found in the Karaganda state (174.09 billion US\$), followed by East Kazakhstan (131.69 billion US\$), Aktobe (121.09 billion US\$) and Almaty (116.70 billion US\$) states. The ESV for these administrative units were mainly contributed by grassland in Karaganda (86.13%), East Kazakhstan (67.14.8%) and Aktobe (86.39%). ESV was generally low in southern Central Asia. Andijon had the lowest ESV of 2.17 billion US\$, 93.73% of which was contributed by cropland. In addition, we calculated the ESV change rates during 1995-2015, 2005-2015, 2015-2025 and 2025-2035 for the administrative units (Figure 4). From 1995-2005, the ESV of Karakaipakstan, Uzbekistan declined 31.08% with a total loss of 17.36 billion US\$ (Figure 4-a). The ESVs in Kyzylorda, Manghystau, Kashkadaria, and Rayons of Republican Subordination also decreased remarkably, which were mainly caused by contraction of water bodies. In contrast, the ESV in Pavlodar and Karaganda increased remarkably, mainly due to the increased cropland ESV. During 2005-2015, the ESV in Karakaipakstan, Kyzylorda and Manghystau further decreased (Figure 4-b), with the highest ESV loss found in Karakaipakstan (-24.77%), followed by Kyzylorda (-8.8%) and Manghystau (-1.05%). In contrast, the Karaganda had the highest increase rate of ESV (5.3%), followed by the Aktobe (1.4%) and Almaty (1.2%).

Changes in values of ecosystem service functions in Central Asia

Table 4 shows the changes in individual ecosystem functions (ESV_f). The most important ESV_f in Central Asia were biodiversity, food production and water regulation, which contributed to 40.44%, 28.30% and 11.78% of the total ESV in 1995, 40.03%, 29.47% and 10.21% of the total ESV in 2015, and 40.51%, 30.14% and 8.93% of the total ESV in 2035, respectively. Most of the ESV_f decreased during 1995-2015 except for food production, raw materials, climate regulation, soil formation and waste treatment, which increased 4.87%, 7.92%, 12.11%, 12.01%, and 2.91%, respectively (Figure 5). It is noteworthy that the ESV of water regulation declined more rapidly than other ecosystem services (-12.70%), followed by gas regulation (-3.00%), cultural and tourism (-3.14%) and biodiversity (-0.29%). However, most of the ESV_f were projected to increase from 2015-2035 (Figure 5). Only the ESV of water regulation and cultural service/tourism were expected to decrease in the future.

Ecosystem Sensitivity Analysis

In the observed (1995-2015) and projected (2025-2035) study periods, CS for grassland was the highest (0.55), due to the high service value coefficient and large grassland area (Table 5). Meanwhile, CS for cropland increased from 0.28 in 1995, to 0.32 in 2015, and to 0.34 in 2035. Compared with grassland and cropland, the CS (0.02) for forestland was relatively stable. The CS for water bodies decreased from 0.11 in 1995, to 0.09 in 2015, and to 0.07 in 2035. In this

study, all CS was far less than “1”, indicating that the total estimated ecosystem values are inelastic with respect to the ecosystem value coefficients.

Discussion

Impacts of LULC changes on ES

Globally, the rapid economic development and continued population growth have led to the expansion of construction land and cropland, which could accelerate the conversion of land-use pattern and cause a significant contraction in ES (Hu et al., 2018; Nahuelhual et al., 2014), and this effects are particularly prominent reflected in Central Asia region. From 1995 to 2015, the urban population in Central Asia grew from 24,015,560 to 102,049,218 (Figure 6). To meet growing demand of people, population growth puts tremendous pressure on food and space. We observed that the significant expansion of cropland and urban area during the study period in Central Asia (Table 2). Although, the expansion of farmland has increased about 67.89 billion US\$ from observed (1995–2015) periods to predicted (2025–2035) periods (Table 3), the ESV of water bodies have shrunk in study period. The agricultural irrigation is an important way to utilize water resource in arid and semiarid regions (Thevs et al., 2015; Zhang et al., 2018). Table 6 shows that agriculture withdrawal accounts for the largest freshwater withdrawal, Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan use 66%, 93.01%, 90.86%, 94.31% and 90% of freshwater resources for agriculture, respectively. Overall, more than 85% of freshwater resources in Central Asia's has used by intensive agricultural production. Our studies have shown that the reduction in water bodies service has led to a loss of 36.61 US\$ from 1995 to 2015 in Central Asia (Table 3). Also, the ESV of water and climate regulation decreased by 21.13% and 2.14% respectively from 1995 to 2035 (Figure 5). Figure 7 clearly shows that fertilizer consumption was gradually increased in five Central Asian countries (except for Turkmenistan), especially in Uzbekistan. From 2006 to 2015, fertilizer consumption per mu increased by 65.9 kg. In recent years, as a result of intensive agricultural activities (e.g. application of organic fertilizers (Collin & Melloul, 2001) and extensive irrigation (Yi et al., 2017), a series of ecological environment problems has produced in this region (Devkota et al., 2015a). In particular, the lower reaches of the Amudarya and Syrdarya as well as the delta ecosystems of the Priaralie are the most affected areas in Central Asia (Dukhovny & Schutter, 2011). Our results also shown that the ESV in Karakaipakistan, Uzbekistan decreased more 50% during 1995-2035 (Figure 4). Since the mid-20th century, salt storms, soil salinization, water and regional climate deterioration have been occurred in these areas, and even some areas have been seriously polluted by agrochemicals, fluorides and heavy metals (Groll et al., 2015).

Limitations and Suggestions for Land-Use Management in Future

LULC Data

Remote sensing data is a most important data source for research in ES, and LULC is the most widely used as variable for assessment in ESV (Barbosa et al., 2015; Song, 2018). However, the uncertainties of global land cover data arise from the product generation process, including satellite sensor characteristics (spectral, temporal and spatial resolutions), definition and

classification methods of land cover. Because of error propagation in the process of quantifying land cover data, LULC change may be considerably underestimate or overestimated (Sexton et al., 2015). Such uncertainties are inevitably introduced in analysis of spatial change pattern when the biomes used as proxies match with LULC categories (Kreuter, 2001). For example, shrubs and sparse vegetation are used as grasslands, which obviously exaggerates the area of grasslands and leads to an overestimation of ESV. However, the CCI LC assessment report shows that the accuracy of water bodies, farmland and construction land is more than 80%, which gives us confidence in the assessment results. Therefore, high resolution remote sensing data should be used in future ESV assessment research to improve the accuracy of land use classification.

Assessment of the value ecosystem services

We used a method proposed by Costanza et al (2014) to assess ESV in this study. Ecosystem service values are obtained by multiplying ecosystem value coefficient and the area of LULC categories. Due to the biomes used as proxies are not perfect match with LULC categories in some case (Kreuter, 2001), and ecosystem heterogeneity in Central Asia, some value coefficients should be modified. For example, the value coefficient of urban built-up was overestimated (Table 1), masking the loss of essential ES provided by other LULC types. Yi et al (2017) also believed that the value coefficient of urban built-up was assigned Costanza et al (2012) seems unreasonable. These possible Limitations will be addressed in future work. we observed that the coefficient of sensitivity for the ESV were quite low (Table 5) when the value coefficients were adjusted by 50% to estimate the effects. The result of sensitivity analysis provides a reasonable level of confidence in our evaluation of ES for Central Asia. Therefore, our findings concerned on changes in ecosystem service value over time is credible. These evaluation of regional ecosystem services can provide some valuable references for ecological resources conservation and sustainable ecosystem management.

Suggestions for Land-Use Management in Future

Our results shown that rapid changes in LULC have led to the drastic decrease in ESV of water bodies in Central Asia (Table 3), which could undermine the capacity of ecosystems providing sustainable ES, and even result in irreversible environmental degradation (Scolozzi et al., 2012). Therefore, the rational and effective ways of utilization of water resources are an important step to maintain the sustainable development of ecosystems in Central Asia. we suggest that modern water-saving technologies and methods of irrigation (e.g. drip irrigation, sprinkler irrigation and micro-sprinkler irrigation) should be introduced in the irrigated farmland. Furthermore, crops with less water consumption and higher added value should be encouraged to cultivate in water shortage region. Some studies have shown that cotton and rice can be gradually replaced by feed crops, oilseeds and vegetables that require less water resources, which will save a great deal of precious water resources in Central Asia (Seidakhmetov et al., 2014). Meanwhile, the efficiency of industrial water utilization also should be improved through construction of purification plants for salt water and municipal sewage treatment plants. In addition, policy makers should take effective measures (e.g. and removal of sludge and vegetation restoration) to restore the ecosystem of Aral Sea Basin. These suggestions could provide policy makers with

important references for ecological environment protection and sustainable development of Central Asia.

Conclusions

Combining the GIS technology with CA-Markov Model, we used basic LULC data and the value coefficients of ecosystem service to analyze and discuss the changes in ESV from the observed (1995–2015) to predicted (2025–2035) periods. Finally, through sensitivity analysis, proved the accuracy of ecosystem service value coefficient table per unit area. We reached three dominant conclusions:

(1) We observed that the significant expansion of cropland and urban area and lessening of waterbodies, bare land cover during the study periods.

(2) Our results demonstrated an increasing trend in ESV from 1995 to 2015, with the total ESV increasing from 1505.31 billion US\$ in 1995 to 1516.23 billion US\$ in 2015 and then to 1527.22 billion US\$ in 2035. The net increase in ESV was about 21.91 billion US\$ from 1995 to 2035, which was mainly caused by the increasing areas of cropland and construction land.

Although the ecological services value continues to grow, our study shows that the proportion of ecological services in water bodies decreased sharply from 11.15% in 1995 to 9.73% in 2005 and then to 8.66% in 2015 with a loss of 36.61 billion US\$. This loss will continue between 2015 and 2035 periods.

(3) Biodiversity, food production and water regulation were the three major service functions, accounting for 80.52% of the total ESV, mainly provided by grassland, cropland and waterbodies cover types. Even though grassland and waterbodies are the major LULC categories providing important ecological functions in Central Asia region, these two categories are gradually degrading.

Therefore, curbing the decreasing in grassland and waterbodies cover is critical links to prevent the loss of the value of ecological services in the Central Asia. The local management should solve the problems of overgrazing, grassland degradation and degeneration of Aral Sea. The concludes of study can provide scientific basis for maker who formulate land uses and agricultural production policies in those ecological fragile areas.

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Table 1 (on next page)

Table 1. ESV of 7 LULC categories in Central Asia. (US\$ha⁻¹ yr⁻¹)

FP – Food Production ; RM – Raw Material ; GR – Gas Regulation; CL – Climate Regulation ; WR – Water Regulation; SFR – Soil Formation and Retention; WT – Waste Treatment ; BD – Biodiversity; RCT – Recreation, Cultural and Tourism.

Service type	Sub-type	Cropland	Forestland	Grassland	Wetland	Urban	Bare land	Waterbodies
Provisioning	FP	2323	299	1192	614	0	0	106
	RM	219	181	54	539	0	0	0
Regulating	GR	0	0	9	0	0	0	0
	CL	411	152	40	3474	905	0	0
	WR	400	191	63	6014	16	0	9322
Supporting	SFR	639	107	46	4320	0	0	0
	WT	397	120	75	3015	0	0	918
	BD	1096	1097	2494	3502	0	0	0
Culture	RCT	82	990	193	4203	5740	0	2166
Total ecosystem value		5567	3137	4166	25681	6661	0	12512

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Table 2 (on next page)

Area changes of LULC in Central Asia from 1995 to 2035.

□	LULC	Cropland	Forestland	Grassland	Wetland	Urban	Bare land	Water bodies	Total
area (*10 ⁴ ha)	1995	7595.03	800.90	20560.52	121.14	27.57	9563.26	1342.06	40010.48
	2005	8591.77	801.05	19810.87	121.69	60.21	9449.80	1175.08	40010.48
	2015	8814.59	800.48	19948.14	125.25	89.19	9183.36	1049.48	40010.48
	2025	9051.58	799.49	20077.26	125.25	90.82	8926.89	939.17	40010.48
	2035	9273.75	798.42	20203.47	128.41	116.47	8662.38	827.58	40010.48
changes (%)	1995-2015	16.06	-0.05	-2.98	3.39	223.45	-3.97	-21.80	-
	2015-2035	5.21	-0.26	1.28	2.52	30.59	-5.67	8905.75	-
	1995-2035	22.10	-0.31	-1.74	6.00	322.40	-9.42	-38.34	-

Table 3(on next page)

Ecosystem service value of Central Asia from 1995 to 2035 .

LULC	ESV (billion US\$)					Changes (%)		□
	1995	2005	2015	2025	2035	1995-2015	2015-2035	1995-2035
Cropland	422.79	478.27	490.68	503.87	516.24	16.06	5.21	22.10
Forestland	25.12	25.13	25.11	25.08	25.05	-0.05	-0.26	-0.31
Grassland	856.54	825.31	831.02	836.40	841.66	-2.98	1.28	-1.74
Wetland	31.11	31.25	32.17	32.47	32.98	3.39	2.52	6.00
Urban	1.84	4.01	5.94	6.45	7.76	223.41	30.59	322.33
Bare land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water bodies	167.92	147.02	131.31	117.51	103.54	-21.80	-21.14	-38.34
Total	1505.31	1510.99	1516.23	1521.78	1527.22	0.73	0.73	1.46

Table 4(on next page)

Estimated values for different ecosystem functions in Central Asia in 1995–2035.

FP – Food Production ; RM – Raw Material ; GR – Gas Regulation; CL – Climate Regulation ; WR – Water Regulation; SFR – Soil Formation and Retention; WT – Waste Treatment ; BD – Biodiversity; RCT – Recreation, Cultural and Tourism.

Service type	Sub-type	Ecosystem service value (billion US\$)				
		1995	2005	2015	2025	2035
Provisioning	FP	426.08	440.12	446.82	453.74	460.31
	RM	29.85	31.64	32.22	32.80	33.37
Regulating	GR	1.87	1.80	1.81	1.82	1.83
	CL	45.09	49.20	50.56	51.59	52.90
	WR	177.36	165.34	154.83	145.58	136.33
Supporting	SFR	63.98	70.02	71.66	73.23	74.84
	WT	62.49	64.37	64.31	64.33	64.38
	BD	609.01	601.26	607.24	613.05	618.73
Culture	RCT	89.59	87.25	86.78	84.92	84.52
Total	□	1505.32	1510.99	1516.23	1521.78	1527.23

Table 5(on next page)

Percentage change in estimated total ESV and coefficient of sensitivity.

Change of value coefficient	1995		2005		2015		2025		2035	
	%	CS	%	CS	%	CS	%	CS	%	CS
Cropland VC \pm 50%	14.04	0.28	15.83	0.32	16.18	0.32	16.56	0.33	16.90	0.34
Forestland VC \pm 50%	0.83	0.02	0.83	0.02	0.83	0.02	0.82	0.02	0.82	0.02
Grassland VC \pm 50%	28.45	0.57	27.31	0.55	27.40	0.55	27.49	0.55	27.56	0.55
Wetland VC \pm 50%	1.03	0.02	1.42	0.03	1.79	0.04	1.06	0.02	1.08	0.02
Urban VC \pm 50%	0.06	0.00	0.13	0.00	0.20	0.00	0.20	0.00	0.25	0.01
Bare land VC \pm 50%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waterbodies VC \pm 50%	5.58	0.11	4.87	0.10	4.33	0.09	3.86	0.08	3.39	0.07

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Table 6(on next page)

Water withdrawal by sector.

<input type="checkbox"/>	Municipalities		Industries		Agriculture	
<input type="checkbox"/>	Volume (10 ⁸ m ³)	%	volume (10 ⁸ m ³)	%	volume (10 ⁸ m ³)	%
Kazakhstan	8.80	4.15	62.60	29.63	140.00	66.23
Kyrgyzstan	2.20	2.80	3.40	4.20	74.50	93.01
Tajikistan	6.50	5.63	4.10	3.55	104.40	90.86
Turkmenistan	7.50	2.70	8.40	3.00	263.60	94.31
Uzbekistan	4.10	7.32	15.00	2.68	504.00	90.00
Central Asia	6.60	5.30	93.50	7.50	1086.50	87.21

Figure 1

Map showing the location of Central Asia.

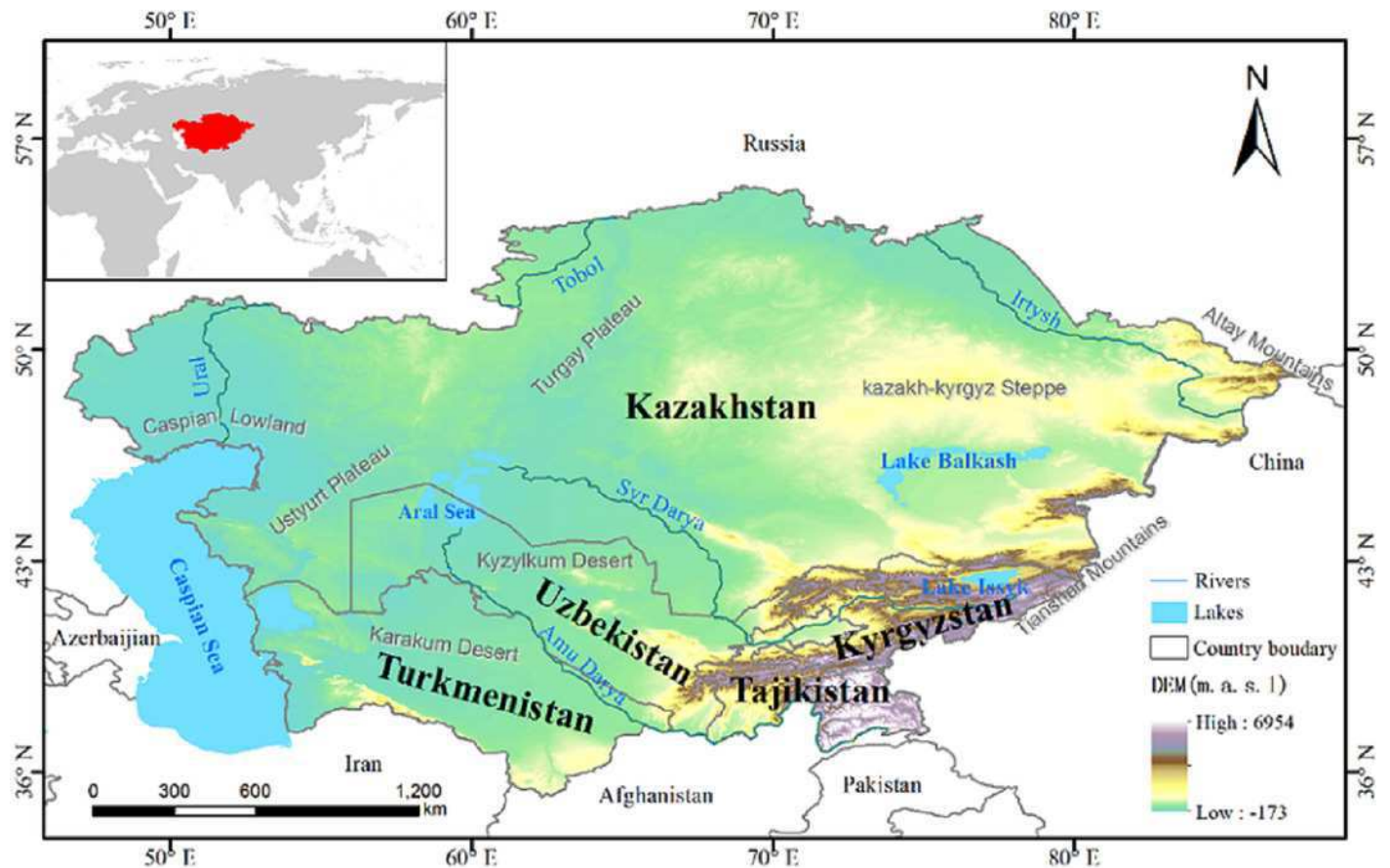


Figure 2

Spatial distribution of LULC in Central Asia.

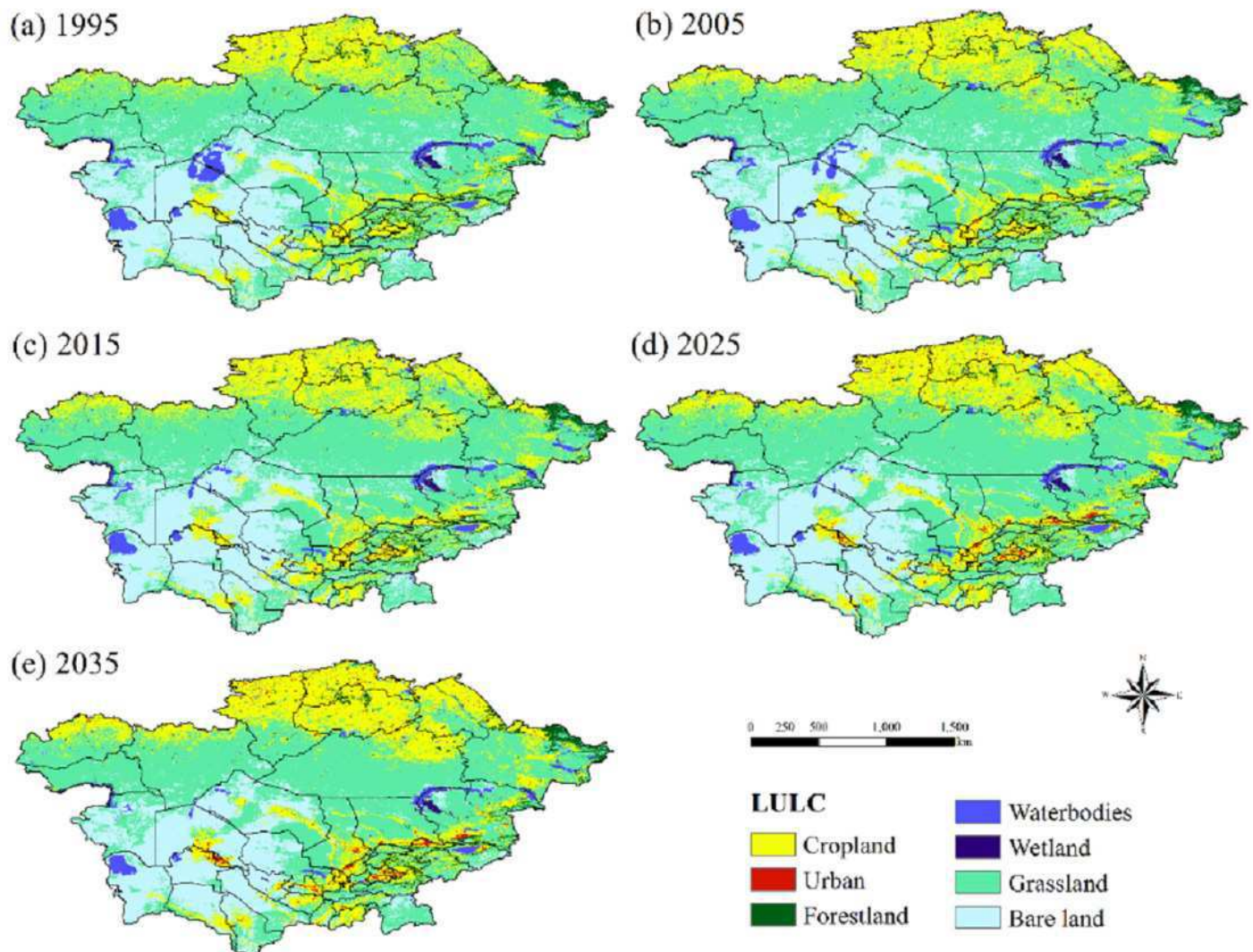


Figure 3

(a) the percentage of land use classification and (b) the percentage of ecosystem service value of different land use classification.

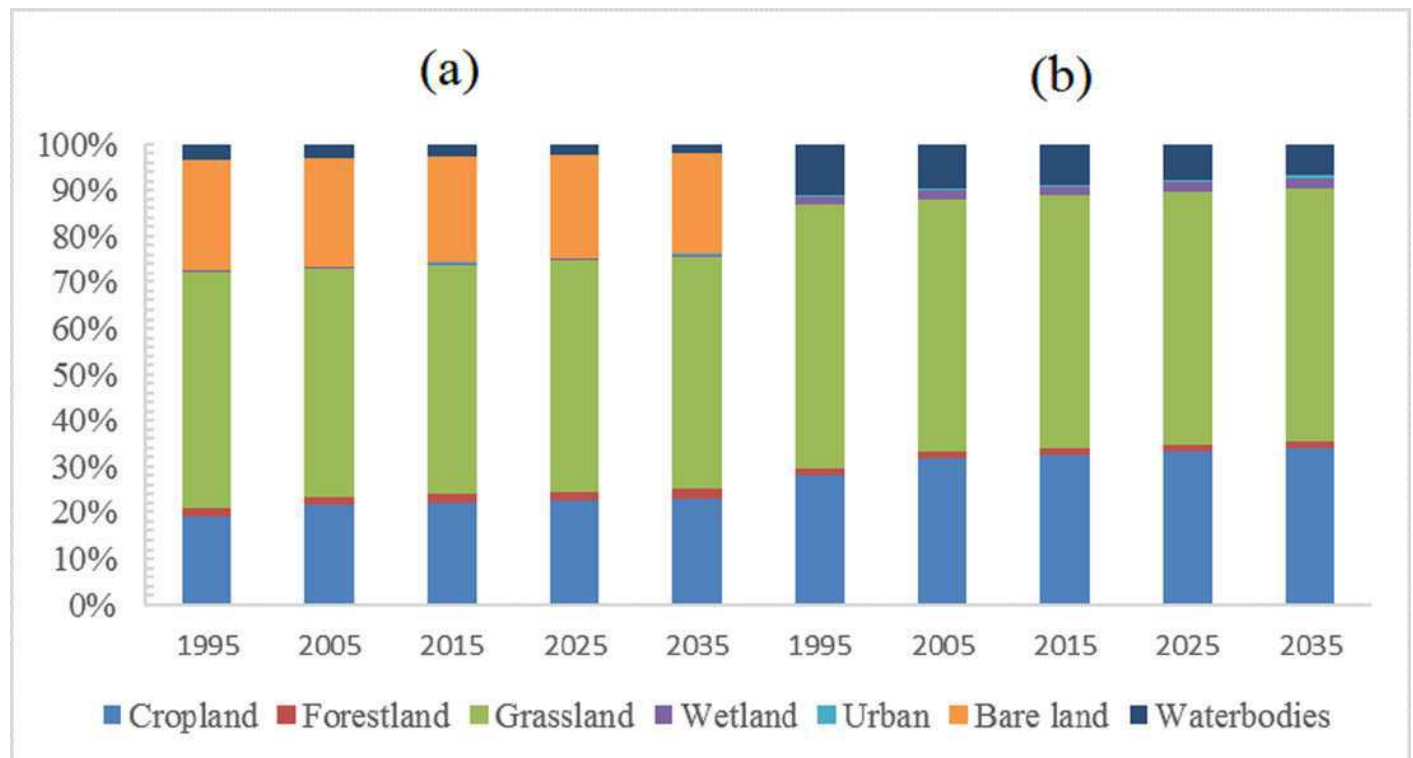


Figure 4

Ecosystem service value change rate (%) from 1995 to 2005(a), 2005 to 2015(b), 2015 to 2025(c) and 2025 to 2035(d).

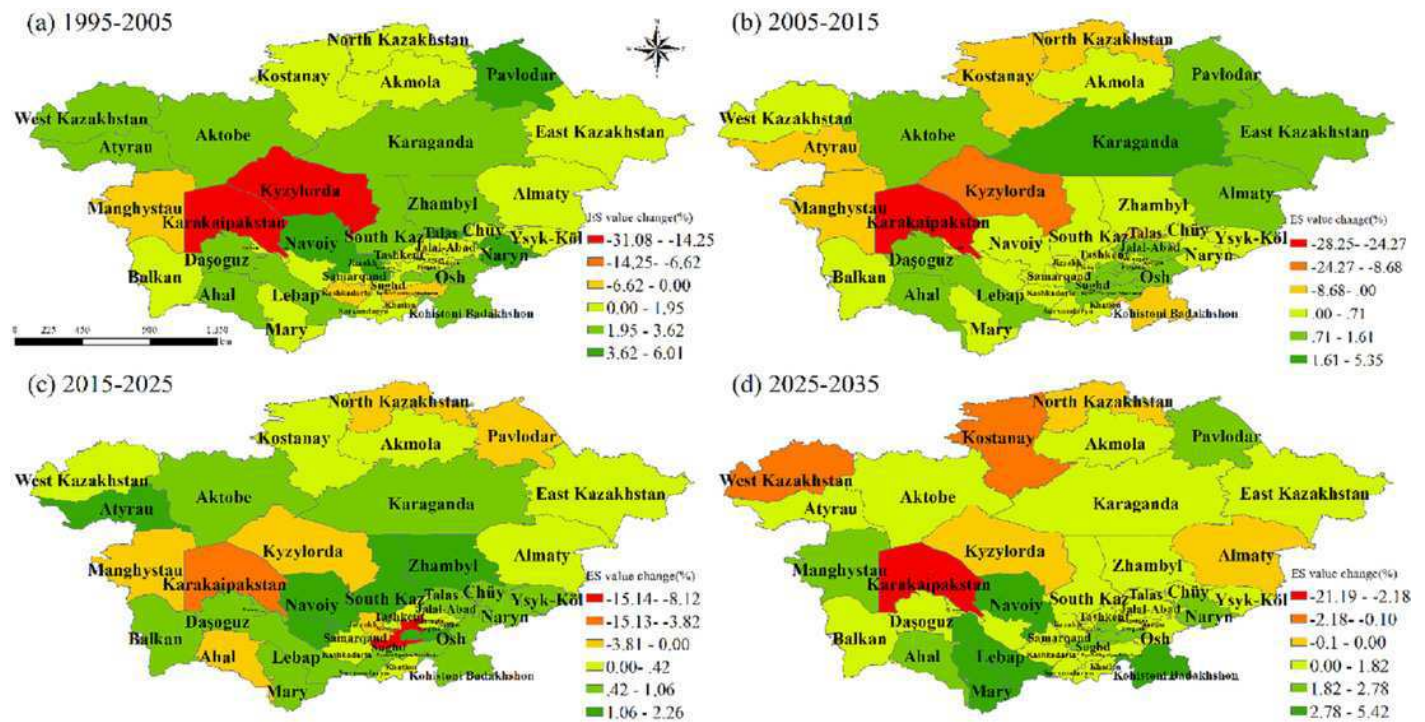


Figure 5

Change rate of ecosystem service function in Central Asia from 1995 to 2015.

FP – Food Production ; RM – Raw Material ; GR – Gas Regulation; CL – Climate Regulation ; WR – Water Regulation; SFR – Soil Formation and Retention; WT – Waste Treatment ; BD – Biodiversity; RCT – Recreation, Cultural and Tourism.

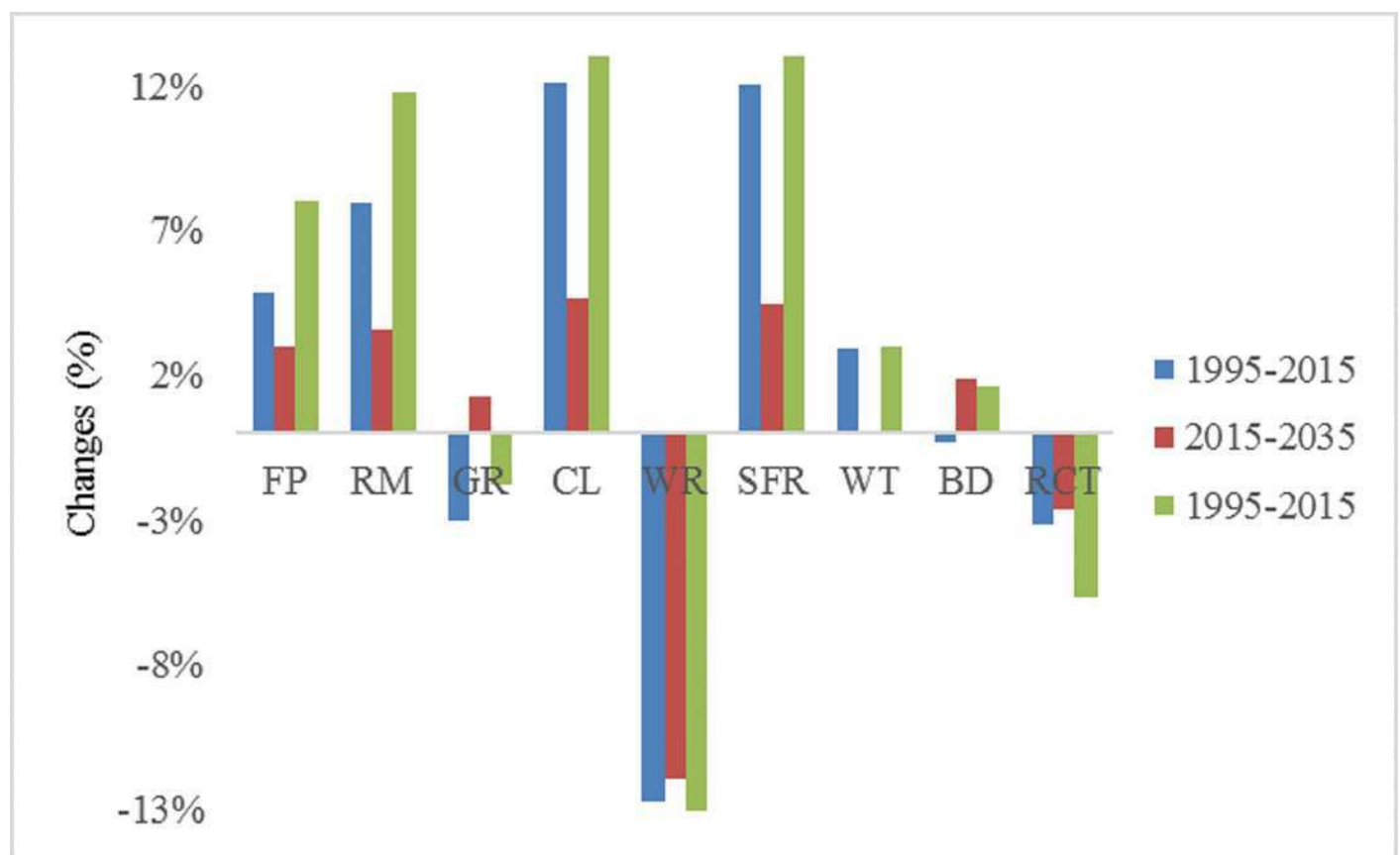


Figure 6

Urban population in Central Asia from 1995 to 2015.

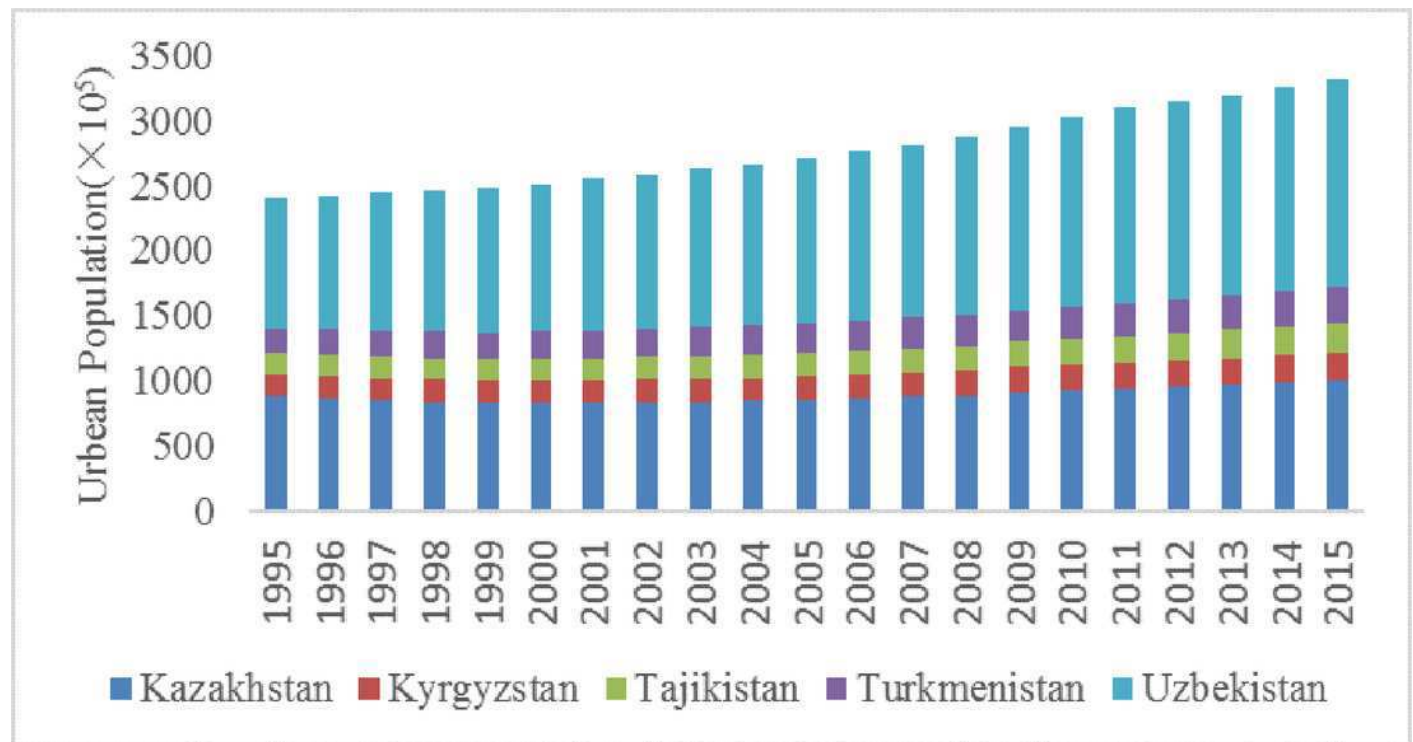


Figure 7

Trends in fertilizer consumption in Central Asia from 2002 to 2015

