Postprint: Impacts of Climate Change and Human Activities on Ecosystem Service Value in the Yanqi Basin

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Abstract

Research on ecological service functions under environmental change holds significant scientific importance and practical value for the sustainable development of ecological environments and socio-economics. This paper takes the Yanqi Basin in Xinjiang as the study area, based on Landsat remote sensing imagery data, DEM data, and meteorological element data, employs non-parametric climate change abrupt point testing (MK, Mann-Kendall-Sneyers test) and trend analysis methods (Mann-Kendall, MK), and through calculating the ecological service value (ESV) and the dynamic degree of land use/cover change (LUCC), analyzes the changes in ecological service functions and their driving factors in the Yanqi Basin of Xinjiang over the past 40 years (1973-2014). The results show: 1) The changes in ecosystem service value and function are the result of the combined effects of climate change and human activities; 2) The shrinkage of glacier area in mountainous regions is the main reason for the decrease in ecological service value in these areas; 3) The ecosystem service value in plain areas exhibits a trend of first decreasing and then increasing, with 2004 as the turning point. The ecological service values for the entire study area are 8.586×10 yuan in 1973, 9.446×10 yuan in 1977, 8.415×10 yuan in 1994, 8.940×10 yuan in 2004, and 9.647×10 yuan in 2014, which aligns with the trends of precipitation and evaporation changes. Human activities such as long-term reclamation, expansion of oasis area, and beneficial climate change support (increased precipitation, decreased evaporation) are the main reasons for the increase in ecological service value in plain areas. In mountainous regions, ecological service value changes with variations in precipitation and evaporation; in oasis areas, the changes in ecological service value result from the combined effects of human activities such as land reclamation for cultivation, returning farmland to forest, returning farmland to grassland, artificial cultivation of reeds, and climate warming.

Full Text

Preamble

The Impact of Climate Change and Human Activity on Ecosystem Service Values in the Yanqi Basin, Xinjiang, China

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Abstract
Research on ecosystem services under environmental change holds significant scientific importance and practical value for the sustainable development of ecological environments and socio-economies. This study examines the Yanqi Basin in Xinjiang as a case area, utilizing Landsat remote sensing imagery, DEM data, and meteorological data to analyze changes in ecosystem service values (ESV) and their driving factors over the past 40 years (1973–2014). Non-parametric climate change breakpoint detection (Mann-Kendall-Sneyers test) and trend analysis methods (Mann-Kendall, MK) were applied, alongside calculations of ESV and land use/cover change (LUCC) dynamic degree. Results show that: (1) Changes in ecosystem service values and functions result from the combined effects of climate change and human activity; (2) The shrinking of glacier areas in mountainous regions constitutes the primary cause of declining ecological service values in these areas; (3) The ecosystem service value in plain areas exhibited a decreasing trend followed by an increase, with 2004 serving as the turning point. The total ecosystem service values for the entire study area were 85.86×10 Yuan in 1973, 94.46×10 Yuan in 1977, 84.15×10 Yuan in 1994, 89.40×10 Yuan in 2004, and 96.47×10 Yuan in 2014, aligning with precipitation and evaporation trends. The main reasons for increased ecosystem service values in plain areas include long-term land reclamation, expansion of oasis areas, and favorable climate change support (increased precipitation and decreased evaporation). In mountainous areas, ecosystem service values vary with precipitation and evaporation changes, while in oasis areas, these changes result from the combined effects of human activities such as land cultivation, afforestation, re-cultivation, and artificial reed cultivation, together with climate warming.

Keywords: Climate change; Human activity; Ecosystem service values; Yanqi Basin

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Introduction

Accelerated socio-economic development and climate warming have intensified contradictions among population, resources, and ecological environments.

Achieving balance between resource-environment systems and socio-economic development under environmental change has become a critical concern for governments and scholars worldwide. Research on climate change, human activity, and ecosystem service value changes constitutes an essential component of environmental evolution assessment, with these factors exhibiting complex interrelationships of mutual influence and constraint. Land use/cover change (LUCC) represents the most critical intersection between humans and nature in processes of environmental change induced by human activity and climate change. LUCC and resulting landscape ecological changes affect ecosystem structure and function [1], thereby altering ecosystem service values (ESV) and functions. Consequently, integrated research on ecosystem service values with climate change and LUCC is crucial for understanding regional ecological environmental changes and trends, maintaining ecological balance, and promoting coordinated regional environmental and economic development [2–3].

Ecosystem service values and functions respond differently to climate change and human activity across various geographical environments. The 2000 IPCC report indicates significant global climate and environmental changes over the past century, particularly evident in the last 50 years [4], with over half of climate warming since the 1950s attributed to human activity [5]. Different regional climate factors such as precipitation, evaporation, and radiation energy exert varying driving effects on different landscape types [6]. In China's arid and semi-arid northwestern regions, terrestrial ecosystem changes result from comprehensive effects of multiple factors [7], with ecosystem service functions being highly sensitive to moisture conditions determined by precipitation-evaporation balances. Meanwhile, continuous population growth and rapid socio-economic development have accelerated large-scale land and water resource development, converting natural vegetation areas into agricultural zones and perennially covered land into seasonally cultivated farmland [8]. Studies demonstrate that LUCC primarily results from human socio-economic activities [9–10], meaning that human socio-economic development drives land use/cover type changes, consequently altering ecosystem service values and functions.

Numerous studies have addressed ecosystem service values in China's northwestern arid regions, but few have connected these with climate change, particularly regarding the Yanqi Basin and its surrounding areas in the central Tianshan Mountains. Investigating correlations among climate change, human activity, and ecosystem service values across different spatiotemporal scales will become a research priority for sustainable development issues encompassing economy, politics, and ecology in the Yanqi Basin. Previous research has described how environmental changes and land use type variations are mainly influenced by human activity. However, under climate warming conditions, these studies have primarily considered human impacts while neglecting climate warming effects, focusing mainly on human-concentrated areas with limited research on mountainous ecosystem service values. Moreover, the applicability of research results and methods from other regions to arid and semi-arid areas remains uncertain.

This study selects the Yanqi Basin in Xinjiang—characterized by significant climate change [11], complex topography [12], and pronounced human impacts on ecosystem service values [13-14]—as the research area to explore the effects of human activity and climate change on ecosystem service values, providing important theoretical and practical significance for correctly identifying environmental responses in arid regions under changing conditions and for regional socio-economic development planning.

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1 Study Area Overview

The Yanqi Basin is located between 85°6 -87°36 E and 41°33 -42°42 N, geographically situated as an intermountain basin among the Yilianhabierga and Hola Mountains of the main Tianshan range, the intermediate Mengerbin Mountain, and the southern Quruktag Mountains. Administratively, it includes Heshuo, Yanqi, Bohu, and Hejing counties in the Bayingolin Mongol Autonomous Prefecture of Xinjiang. This study primarily focuses on the Landsat remote sensing imagery WRS2-Path143/Row31 strip covering the Yanqi Basin and surrounding mountain distributions, with the spatial boundary defined by considering basin watershed boundaries and trimming a small southeastern portion due to remote sensing data limitations [Figure 1: see original paper].

The total study area covers 14,504.53 km², with terrain sloping from high in the west and north to low in the east and south, forming a basin-centered morphology with distinct "three-dimensional climate" characteristics. Based on human activity intensity and natural geographical conditions, the Yanqi Basin can be divided into: (1) the oasis plain area where human disturbance is strongest (areas below the 1,400 m contour, covering 9,018.46 km²), and (2) the mountainous area where climate change dominates environmental evolution (areas above 1,400 m, approximately 5,486 km²) [15].

The study area lies in arid and semi-arid zones with a warm temperate continental arid climate, abundant heat and sunlight. Multi-year average temperatures are -4.84°C in mountainous areas and 8.6°C in oasis plains, with evaporation of 1,408.23 mm and 1,973.65 mm, and precipitation of 200.25 mm and 76.27 mm, respectively. Since the 1950s, particularly after the 1970s, agricultural cultivated land in oasis areas has shown continuous growth, making the Yanqi Basin a region significantly impacted by human activity in China.

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2 Data and Methods

2.1 Data Sources

This study utilized Landsat MSS, TM, and ETM+ remote sensing data from 1973-2014 provided by the US Geological Survey (USGS, http://earthexplorer.usgs.gov/), ASTER GDEM V2.0 data (30 m resolution) jointly completed by NASA and Japan' s Ministry of Economy, Trade and Industry (METI), extensive control point data collected through field surveys in October 2014, and various ground object positioning samples. Landsat imagery underwent preprocessing including geometric correction, format conversion, atmospheric correction, histogram-based image mosaicking, and image cropping. DEM and control points were combined to determine the 1,400 m elevation contour as the boundary between mountainous and plain areas.

2.2 Methods

2.2.1 Climate Change Breakpoint Detection and Trend Analysis The non-parametric Mann-Kendall (MK) trend test [16–17] was applied to analyze precipitation and evaporation trends in mountainous and plain areas. For time series data with breakpoints, the non-parametric MK-Sneyers breakpoint test [18] was used for significance verification to identify genuine breakpoints and determine appropriate remote sensing data periods. ENVI 5.1 software was then used to extract land use/cover changes in the Yanqi Basin and surrounding mountains.

2.2.2 Land Use Dynamic Data Acquisition Based on the "Current Land Use Classification" standard issued by China' s Standardization Administration in August 2007 [19] and the FAO/UNEP land classification system, and considering the land use/cover characteristics of the study area, land use/cover was classified into seven types through field verification: cultivated land, alpine meadow steppe (vegetation above 1,400 m), warm shrub grassland (naturally formed vegetation with primarily ecological functions), wetland, water bodies (lakes, rivers, ponds, reservoirs), glacier/snow cover, and desert. Using field sampling data, preprocessed Landsat imagery was interpreted, classified, and accuracy-assessed. Accuracy evaluation showed average overall classification accuracies exceeding 89.60% for all five periods (Kappa coefficient > 0.84), with some annual results shown in [Figure 2: see original paper]. Subsequently, landscape type transfer analysis was conducted using the five classified remote sensing images from 1973–2014.

2.2.3 Land Use Change Trend and Ecosystem Service Value Calculation Land use dynamic degree reflects the change rate of a particular land use type quantity, expressing both single-type spatiotemporal changes and overall regional land use dynamics [20]. Single land use type dynamic degree expresses quantity changes of a specific land use type within a certain period, calculated as:

$$L = \frac{U_{\text{out}} - U_{\text{in}}}{U_{\text{initial}} \times N} \times 100\%$$

where U_{out} represents the total area of a land use/cover type converted to other types during study period N; U_{in} represents the area converted from other types to this type; U_{initial} is the initial area of the land use/cover type; and N is the study period. When N is set in years, L represents the annual change rate. However, L only reflects annual area changes without spatial variation [21]. Therefore, spatial change dynamic degree K for a land use/cover type is expressed as:

$$K = \frac{U_{\text{out}} + U_{\text{in}}}{U_{\text{initial}} \times N} \times 100\%$$

where U_{out}, U_{in}, U_{initial}, and N share the same meanings as in equation (1).

Numerous scholars have conducted value assessments at different scales for individual ecosystems and ecosystem services. Costanza et al. [22] established the scientific principles and methods for ecosystem service valuation in 1997. Xie et al. [23] adapted these results to Chinese conditions, deriving unit area ecosystem service values for China' s terrestrial ecosystems. This study employs the coefficient of sensitivity (CS) to determine the dependency of ecosystem service values on temporal and value index changes. By adjusting the value indices of various land use types by 50%, total ecosystem service value changes were measured. Adjusted ecosystem service value coefficients were estimated for 1973, 1977, 1994, 2004, and 2014, with CS > 1 indicating elasticity and CS < 1 indicating inelasticity relative to ecosystem service values. The sensitivity index is calculated as:

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

where CS is sensitivity, ESV is total ecosystem service value, VC is value coefficient, m and n represent adjusted and initial ecosystem service values, respectively, and c denotes each land use type.

Based on these calculations, the equivalent factor table for unit area ecosystem service values in the Yanqi Basin was derived [23] .

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3 Results and Analysis

3.1 Climate Change Characteristics

As shown in [Figure 2: see original paper], precipitation increasing trends in both mountainous and oasis plain areas reached significant levels, with Z-values of 3.0 and 3.2 ($P < 0.01$), respectively. Over the past 40 years, annual average precipitation in the Yanqi Basin' s mountainous and plain areas showed significant increasing trends. MK-Sneyers breakpoint test results also revealed clear precipitation breakpoints since 1970.

Evaporation MK trend test results indicated decreasing trends during 1980-2014 in both mountainous and plain areas, with Z-values of -4.2 and -3.60, both reaching 99% significance levels. While mountainous evaporation showed a decreasing trend over the past 30 years, plain area evaporation decreased before 1998 but slightly increased afterward, exhibiting overall fluctuating decreasing trends.

3.2 Land Use Type Transfer Analysis

Based on the time periods identified through MK breakpoint analysis, Landsat images from 1973, 1977, 1994, 2004, and 2014 were selected for interpretation [Figure 3: see original paper] and landscape type transfer analysis and .

The plain area conversion matrix shows that wetland converted to water bodies during the high water level periods of Bosten Lake in the early 1970s and around 2000, while water bodies converted to wetland during other periods. Wetland consistently converted to cultivated land during 1977-2014 due to extensive reclamation. Throughout the study period, increased precipitation and decreased evaporation raised soil moisture content, causing desert conversion to warm shrub grassland. Additionally, long-term reclamation activities converted large areas of warm shrub grassland.

The mountainous area conversion matrix reveals glacier conversion to alpine meadow steppe throughout the study period, with glacier area reduction trends consistent with Tianshan glacier changes [24-25]. Desert changes were insignificant. Overall, increased plain area population and extensive reclamation rapidly expanded cultivated land into surrounding desert areas, reducing plain desert area. In mountainous areas, increased precipitation and decreased evaporation primarily drove the fluctuating increase in alpine meadow steppe area. These findings demonstrate that plain area land use changes closely relate to human activity, while mountainous areas are mainly influenced by climate change.

3.3 Land Use Type Dynamic Degree Analysis

As shown in , during 1973-1977, warm shrub grassland area increased most rapidly (11.51%) with the largest spatial change dynamic degree (32.93%), while plain desert area decreased fastest (-5.39%), consistent with increased precipitation during this period. During 1977-1994, wetland area increased at 3.98% with relatively high spatial dynamic degree, while plain desert area decreased fastest (-2.46%). Glacier and mountain desert changes were weak with minimal spatial dynamic degrees. During 1994-2004, plain desert area increased rapidly (8.89%) with maximum spatial dynamic degree (11.22%), while water body area decreased fastest (-3.17%). During 2004-2014, glacier area decreased fastest (-3.59%) and cultivated land showed the highest spatial dynamic degree (12.76%).

Overall, spatiotemporal dynamic degrees varied across land use/cover types. Cultivated land consistently showed net increasing trends throughout the study period, while water bodies and glaciers generally showed decreasing temporal dynamic degrees. This indicates that contradictions between water and land resources have become more pronounced after development than before.

3.4 Land Use Type Impacts on Ecosystem Service Values and Sensitivity Analysis

Tables 5-7 show that during 1973-1977, plain area ecosystem service functions including gas regulation, climate regulation, soil formation, waste disposal, biodiversity protection, food production, raw materials, and recreation all declined, while cultivated land, water body, and wetland ecological service values increased by 97.14×10 Yuan · a^{1}, 76.93×10 Yuan · a^{1}, and 758.86×10 Yuan · a^{1}, respectively. Waste disposal service value increased by 0.28×10 Yuan. All ecosystem service functions and values improved in mountainous areas.

During 1977-1994, all plain area ecosystem service functions showed decreasing trends, with waste disposal value decreasing most (0.15×10 Yuan). Except for cultivated land, other land use types also showed decreased ecological service values. In mountainous areas, alpine meadow steppe ecological service value increased by 12.78×10 Yuan · a^{1}, while glacier and desert reductions decreased their ecological service values by 0.03×10 Yuan · a^{1} and 48.37×10 Yuan · a^{1}, respectively. Water conservation and waste disposal service values decreased by 0.17×10 Yuan.

During 1994-2004, plain area waste disposal value increased by 20.79×10 Yuan while mountainous area decreased by 0.4×10 Yuan. Plain area water conservation value increased by 19.32×10 Yuan. Plain area cultivated land, wetland, and water body ecological service values increased by 163.91×10 Yuan · a^{1}, 189.34×10 Yuan · a^{1}, and 56.33×10 Yuan · a^{1}, respectively. Glacier and alpine meadow steppe ecological service values showed decreasing trends, while mountain desert ecological service value increased and plain desert value decreased.

During 2004-2014, plain area wetland ecological service value increased most significantly (693.56×10 Yuan · a^{1}), while water body ecological service value decreased (452.09×10 Yuan · a^{1}). In mountainous areas, waste disposal, water conservation, and climate regulation values increased by 0.45×10 Yuan, 0.43×10 Yuan, and 0.22×10 Yuan, respectively, while these values decreased in plain areas by 23.06×10 Yuan, 22.08×10 Yuan, and 11.08×10 Yuan, respectively. Mountain desert ecological service value increased by 25.73×10 Yuan · a^{1}.

After adjusting various land use type value indices by 50%, the ecosystem service value sensitivity indices for 1973, 1977, 1994, 2004, and 2014 were calculated . Cultivated land and wetland sensitivity indices showed increasing trends, while water body, plain desert, and mountain desert sensitivity indices decreased. This indicates that changes in cultivated land and wetland ecological service value coefficients amplify total ecosystem service value fluctuations, while water body and desert coefficient changes dampen these fluctuations. Overall, sensitivity indices for different land use types were far less than 1, indicating that ecosystem service values are inelastic to functional index changes, confirming result reliability. The unit area ecosystem service value coefficients established by Xie et al. [23] are suitable for ecosystem service value research in this study area.

3.5 Climate Change and Ecosystem Service Value Change Analysis

Based on MK breakpoints [Figure 2: see original paper] and , ecosystem service value change trends were analyzed. During 1973–1977, mountainous annual average precipitation increased by 29.4 mm, with ecosystem service values showing slight increases. Plain area precipitation increased by 15.64 mm, with ecosystem service values increasing by 8.54×10 Yuan. During 1977–1994, mountainous and plain area annual average precipitation increased by 19 mm, while annual average evaporation increased by 404 mm—substantially more than precipitation increases—causing overall ecosystem service value decreases .

During 1994–2004, mountainous annual average precipitation increased significantly, reaching a historical maximum of 269.2 mm in 1998, while evaporation decreased, increasing ecosystem service values by 0.24×10 Yuan. In plain areas, precipitation increases and evaporation decreases were less pronounced, yet ecosystem service values increased by 5.01×10 Yuan. During 2004–2014, mountainous precipitation slightly decreased while evaporation showed clear decreasing trends, reducing ecosystem service values to 0.67×10 Yuan. In plain areas, precipitation slightly increased but evaporation increases exceeded precipitation increases, yet ecosystem service values continued increasing by 6.37×10 Yuan.

In summary, climate change represents the primary factor affecting mountainous ecosystem service values, while plain area ecosystem service value changes result from combined climate change and human activity effects, with human impacts on plain area ecosystem service values becoming increasingly pronounced.

Discussion and Conclusion

Ecosystem service values and functions in the Yanqi Basin vary with precipitation and evaporation changes. Cultivated land ecological service values show linear increases. In plain areas during 1973–2004, gas regulation, climate regulation, water conservation, soil formation, waste disposal, biodiversity protection, food production, raw materials, and recreation values continuously decreased, while all these values increased during 2004–2014. This primarily resulted from combined effects of human activities including land reclamation, afforestation, re-cultivation, and artificial reed cultivation, together with climate warming. In mountainous areas during 1973–2014, ecosystem service values showed continuous decreasing trends, mainly related to glacier area shrinkage caused by climate change.

Ecosystems and their functions are undergoing profound changes at different scales under the dual impacts of climate change and human activity. Therefore, research on ecosystem service functions under changing environments holds important scientific significance and application value for sustainable ecological environment and socio-economic development. This study integrated Landsat remote sensing interpretation data, DEM data, and meteorological data from 1973–2014 to analyze ecosystem service function changes and their driving factors in the Yanqi Basin, Xinjiang over the past 40 years. Results indicate:

1) LUCC analysis showed that during 1973–1977, most water bodies converted to wetlands, and most warm shrub grassland converted to cultivated land and desert. During 1977–1994, cultivated land proportions increased while wetland and warm shrub grassland proportions decreased, with continuous desert area reduction. During 1994–2004, cultivated land showed the fastest increase among all land use types in plain areas, while alpine meadow steppe showed the largest increase in mountainous areas. During 2004–2014, cultivated land, warm shrub grassland, and wetland areas increased in plain areas, while alpine meadow steppe showed the largest and fastest increase in mountainous areas, synchronized with climate warming, precipitation increases, and evaporation decreases. Biological mass fluctuated and increased across the study area, with improving ecological environments, though decreasing water bodies and glaciers pose challenges to sustainable healthy ecological development.

2) Dynamic degree analysis of LUCC revealed varying spatiotemporal changes across land use/cover types. Throughout the study period, cultivated land consistently showed net increasing trends, while water bodies and glaciers generally showed decreasing temporal dynamic degrees. Contradictions between water and land resources became more pronounced after development than before.

3) All ecosystem service functions showed increasing trends in the Yanqi Basin plain areas, with cultivated land ecological service values increasing linearly due to large-scale reclamation and oasis expansion.

4) Ecosystem service values and functions varied with precipitation and evaporation changes. In plain areas during 1973–2004, gas regulation, climate regulation, water conservation, soil formation, waste disposal, biodiversity protection, food production, raw materials, and recreation values continuously decreased, while all these values increased during 2004–2014 due to combined effects of land reclamation, afforestation, re-cultivation, artificial reed cultivation, and climate warming. In mountainous areas during 1973–2014, ecosystem service values showed decreasing trends primarily related to glacier area shrinkage caused by climate change.

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Note: Figure translations are in progress. See original paper for figures.