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Integrated land restoration impact assessment in the Chinese Loess Plateau

Hao Chen 陈昊

INTEGRATED Land Restoration Impact Assessment

in the Chinese Loess Plateau

Hao Chen

INVITATION

It is a great pleasure to invite you to attend the thesis defense entitled

Integrated land restoration impact assessment in the Chinese Loess Plateau

Thursday 25 November 2021
at 11 a.m. in the
Aula of Wageningen
University & Research,
Generaal Foulkesweg 1,
Wageningen

A reception will be held after the defense

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Propositions

1. Although land restoration is globally heralded as the pathway to integrally improve ecosystem service delivery from landscapes, its side-effects deserve critical scrutiny. (this thesis)

2. Restoration-induced environmental changes observed by ecological models are also perceived by local stakeholders. (this thesis)

3. Scientific findings are meaningful for researchers rather than policy makers, especially in a top-down policy context.

4. Urbanization offers rural areas space and time to rebuild damaged ecosystems.

5. The COVID-19 pandemic makes the Sustainable Development Goals in 2030 more difficult to achieve.

6. Food security will remain an essential scientific and society issue in the future even if agricultural technics is further developing.

Propositions belonging to the thesis, entitled
Integrated land restoration impact assessment in the Chinese Loess Plateau

Hao Chen
Wageningen, 25 November 2021

Integrated land restoration impact assessment in the Chinese Loess Plateau

Hao Chen

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Integrated land restoration impact assessment in the Chinese Loess Plateau

Hao Chen

Thesis
Submitted in fulfilment of the requirements for the degree of doctor
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Prof. Dr A.P.J. Mol
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Abstract

Land restoration has been implemented worldwide as an effective way to combat land degradation and improve biodiversity. As one of the most severely eroded regions in the world, the Chinese Loess Plateau has been given a lot of attention by the national government since the 1970s in terms of land restoration policies, most recently and most comprehensively by the Grain for Green Project (GGP) (1999-2021). The main goal of the GGP was to restore the ecosystem through afforestation and soil and water conservation. Over the past few decades, land restoration actions have not only altered land use and delivery of ecosystem services in the Loess Plateau, but also changed the living conditions of many of the stakeholders. The main objectives of this thesis are to comprehensively understand the hydrological, bio-physical, economic and societal impacts of land restoration in the Chinese Loess Plateau.

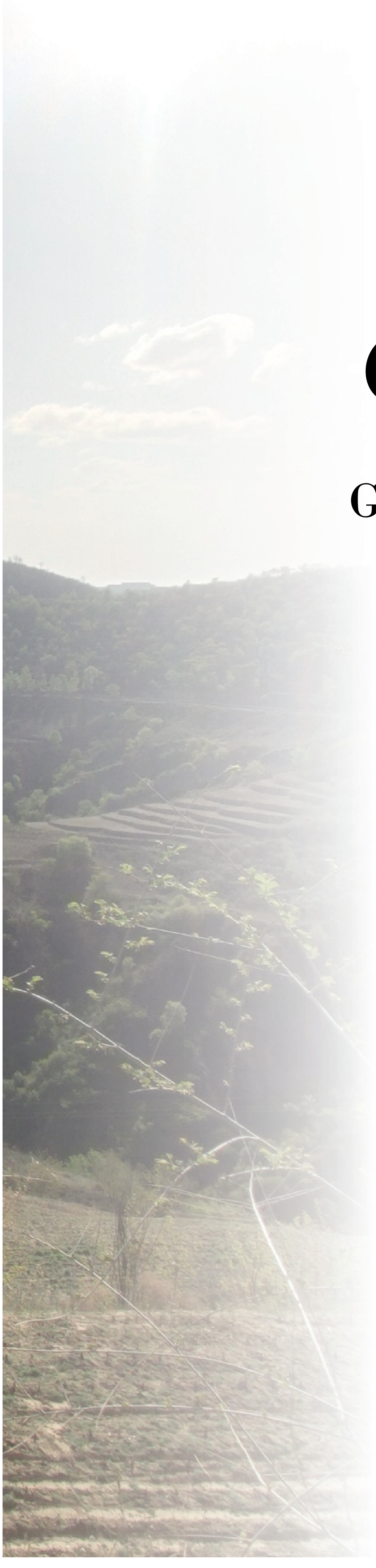
Using 52 published watershed case studies, a meta-analysis was conducted to describe the impacts of changes in land use and climate on streamflow in the Chinese Loess Plateau. The majority of the studied watersheds showed that the streamflow decreased significantly (-0.46mm/year over the period 1959-2015). 64% of this decrease in streamflow can be attributed to land use changes and 36% to climate change.

Subsequently, based on ecological models and statistical data, the temporal and spatial dynamics of ecosystem services over the course of the GGP was studied. Building land use scenarios, we were able to conduct a cost-benefit analysis to estimate the monetary benefit from this land restoration project. We found significant increases in fruit production, sediment retention, habitat quality, and aesthetic landscape value, as well as learning and inspiration value over time (from 2000 to 2018). We also found decreases in timber production and water yield. The majority of county-level ecosystem service bundles have transitioned from focusing on timber production to focusing on aesthetic landscape value. Meanwhile, the total monetary value of the ecosystem services minus restoration costs reached a net present value of 19.41 billion RMB over the period 2000-2020 as compared to the scenario without land restoration.

We also surveyed 150 stakeholders to understand their perceptions on current and future land restoration policy and its impacts on ecosystem services. The survey results indicated that 72% of stakeholders supported current land restoration, with government officers reporting the highest values and tourism operators the lowest. Only 51% of stakeholders supported future land restoration. Some farmers could eventually decide to recultivate restored forest, mainly for economic reasons.

Overall, this thesis compiles a comprehensive study of the impacts of previous land restoration in the Loess Plateau, providing a framework for land restoration appraisal from ecological, economic and societal perspectives. The introduction of land restoration bolsters local regulating and cultural services, and is also monetarily beneficial. Land restoration was found to induce streamflow reduction. To avoid potential conflicts, any future land restoration policy should attempt to reduce negative economic impacts for farmers. By conducting ex ante assessments of restoration alternatives and involving stakeholders in potential designs, such trade-offs can be anticipated and addressed, e.g., by diversifying tree species to be planted.

Table of contents



Chapter I

General Introduction

1.1 Introduction

Over 40% of the world's land surface is arid and semi-arid, yet these dry zones are home to 38% of the human population (Allan et al., 2013). Arid and semi-arid areas are more sensitive and ecologically vulnerable to the impacts of climate change and human activities, and thus the effective management of the biophysical environment of these regions is a critical issue (Li et al., 2016). In order to address land degradation and ecological deterioration of these regions, a number of large-scale land restoration projects have been implemented worldwide which have significantly improved biodiversity and changed local ecosystem services (Benayas et al., 2009).

The Chinese Loess Plateau region is an arid area that has experienced severe soil erosion and land degradation due to strongly dissected landscapes, high soil erodibility, intensive rainfall and human activities (Tsunekawa et al., 2014). As one of the most severely eroded regions in the world, the Chinese Loess Plateau has been given a lot of attention in terms of land restoration policies implemented by the national government (Cao et al., 2009). A brief history of the land restoration policies and legislation in the Chinese Loess Plateau is displayed in Fig. 1.1.

Starting from the establishment of the People's Republic of China (PRC) in 1949, legislation and regulations have been established for forest protection and soil and water conservation. Between 1949 and 1960, the main restoration activity in the Loess Plateau was terrace building to maintain food security. After 1960, engineered measures for soil and water conservation were introduced in the plateau, such as the check-dams, for example. From 1970 till the end of the last century, multiple land restoration projects took place on the Loess Plateau which focused on vegetation rehabilitation, soil and water conservation measures and desertification control (Deng et al. 2019).

In 1999, one of the world's largest ecological restoration programs named the Grain for Green project (GGP) was initiated (Person et al. 2013). It is well-known for its large implementation area and ambitious goals (Zhou et al. 2016; Jian et al. 2015). The major goal of the GGP was to restore ecologically damaged land by converting all agricultural land with a slope steeper than 25° and bare land into forest and grassland (Yin, 2009). With the implementation of the GGP, around 28 million hectares of cropland and bare land were converted into grassland and forest from 1999 to 2009 (Zhou et al. 2012). The GGP was realized in 25 provinces, municipalities and autonomous regions of China, covering more than 20 million hectares of cropland and barren land (Persson et al., 2013). Geographically, the GGP covered the middle and upper reaches of the Yangtze River and the Yellow River within the Chinese Loess Plateau, where frequent land degradation and soil erosion had occurred over the past five decades (Zhang 2000).

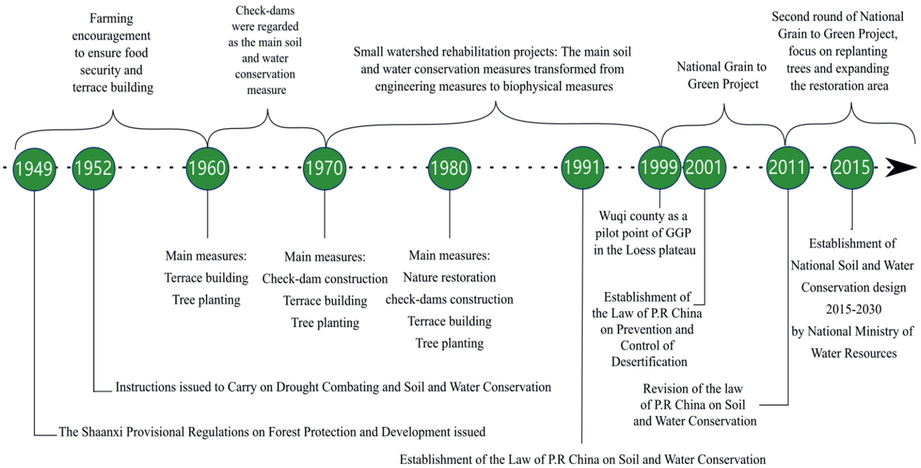


Figure 1.1 Timeline of the Loess Plateau restoration policies and legislation. Compiled based on: Shi & Shao (2000); Su & Fu (2013); Yin (2009).

Meanwhile, subsidies and grain were provided by local governments as a compensation for farmers' loss of farmlands (Cao et al., 2009). The GGP was initiated by the Chinese government which invested billions of RMB and included millions of rural households (Lü et al., 2012a). For example, in Ansai County in the Loess Plateau, farmers first received a subsidy of 160 RMB/mu (1404 €/ha[1]) for 8 years, followed by a subsidy of 90 RMB/mu for another 8 years when converting their croplands into forests. Additionally, farmers were requested by the local GGP office to maintain the restored forests, which mainly involved replanting dead trees. Every year before granting the subsidy, the GGP office would examine the survival rate of the planted trees and only the farmers who's forests met the requirements would get the subsidy.

Meanwhile, the livelihoods of the local farmers changed: part of their main income source shifted from agricultural production to government subsidies (Yan Liu & Dong, 2014). With the implementation of the GGP, a series of changes in land use and vegetation cover took place in this region (Wang et al. 2015). The GGP brought a dramatic alteration of land use and, thus, a transformation in the delivery of ecosystem services (Chen et al. 2015).

In general, the Chinese Loess Plateau has experienced a series of land restoration projects over the last century. These human-induced projects have altered the land cover, transformed the delivery of ecosystem services and changed the livelihoods of the local farmers.

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[1] 1 EUR = 7.60 RMB, 1 mu = 0.0667 hectares

1.2 Research problem: Integrated impacts of land restoration

Land restoration projects have been implemented in the Chinese Loess Plateau over the last several decades, bringing dramatic changes in terms of hydrological, bio-physical, economic, and social perspectives to the restored area. Until now, research concerning the impacts of land restoration in the Chinese Loess Plateau have been limited to certain fields of science. Few of the previous studies examined the integrated impacts of land restoration in the Chinese Loess Plateau.

Over the past few decades of land restoration in the Chinese Loess Plateau, revegetation has been the primary method used to reduce soil erodibility and conserve soil and water. For instance, from 1998 to 2005, forest and grassland cover in the Shaanxi province increased from 29.7% to 42.2% (Cao et al. 2009). However, the increased vegetation cover brought unexpected side-effects, namely increased pressure on the local water supply. The growth in forested areas as a result of land restoration led to increased water consumption, resulting in decreased streamflow for these areas (Duan et al., 2016). Bear in mind that the climate of the Loess Plateau is identified as semi-arid, with precipitation varying from 800 mm in the south to 400 mm in the north. To add to this, the bulk of the precipitation usually occurs in the summer season in the form of rainstorms. Therefore, during the rest of the year, the water supply is limited in the Loess Plateau. In previous studies, increases and decreases in the surface waterflow in different watersheds and rivers of the Loess Plateau have been identified (Zhang et al. 2017; Zhang et al. 2008; Jin et al., 2014; Li, 2013). No research has yet focused on the general trend of surface water flow or to what extent land cover change has influenced this trend.

Secondly, the implementation of the land restoration projects have altered the land use and vegetation cover of the Loess Plateau, simultaneously changing the delivery of the ecosystem services. Ecosystem services are defined as flows of materials, energy and information which are directly or indirectly provided by ecosystems to human society, including provisioning, regulating, and supporting services as well as cultural services (Costanza et al. 1997). Many previous studies have analyzed ecosystem services on the Chinese Loess Plateau, with several addressing the dynamics and relationships between different ecosystem services. For example, Lü et al. (2012) discovered that the entire Chinese Loess Plateau had been transformed from a carbon source to a carbon sink by mapping carbon sequestration dynamics from 2000 to 2008. Feng et al. (2017) found that vegetation type and cover were the main factors affecting soil erosion control, soil moisture conservation and carbon sequestration based on field experiments in 2014. However, most previous studies examined only single trade-off and synergy relationships between regulating services, such as soil retention, water retention and water purification, ignoring the changes of other ecosystem services and the

driving forces behind such changes. Meanwhile, there is a lack of research studying the dynamics and spatial distributions of the ecosystem services during the land restoration implementation process, particularly on longer time scales.
Moreover, although the Chinese government has invested an enormous amount of time and money into land restoration projects over the past few decades, there has been a lack of studies unraveling the economic benefits from the land restoration. This kind of economic valuation could reveal the full picture of nature's societal value, meanwhile solving the shortcomings of traditional conservation, where the main focus has been on biophysical conservation and the investment value has been ignored (Gómez-Baggethun et al. 2011). Monetizing techniques are widely applied for evaluating the impact of changes in ecosystem services on components of human wellbeing, and these techniques are regarded as ways to guide decision making processes (Winkler, 2006). For example, Plummer (2009) promoted the benefit transfer method to valuate ecosystem services for conservation planning and ecosystem-based management. Decision making involving the valuation of ecosystem services can be a complex task, while cost-benefit analysis (CBA) is often considered as an effective way to guide this process (Wegner & Pascual, 2011).

Another issue arising from land restoration concerns the social impacts. To effectively achieve sustainable land management, it is very important that stakeholders in the land restoration program are fully involved in the decision making, project framing and implementation process phases (Reed, 2008). Stakeholders can be individuals or groups of people that affect or are affected by the actions and results of an initiative (Mcwilliams, 2014). Ignoring local peoples' interests and excluding them from the planning, management and decision making process of the restoration has been found to be a main source of conflict between people and the environment (Lewis 1996; Nepal 2002). The stakeholders' perception and willingness in achieving landscape restoration is essential for governmental policy making and landscape management (Cao et al. 2009).

1.3 Conceptual approach

Primary work linking ecosystem functions, services and economic value can be traced back to the 1960s and involved research conducted in New Jersey that evaluated the monetary value of global ecosystem services, which raised the general public's awareness of an ecosystem's economic value and natural capital (Costanza et al. 1997). In 2005, the Millennium Ecosystem Assessment (MEA) published by the United Nations, introduced the concept of ecosystem services, defined as the conditions and processes of ecosystems that are a benefit to human society such as provisioning, regulating and cultural services (MEA, 2005b). Later on, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) established a conceptual framework to simplify the complex interactions between natural and human societies (Díaz et al., 2015). Most recently, the

Nature's Contribution to People (NCP) concept has been coined as a central notion in the assessment carried out by IPBES, which holds a more inclusive and diverse interpretation of human-nature relations (Díaz et al., 2018). The NCP concept emphasizes the value of cultural services as nature's contribution to people, and IPBES highlights the importance of indigenous and local knowledge in the international biodiversity assessment and ecological policy making process (Ellis et al., 2019).

For the current study, a framework was created (Fig. 2.2) which explains the basic research process of this PhD study. The framework was developed based on the DPSIR model and proposes a strategy for integrated environmental assessment which distinguishes driving forces, pressures, states, impacts and responses (Smeets & Weterings, 1999). In this figure, the DPSIR of the Chinese Loess Plateau management is explained in separate boxes: the yellow box indicates the coverage of this study, while the pink box represents the outcome of this research and its potential contributions to the Loess Plateau land management. In the DPSIR framework, drivers are the governmental willingness to mitigate the land degradation issues in the Loess Plateau, and the GGP can be understood as the action pressing changes to the current environmental states.

Integrated impact assessment, which forms the core of this study, is divided into 3 parts: impacts on ecosystem services, economic values and social response. This leads to the four research questions (green boxes) to study the separated impacts in terms of ecosystem services, monetary value of ES and stakeholder perception of ES changes. The pink box indicates how this study of analyzing impacts contributes to the response, mainly through providing recommendations for future policy making. Future policy making is the main response reacting upon drivers, pressures and impacts through altering targets, changing GGP plans and influencing social responses. Arrows determine which DPSIR element is to be changed by responses. Additionally, this framework also refers to the 4 Returns Framework for landscape restoration in terms of disciplinary impact assessments, which was developed by the Commonland Foundation (Dudley et al., 2021).

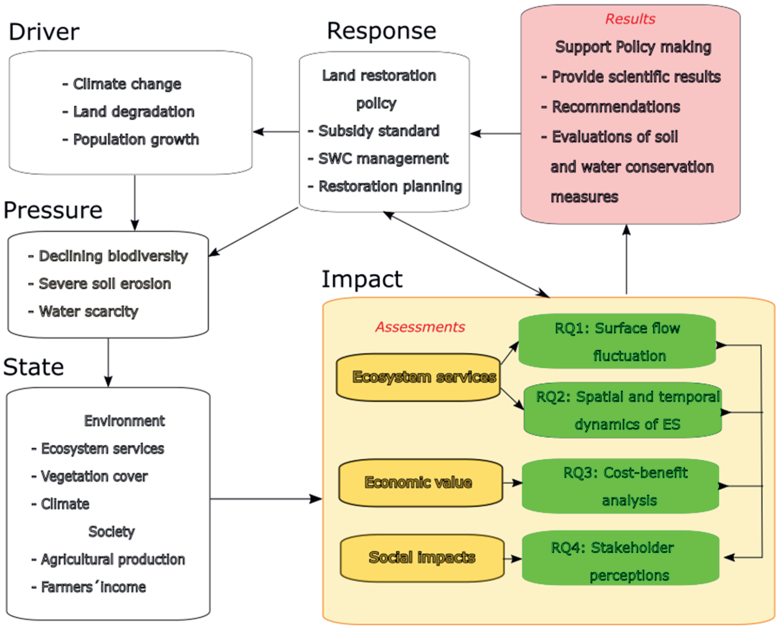


Figure 1.2 DPSIR Framework of integrated landscape restoration impact assessment. Pink and yellow boxes indicate the contribution of this study to the DPSIR framework.

1.4 Research objectives and research questions

Land use/cover change (LUCC) is highly sensitive to natural and human influences, which affects the sustainable development of human society (Lambin et al., 1999). Human-induced activities lead to inevitable changes in land use and vegetation cover on both national and regional levels. Zhou et al. (2012) found a significant rise in newly forested land and an obvious reduction in both cropland and shrub-grassland between 2000 and 2010. The ecological restoration projects in China led to obvious alterations in land cover (Chen et al. 2015; Zhou et al. 2012). Changes in land use can result in surface flow fluctuations through altered evapotranspiration, soil structure, plant water consumption and other factors (Price 2011; Fohrer et al. 2001). Additionally, climate variables influence surface flow through precipitation and temperature (Patterson et al. 2013). It has been determined that the impacts of land use and precipitation variations on surface flow were different in diverse basins (Zhang et al., 2015).

In the Chinese Loess Plateau, a huge number of studies have addressed the integrated impacts of climate and land use changes on the hydrological flow (Zuo et al. 2016; Liang et al. 2015; Zhang et al. 2017). These studies have covered different regional and catchment scales, and differed in methods used, including hydrological models and field/plot experiments. There is a need for integrating previous results and scaling field and watershed observations up to regional

processes, for example, the Loess Plateau region. Understanding and quantifying the relationships between land use, climate change and surface flow is helpful for future hydrological risk assessment, and essential for sustainable water resource management of the Yellow River basin within the Chinese Loess Plateau. Thus, I propose the first research question:
RQ1: What are the impacts of ecological restoration and climate variability on surface flow in the Chinese Loess Plateau?

Ecosystems provide services to society in terms of flows of materials, energy and information, which are defined as ecosystem services (Costanza et al. 1997). Ecosystem restoration is an important part of conservation programs and is essential to the need for long-term sustainability of human life (Aronson & Alexander, 2013). The purpose of the GGP is to reverse the land degradation status and improve ecosystem services, both in terms of quality and quantity aspects. (Chen et al., 2015). The altered land use types as well as vegetation cover changed the original ecosystem services. Trade-offs occur when one of the ecosystem services is improved at the expense of another. On the contrary, when the improvement of one ecosystem service leads to the improvement of another, the relationship could be described as synergistic. Researching synergies and trade-offs between different ecosystem services helps people understand the hidden consequences of human interference (Jopke et al. 2015; Yang et al. 2017), or the overall impacts of land restoration.

Previously, researchers compared different ecosystem service indicators to assess the impact of the GGP in different locations of China (Yang et al. 2017; Jia et al. 2014; Wang et al. 2017). Most of these studies have focused on the early impacts of the program, but few studies have reported on the later-stage impacts of ecological restoration on the Loess Plateau. Hence, the following research question is proposed:
RQ2: What are the spatial and temporal dynamics of ecosystem services before and after the Grain for Green project in the Chinese Loess Plateau?

The main functions of the ecosystem towards human wellbeing are to maintain and meet human life requirements. In 2005, the Millennium Ecosystem Assessment (MEA) published by the United Nations attracted a lot of attention, not in the least because over 1300 scientists made contributions to the MEA within a four-year period of time to integrate scientific insights for enhanced policymaking (United Nations 2005; Costanza et al. 2014). During the last few years, various frameworks and approaches have been suggested to identify, specify and quantify ecosystem values. De Groot et al. (2012) conducted 665 ecosystem monetary valuation studies over the last half-century, while Schwilch et al. (2016) developed, within the RECARE project, a framework suitable to practical application in the prevention and remediation of soil degradation as well as for the estimation of ecosystem values. Landscape restoration not only mitigates the environmental

degradation issues, but also increases the economic value of the land (Stoms et al., 2004). Land presents its direct economic value to human beings in terms of food security, water supply, and productivity (Godin et al., 2015). Unlike direct land productivity and land price, some ecosystem service values are usually non-material and often neglected (Qian & Linfei, 2012). CBA has been applied to support policy formulation and decision making in many land restoration cases, while there is an increasing tendency in the use of CBA to evaluate projects and policies which affect ecosystem services, and to promote policies that maximize net benefit flow to the society. For the current study, in order to assess the economic value of the GGP, the framework of TEV (Total Economic Value) has been introduced to study the integrated ecological and economic value from the GGP effects:
RQ3: What are the costs and benefits of the Grain for Green project and how did the monetary value of ecosystem services change after the land restoration?

During the implementation process of landscape restoration, participatory approaches are being increasingly adopted by environmental authorities worldwide (Westberg et al., 2010). Farmers, however, are not the only stakeholders in the GGP. In previous studies, less attention was given to the diverse range of stakeholders in landscape restoration. The GGP itself is of huge societal importance for every citizen in the Loess Plateau, hence it's essential to understand stakeholders' perceptions toward current landscape restoration, their personal interests in the ecosystem services and opinions of GGP impacts on local ecosystem services, as well as their expectations for future land management policy. Thus, I propose the last research question:
RQ4: What are the stakeholders' perceptions towards landscape restoration actions and impacts on the ecosystem services in the Loess Plateau?

The overall objective of this study is to understand the multidisciplinary impacts of landscape restoration on the Chinese Plateau, in terms of land use change, ecological environments, economic value and stakeholders' perceptions. Specific objectives are to:

- Quantify the impacts of ecological restoration and climate variability on surface flow.
- Assess the trade-offs and synergies of GGP on ecosystem services.
- Analyze the consequences of the GGP in terms of total monetary value (TMV).
- Conduct a cost-benefit analysis for the GGP.
- Identify the key stakeholders in the GGP and understand their perceptions towards the land restoration policy and its impacts on ecosystem services.

1.5 Methodological design

1.5.1 Ecological restoration, climate and surface hydrology

Land cover and climate variety are the two main factors influencing hydrological flow (Changnon et al. 1996; Li et al. 2009). In order to improve the understanding of regional-scale surface flow alteration processes at different spatial scales, meta-analysis is a preferable method to synthesize data from different sources. A meta-analysis can integrate and analyze diverse results of surface flow impacts from multiple studies, revealing the water distribution and scarcity issues from different locations within the Loess Plateau. Systematic review and meta-analysis are considered to be good methods which can be combined to evaluate and monitor the performance of ecological restoration (Crouzeilles et al. 2016). In this study, using a meta-analysis, we integrated results from hydrological modelling studies to quantify the effects of ecological restoration and climate change on streamflow. Moreover, different SWC measures have been applied in land restoration projects, and their effects have been assessed in various hydrological modelling studies (Chen et al. 2017; Dou et al. 2009). This study seeks to investigate the consistency of findings emerging from modelling and to indicate the key factors affecting streamflow.

1.5.2 Trade-offs and synergies of ecosystem services

Ecosystem services are usually classified into three categories: provisioning services, regulating services and cultural services. Generally, trade-offs occur within provisioning and regulating services, whereas synergies are relatively common in all three ecosystem services (Chisholm, 2010; Yang et al. 2017). In this study, the following indicators were selected from different ES categories to determine the trade-offs and synergies of ecosystem services: grain, fruit, livestock and timber production, carbon sequestration, soil retention, water yield, habitat quality, aesthetic landscape value, and outdoor recreation as well as learning & inspiration. This list covers four provisioning services, four regulating services and three cultural services. Trade-offs and synergies between different indicators will be assessed using different methods. The land cover of the Yan'an area in 1990, 2000, 2005, 2010, 2015, 2018 provide a temporal trend of land-use change for the study area. The values of each indicator will be quantified by statistical yearbook and different ecological models. The InVEST model, as a commonly used ecological model, has been adapted by many studies to quantify ecosystem services (Redhead et al., 2016; Yang et al., 2019). All values of ecosystem service indicators will be presented in the form of maps and analyzed using ArcGIS software. In addition, trade-offs and synergy analysis will be processed by fitting different indicators into a regression model, where the correlations between ecosystem services indicate trade-offs or synergistic relations.

1.5.3 Total Monetary value

Monetary value captures the value of the land from a financial perspective and can be classified into two broad values: use value and non-use value. Use values encompass direct use values and indirect use values, whereas non-use value is the importance attributed to an aspect of the environment. Direct values will be indicated for the resources obtained directly from an ecosystem, mainly provisioning (e.g., water, food) and cultural services (e.g., recreation). Meanwhile, indirect value encompasses values provided by an ecosystem indirectly, which applies to the majority of regulating services (e.g. flood prevention), while non-use value is understood as bequest values and existence values (De Groot et al., 2006). Depending on the type of value, different methods are available to quantify the monetary value, consisting of Direct Market Value (DMV), Indirect Market Value (IMV), Non-Market Value (NMV), benefit transfer and cost avoiding value. The sum of the ecosystem services value associated with resources or an aspect of the environment, is named as Total Economic (Monetary) Value (TEV) (De Groot et al. 2002). To address RQ3, land use scenarios will be introduced to project land use in 2020 in the case where land restoration was not implemented in the research area. The TEV derived from different land use (current 2020 and 2020 without GGP scenario) indicates the monetary value change brought by land restoration. Furthermore, a cost-benefit analysis is needed to understand the investment value of the GGP. By assessing the TEV of pre- and post-implementation stages of restoration, the economic return from landscape restoration could be determined.

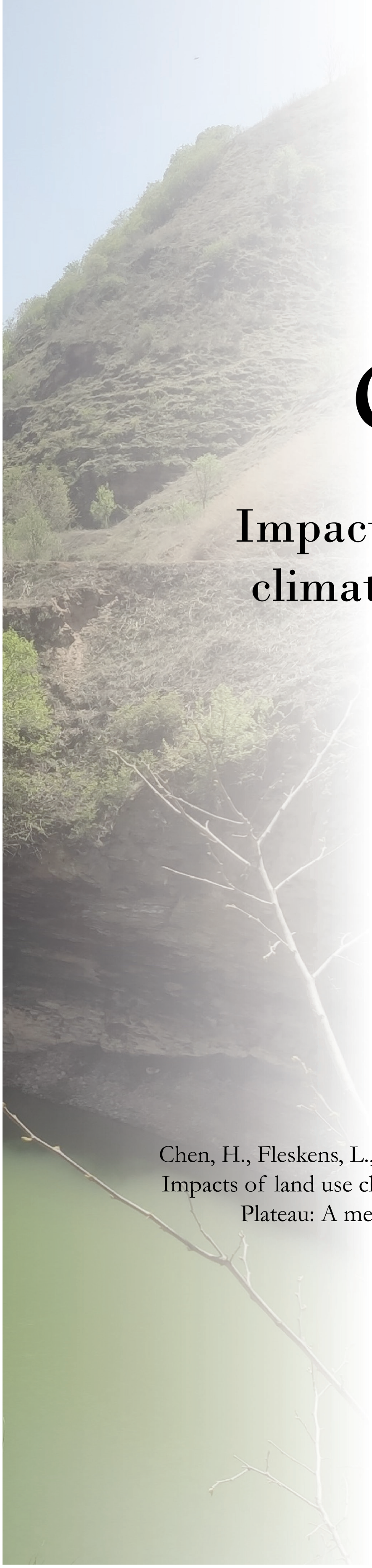
1.5.4 Analysis of stakeholders' perceptions

Interview investigation is the main method used to study environmental management and public governance issues (Xu et al. 2016). In order to answer the last research question, stakeholders' perceptions were inventoried by means of a detailed stakeholder survey, which comprised: 1) stakeholder identification and categorization; 2) Investigation of stakeholder perception towards current GGP policy and future land restoration plans; 3) Stakeholder's perception of GGP impacts on local ecosystem services; and 4) Factors influencing a farmer's decision to recultivate the restored forest. In our study, the societal impacts of land restoration were determined with farmers and other stakeholders in mind. There is no doubt that local farmers are one of the key stakeholders, as their crop and bare land are directly involved and affected by the GGP. Therefore, by separating farmers from other stakeholders we aimed to obtain more detailed GGP implementation information. In order to get an objective view of farmers' perceptions of the current land restoration actions, as well as their expectations of the land restoration managements in the future, we conducted a survey. An open and closed format semi-structured questionnaire was used to interview individual farmers face-to-face according to the method from Neuman (1991) and Graves et al. (2017).

Based on stakeholder identification and survey design, a social investigation was conducted in the Loess Plateau engaging different stakeholders including farmers. The referral sampling method is considered to be the main sampling method of interview objects. Additionally, questions concerning the GGP impacts on the ecosystem services were posed to the stakeholders in the survey with succinct and easily understandable language, asking for stakeholders' agreement and attitudes. Feedbacks and perceptions of the stakeholders were collected to understand how stakeholders value the landscape restoration impacts, comparing the coherence and heterogeneity between social cognition and environment changes.

1.6 Thesis outline

This study consists of six chapters researching the hydrological, biophysical, economic and sociological impacts of land restoration. After this introduction, in Chapter 2, impacts of land restoration and climatic variability on the surface flow are investigated by means of meta-analysis and systematically reviewing 52 case studies of 25 watersheds and rivers in the Loess Plateau. Chapter 3 focuses on studying the temporal and spatial impacts of land restoration on the ecosystem services. We used the InVEST model and referred to statistical yearbooks to estimate the provisioning of 11 ecosystem services from 1990 to 2018 in the Yan'an area of the Loess Plateau and monitored spatial and temporal dynamics of ecosystem services by ecosystem service bundles. In Chapter 4, the total monetary value of ecosystem services of Yan'an area from 2000 to 2020 is estimated by using different monetary valuation methods. In addition, a non-restoration scenario has been used to conduct a cost-benefit analysis for the GGP in 2020. In Chapter 5, the stakeholder perceptions towards current and future GGP, as well as their perspectives of GGP impacts on the local ecosystem services are investigated by face-to-face questionnaire surveys. In the final Chapter 6, findings from previous chapters are discussed and research gaps, implications, future policy recommendations for GGP and conclusions are identified.



Chapter 2

Impacts of land use change and climatic effects on streamflow[2]

[2] This chapter has been published as:
Chen, H., Fleskens, L., Baartman, J., Wang, F., Moolenaar, S., & Ritsema, C. J. (2021). Impacts of land use change and climatic effects on streamflow in the Chinese Loess Plateau: A meta-analysis. *Science of the Total Environment*, *703*, 134989

Abstract:

Land use and climate change are recognized as two major drivers affecting streamflow. On the Chinese Loess Plateau, implementation of several land restoration projects has changed land cover in recent decades. The main objective of this study is to understand how streamflow evolved in the Loess Plateau and how land use and climate change have contributed to this change. In this study, we selected 21 hydrological modelling studies covering 25 different watersheds in the Loess Plateau and we performed a meta-analysis using the hydrological and metrological data collected from these studies. The results indicate a decrease in annual streamflow depth in 41 of a total of 52 case studies whereas climate change was found to be non-significant in the majority of the cases. Streamflow depth reduction was estimated to be -0.46mm/year by meta-analysis among all case studies. Land use change was estimated to have 63.52% impact on the streamflow reduction whereas climate change accounted for 36.48% of the impact. According to meta-regression, an increasing soil and water conservation area was negatively correlated to streamflow reduction. We conclude that in the Chinese Loess Plateau, streamflow shows a decreasing trend and land restoration is the major cause of this reduction. To the knowledge of the authors, this is the first study that estimates streamflow dynamics among various watershed case studies on the entire Loess Plateau.

2.1 Introduction

According to observational evidence from most regions of the world, land cover and climate variability are the two main factors influencing hydrological flow (Huntington, 2006; Changnon *et al.* 1996; Li *et al.* 2009). Labat et al. (2004) demonstrated that climate change is leading to continental precipitation increase, which results in intensification of the global hydrological cycle. Simultaneously, human activities have altered the spatial-temporal distribution of water resources which has contributed to fluctuations of surface hydrology (Milly *et al.* 2005). Uncertainty of surface streamflow may cause natural disasters such as flood and drought, which is threatening human life and property. For the sake of safeguarding human security and avoiding economic loss from floods and droughts, investigating the impacts of climate change and human activities on streamflow is becoming an important scientific issue (Zhao *et al.* 2014). Understanding how streamflow is affected by land cover and climate change is crucial to inform adaptive land and water management. Assessment of human activities and climate change impacts on streamflow is usually performed by applying various hydrological models at regional scale (Akter *et al.* 2018; Op de Hipt *et al.* 2019). For instance, Zipper *et al.* (2018) developed a regression-based framework to separate climate and land use effects on hydrological fluxes in the Yahara River Watershed in Wisconsin, USA. The Soil Water Assessment Tool (SWAT) model is also widely used to understand the long-term impacts of watershed management and climate change (Ghaffari *et al.* 2010; Lin *et al.* 2015; Narsimlu *et al.* 2013).

To address land degradation and ecological deterioration issues, a number of large-scale land restoration projects have been implemented globally which have significantly changed the local land use and land cover (LUCC) (Benayas *et al.* 2009). As an example of large-scale LUCC programs, China has initiated land restoration projects to recover large-scale degraded land since the 1950s. The Chinese Loess Plateau, as one of the most severely eroded regions in the world, was given strong attention from government-led land restoration policy (Sun *et al.* 2014). From 1970 till the end of the last century, the plateau was covered by multiple land restoration projects in terms of vegetation rehabilitation, soil and water conservation measures and desertification control (Deng *et al.* 2019). In 1999, one of the world's largest ecological restoration programs named Grain for Green project (GGP) was initiated. It is well-known for its large implementation area and ambitious goals (Zhou *et al.* 2016; Jian *et al.* 2015). GGP has achieved initial success on vegetation recovery, for instance, from 1998-2005, forest and grassland cover in Shaanxi province raised from 29.7% to 42.2% (Cao *et al.* 2009).

Previous studies have investigated the Loess Plateau watersheds at varying regional and catchment scales with various methods, most commonly using hydrological models and field/plot experiments (Zhao et al. 2017; Li et al. 2007). However, there has been little quantitative impact analysis reviewing previous findings systematically. Hu *et al.* (2017a) concluded that ecological restoration accounted for 72.18% of the streamflow reduction by means of a meta-analysis based on field experimental data in the Loess Plateau. However, far too little attention has been paid to summarizing and synthesizing results from hydrological modelling studies. Systematic review, combined with meta-analysis are considered as good methods to evaluate and monitor the performance of ecological restoration (Crouzeilles *et al.* 2016). A meta-analysis is a statistical method to synthesize data from a series of studies, providing an objective, transparent and reliable framework (Borenstein *et al.* 2011; Akter *et al*. 2018). In this study, using a meta-analysis, we integrated results from hydrological modelling studies to quantify the effects of ecological restoration and climate change on streamflow. Moreover, different soil and water conservation measures (SWC) have been applied in land restoration projects, and their effects have been assessed in various hydrological modelling studies (Chen *et al.* 2017; Dou *et al.* 2009). This study seeks to investigate the consistency emerging from modelling sources and indicate the key factors affecting streamflow. The aims of this study therefore were to: a) Understand the temporal trends in precipitation and surface streamflow; b). Identify the land use and climate impacts on streamflow; c). Reveal impact levels of different soil and water conservation measures on streamflow.

2.2 Materials and Methods

2.2.1 Article search and data extraction

To quantify land use and climate impacts on surface water flow in the Chinese Loess Plateau, an article search was conducted by means of various search engines. English articles were mainly collected from Web of Knowledge (http://www.isiwebof-knowledge.com/), Science Direct (https://www.sciencedirect.com/) and Google Scholar (https://scholar.google.com/); meanwhile China National Knowledge Infrastructure (http://www.cnki.net/) was used for searching articles written in the Chinese language. The article search was carried out up to 18th of May in 2018 with restricted publication year from 1945-2018, in which keywords were combined as: (“runoff” OR “surface flow” OR “discharge” OR “streamflow” OR “hydrological” OR “water yield”) AND (“land use” OR “human” OR “restoration” OR “climatic” OR “climate”) AND (“Chinese” OR “Loess Plateau” OR “Yellow River”). The article selection process is explained in Figure 1. Web of Knowledge and Science Direct were the main sources of articles. Articles meeting the following conditions were considered: 1) both land use change and climate change influences are included and impacts on surface water flow are studied at the same time; 2) the research site was located within the Chinese Loess Plateau, i.e. the middle Yellow river basin is out of the Loess Plateau scope and thus excluded; 3) quantitative information on land use change, runoff and precipitation are directly provided or could be indirectly estimated from the article.

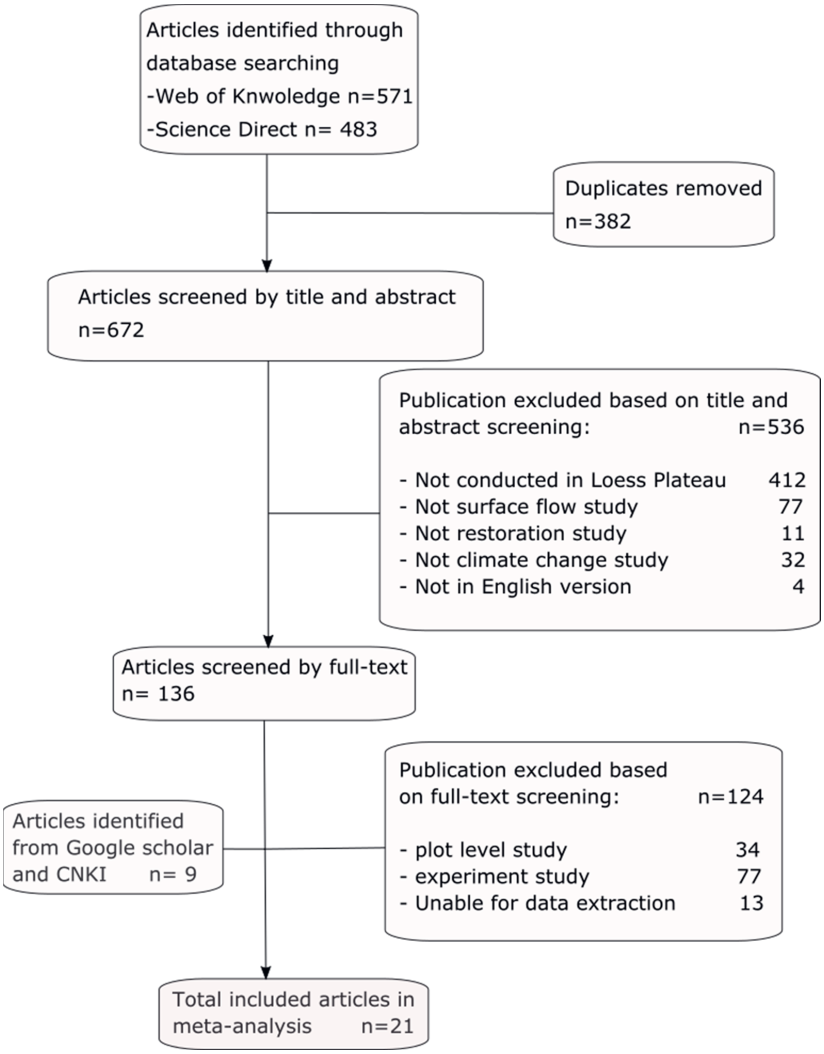


Figure 2.1 Flow chart of article selection.

Following Hu *et al*. (2017), Engauge Digitizer was used to extract numerical data from scatter plot and bar plot figures, yielding yearly precipitation and runoff data from the articles. The land use change data were collected directly from the articles including land use type, land use area, drainage location, year and total basin area.

Table 2.1 Categories of collected studies.

Type of studies	Number
Literature collected	22
Watersheds studied	25
Trend analysis	60
Impact analysis	61

2.2.2 Data description

First, the characteristics of 21 selected articles (*Appendix 2.1*) were determined. A summary of the data obtained is given in Table 2.1 and shows that the 21 articles collected data covering 25 different watersheds in the Loess Plateau, and conducted 52 trend analyses and 61 impact analyses. Publication year among all articles is displayed in Figure 2.3; the majority of the articles were published in year 2016. Overall, this study reviewed 61 case studies from 25 watersheds from the Chinese Loess Plateau. The names of the watersheds can be found in Figure 2.4 and their locations are visualized in Figure 2.2 with a Digital Elevation Model (DEM) map.

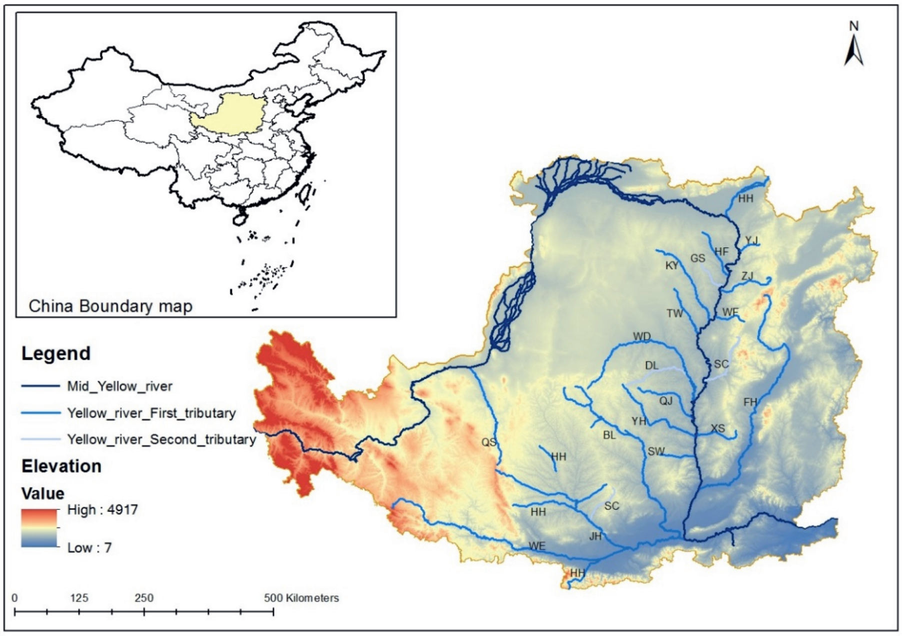


Figure 2.2 Geological location of Loess Plateau and studied rivers.

Note: WE: Wei river; JH: Jing river; HF: Huangfuchuan river; WD: Wuding river; JL: Jialu river; KY: Ku Ye river; XS: Xinshui river; YH: Yan river; BL: Beiluo river; DL: Dali river; GS: Gushan river; LY: Luoyugou watershed; NX: nanxiaohe river; QJ: Qingjian river; TW: TuWei river; YJ: Yangjiaping watershed; FH: Fen river; HH: Heihe river; YW: Yanwachuan watershed; QS: Qingshui river; SC: Sanchuan river; SW: Shiwang river; WF: Weifen river; ZF: Zhifanggou watershed; ZJ: Zhujia river.

2.2.3 Statistical methods

A meta-analysis was carried out for 61 watershed case studies in the 21 selected articles. The main purpose was to determine the temporal trend of streamflow, as well as climate and human activity impacts on the streamflow emerging from all studies. Specific indicators were used to define climate and human activity. In order to eliminate the scale difference from various watersheds in the Loess Plateau, we transferred all collected streamflow units to annual streamflow depth, which is the annual streamflow volume divided by watershed area. For climate change, because soil evaporation and temperature values are missing in the majority of the articles, we selected annual precipitation as indicator for climate change. Additionally, the annual mean runoff coefficient (Rc) was introduced as an indicator to describe relations among precipitation and streamflow. Rc is widely used as a diagnostic variable to describe the runoff generation ability of a catchment (Merz *et al*. 2006), which is given by:

$$R_c = \frac{Q}{P} \tag{2.1}$$

Where Q is the annual streamflow depth (mm) and P is the annual precipitation depth (mm). Human activity was defined as land management measures, i.e., SWC measures area coverage, implemented in the Loess Plateau. In this study, we grouped SWC measures into four categories: afforestation, grass planting, terrace building and dam building.

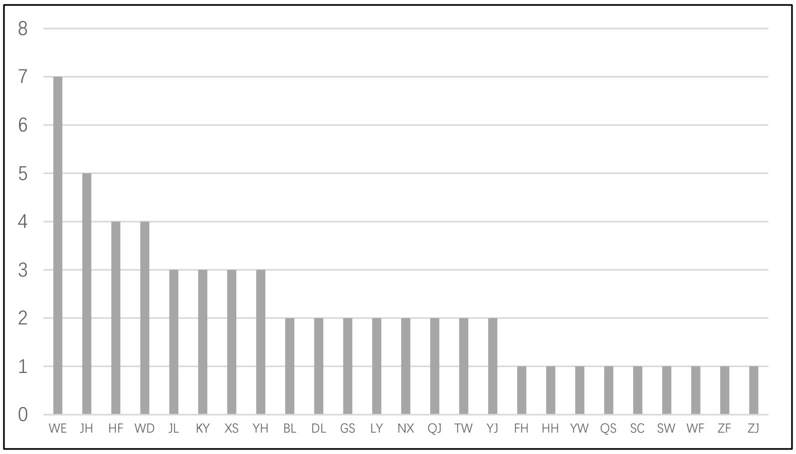


Figure 2.3 Number of studies per watershed (n total = 61).

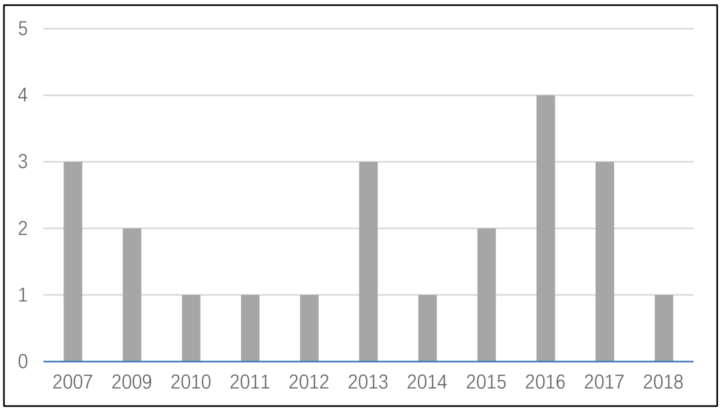


Figure 2.4 Number of selected articles per publication year (n=21).

2.2.4 Mann-Kendall test

The Mann-Kendall (M-K) test (Mann 1945; Kendall 1975) is a rank-based nonparametric method used for assessing the randomness of a time-series trends (Xia et al. 2017). It has been widely adopted to analyze the significance of trends in hydro-meteorological data such as water quantity, stream flow, temperature and precipitation (Yue et al. 2002). In this study, the M-K test was applied to assess the trends of precipitation, runoff and runoff coefficient (Rc) in individual studies. The M-K test statistic (S) is displayed as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(x_j - x_k) \tag{2.2}$$

where n represents the length of the data series, x_j and x_k are sequential data values, sgn determines the sign of the corresponding elements. Under the null hypothesis the data are identically distributed with no tendency, mean μ of distribution S is expected to be 0, and the significance level σ^2 is calculated as:

$$\sigma^2 = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5) \right\} / 18 \tag{2.3}$$

The value of Z is a standard normal distribution indicating the trend of a time series data; a positive value of Z signifies a rising trend whereas a negative value indicates a decreasing trend (Zhang et al. 2008). The Z-test statistic is calculated as:

$$Z = sgn(S)(|S| - 1)/\sigma \tag{2.4}$$

2.2.5 Pettitt's test

Pettitt's test is a nonparametric rank based test developed by Pettitt (1979), which is used for detecting the change point from time series data. In this study, the Pettitt's test was performed on annual Rc, annual precipitation and streamflow time series to determine in which year the trend started to alter. The change point calculation statistics is given by:

$$U_{t,N} = U_{t-1,N} + \sum_{j=1}^{N} sgn\left(x_t - x_j\right), \;\; t = 2, \dots, N \qquad (2.5)$$

The change point T should fit in the formula $K_{t,n} = Max_{1 \le t \le N} \left| U_{t,N} \right|$, and the significant level of Pettitt's test is calculated as:

$$p = exp\left[\frac{6K_{T,n}^2}{(n^3 + n^2)}\right] \qquad (2.6)$$

2.2.6 Separating land use and climate change impacts

In the collected articles, land use change and climate change impacts were considered as the only two factors affecting streamflow, and these two impacts were calculated by various hydrological models. Generally, human activity and climate change impacts results are simulated as two separated impact indices from the model, with unit percentages used to attribute effects to either driver. However, impact indices were not documented in some of the selected articles. In this case, we applied the approach from Huang and Zhang (2004) to estimate the missing impact indices. The method assumes that runoff change is caused only by variations in land management and rainfall, given by:

$$\Delta Q = \Delta Q_{climate} + \Delta Q_{land\ use} \qquad (2.7)$$

Where $$\Delta Q = Q_2 - Q_1 \qquad (2.8)$$

Calculation of the streamflow change ΔQ is based on comparison of two time periods: a) pre-treatment period: considered as reference period assuming the initial land use; and b) post-treatment period, after land use change occurred. Q_1 is the mean annual streamflow of the pre-treatment period and Q_2 is the mean annual streamflow of the post-treatment period. First, it is assumed that climate impacts remain the same in both pre-treatment and post-treatment period, i.e. the ΔQ is only caused by land use change in two periods (Zhang et al. 2014). A linear regression R_1 was applied between annual precipitation and annual streamflow in the pre-treatment period. By fitting annual precipitation from the post-treatment period into R_1, the hypothetic streamflow Q_2' without land use change impacts could be calculated. Then the separated impacts are calculated as:

$$\Delta Q_{climate} = Q_1 - Q_2' \tag{2.9}$$

$$\Delta Q_{land\ use} = Q_2' - Q_2 \tag{2.10}$$

2.2.7 Meta-analysis

In meta-analysis, the impact from an intervention is represented as effect size. Generally, impact size is used to indicate the differences between treatment and control group in the experimental research, but it is also possible to identify relationships between two variables (Borenstein et al, 2011). In our study, we used Rc, precipitation and streamflow change rate as effect size which were calculated from the M-K test to compare the streamflow change level among different articles in different periods of time. In the selected articles, methods to determine the land use and climate impacts on streamflow were not identical. Methodological differences may lead to heterogeneity among the true effect size. One way to treat this variability is to model it as purely random. A random effect model of meta-analysis was applied by:

$$\theta_i = \mu + u_i \tag{2.11}$$

Where $u_i \sim N(0, \tau^2)$. The true effect size was assumed to be normally distributed with mean μ and variance τ^2. If $\tau^2 = 0$, then $\mu = \theta_i$. μ was the change rate estimated from the M-K test, τ^2 was implied by Borenstein et al. (2011):

$$\tau = \frac{S_{diff}^2}{n} \tag{2.12}$$

Where S_{diff} is the standard deviation of within group differences and n is the sample size. In the random effect model, the overall mean effect size among all studies is based on study weight. Under the random effect model, the weight of each study is:

$$w_i = \frac{1}{V_{yi}^*} \tag{2.13}$$

Where V_{yi}^* is the sum of within study and between study variances.

In this study, both MK-test and Pettitt's test were performed using the R package '*trend*' (https://cran.r-project.org/web/packages/trend/index.html). Results of the M-K test were then processed for the meta-analysis by a random effect model, which was performed using the R package '*metafor*' (https://cran.r-project.org/web-/packages/metafor/index.html) (Viechtbauer *et al.* 2010). Significance and 95% lower and upper limits for the summary effect of the meta-analysis were also calculated by the metafor package. Moreover, a meta-regression was conducted to estimate the relationship between SWC area and streamflow change. In order to understand to what extent soil and water conservation measures played a role, a meta-regression was performed between annual streamflow change rate and SWC area change rate. Streamflow change rate was obtained from the M-K test, and SWC area change rate was calculated by SWC change area divided by period of study time. The SWC indicators were defined as afforestation, grass planting, terrace building and dam building. Additionally, a categorical principal components analysis (non-linear PCA) was performed by SPSS 23.0 to determine the impact level among the SWC measures.

2.3 Results

2.3.1 Trend of precipitation and streamflow

To determine the trend of Rc, precipitation and streamflow in the recent decades, we performed a M-K test with annual time series data from the collected articles. Figure 2.5 and 6 present an overview of the studies including watershed name, research duration and trend results of streamflow (measured as annual streamflow depth) and runoff coefficient respectively. Overall, the majority (41 of 52) of the studied watersheds show a decreasing annual streamflow depth in recent decades and nearly half of them are significant, and none of the increasing trends was found to be significant. The highest decreasing trend is in Wei River, with a rate of -4.91 mm/year between 1980-2008. Some M-K results from different articles indicated similar results, for example, in Nanxiaohe watershed, results from both Huaxing Bi et al. 2009 and Lu Xia *et al.* 2017 were the same of -0.47mm/year with significance p<0.01, although the research period was slightly different. The M-K results for precipitation (*Appendix* 2.2) present a large fluctuation among all the watersheds, ranging from -32.5 mm/year to 13.64 mm/year, however, the trend is found to be much less significant. M-K results for Rc were similar to those of the streamflow; 37 out of 52 case studies show a decreasing trend of Rc and none of the 12 increasing trends was found to be significant. From the M-K test, we found a significant decrease of streamflow and Rc whereas change of precipitation was not clear. This indicates that during the recent decades in the Loess Plateau, less streamflow was generated from the watersheds while precipitation did not show a clear increasing or decreasing trend.

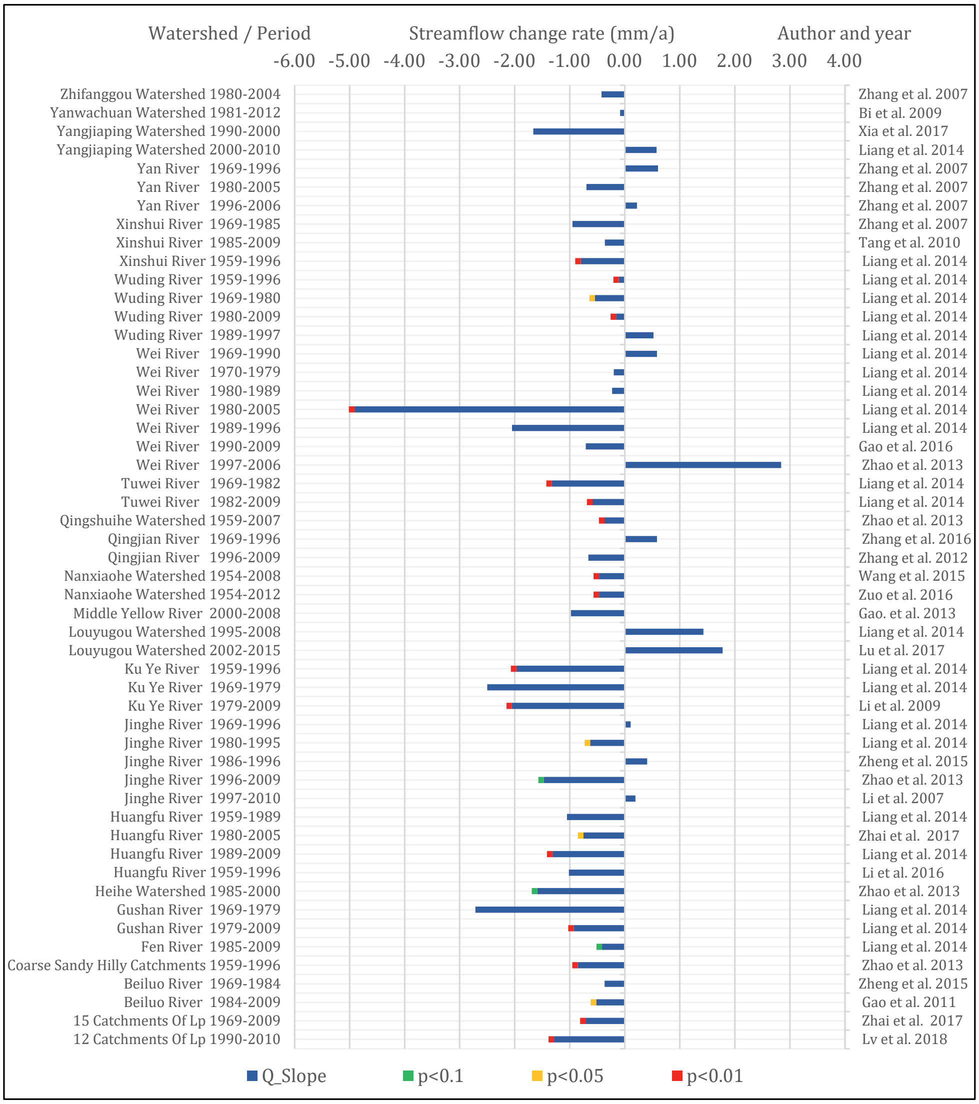


Figure 2.5 Streamflow depth change of 52 watershed case studies. Note: colors on top of the bars indicate the significance level.

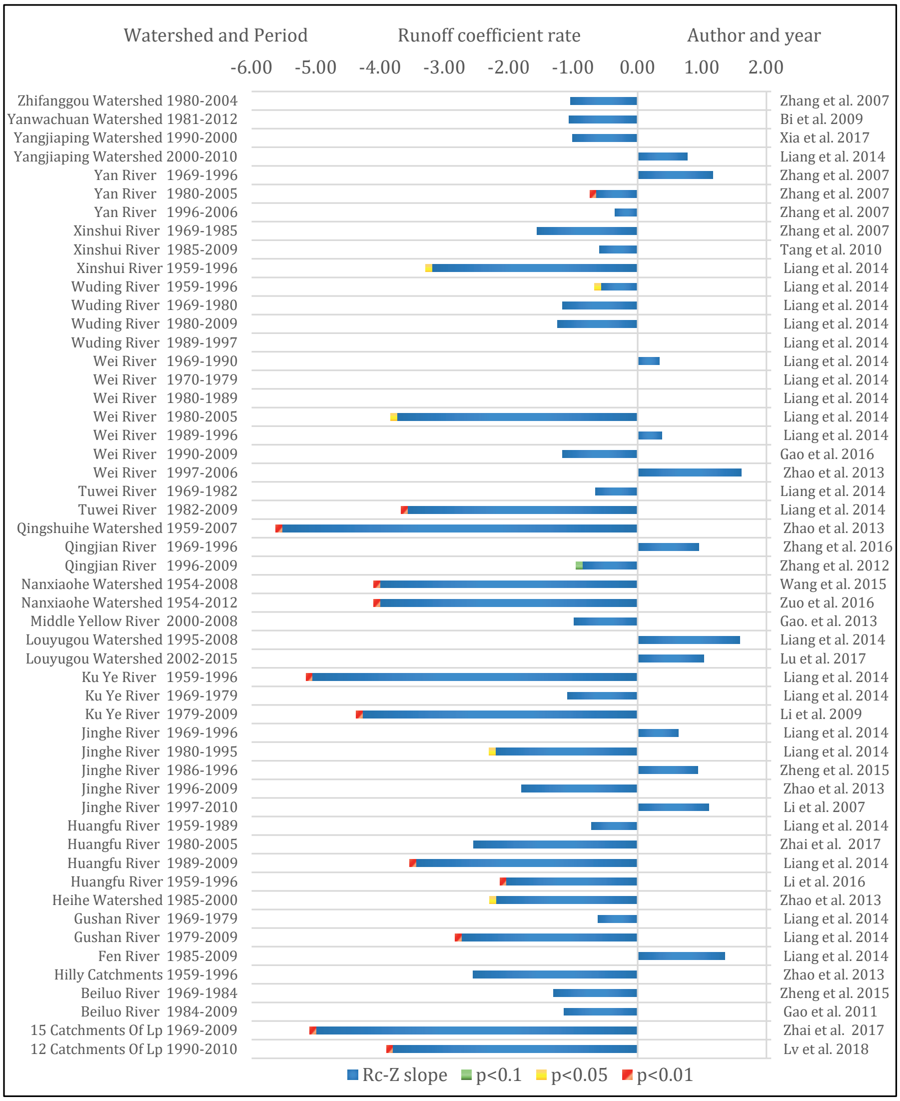


Figure 2.6 Runoff coefficient change of 52 watershed case studies. Note: colors on top of the bars indicate the significance level.

2.3.2 Change point in the trend

Change point detection indicates a certain time (year) that change occurred in a time series. By means of Pettitt's test, change points were determined. Figure 2.7 presents the results from Pettitt's test for streamflow (Q); only the studies with a significant ($p<0.1$) change point year (n=23 out of 52) are displayed in the figure. This figure illustrates that although the research period of different case studies varied, streamflow changes occurred mainly between 1990 and 2000, concentrating at the end of the 1990s. For the Nanxiaohe watershed the change point years were different when calculated from data from two articles. We observed that a longer research period led to a later change point year, and this finding indicates that streamflow changed more sharply after 2008 in the Nanxiaohe watershed.

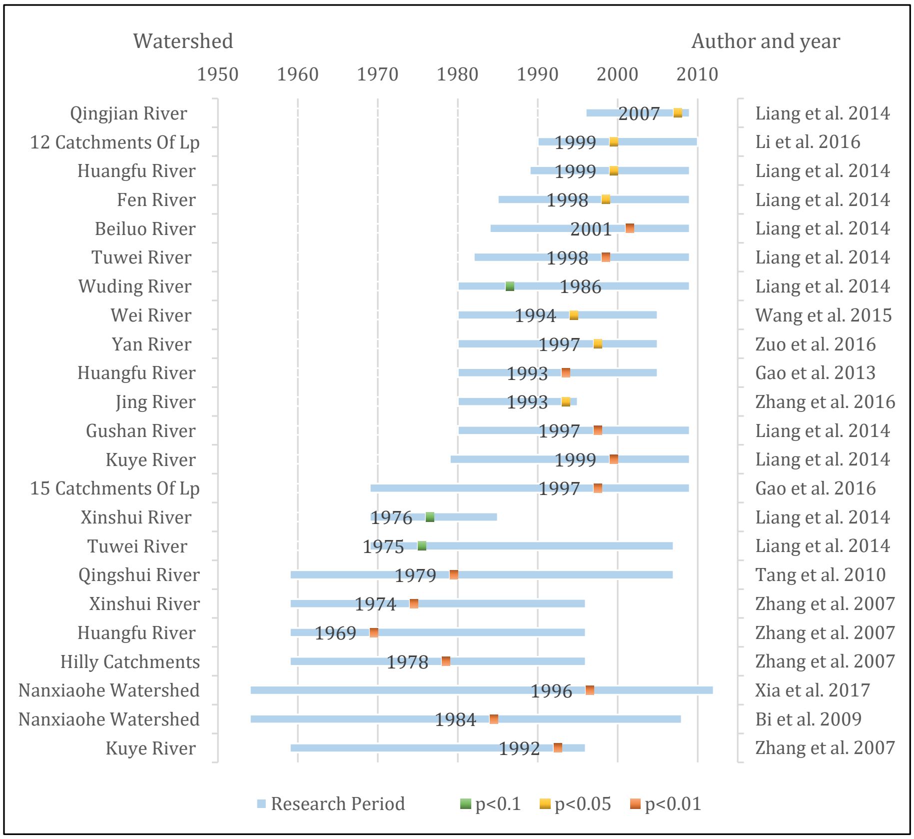


Figure 2.7 Change point of streamflow in watershed case studies. Note: cubes in the figure indicate the significant level (n=23).

In contrast, and in line with the findings for the trends given in the previous section, very few (2 of 52) significant change points were found in precipitation time series (*Appendix* 2.3), which indicates no sharp precipitation changes happened in the studied watersheds. Similar to the results from stremflow, change points of Rc presented 18 significant values in total, and the majority of these points concentrate between 1990 and 2000, with 9 of the changes occurring in 1999 and early 2000. For Nanxiaohe watershed, we observed a large difference in different articles; this may due to precipitation variance. Additionally, there's similarity we can observe from Figure 2.7 and 2.8 that majority of the change point years were concentrated around year 2000.

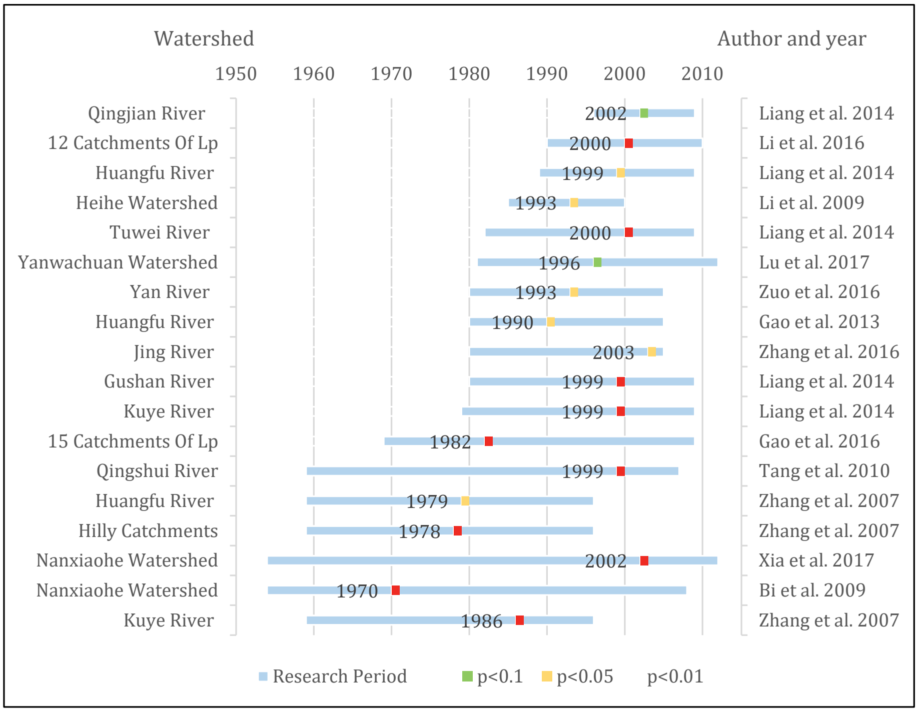
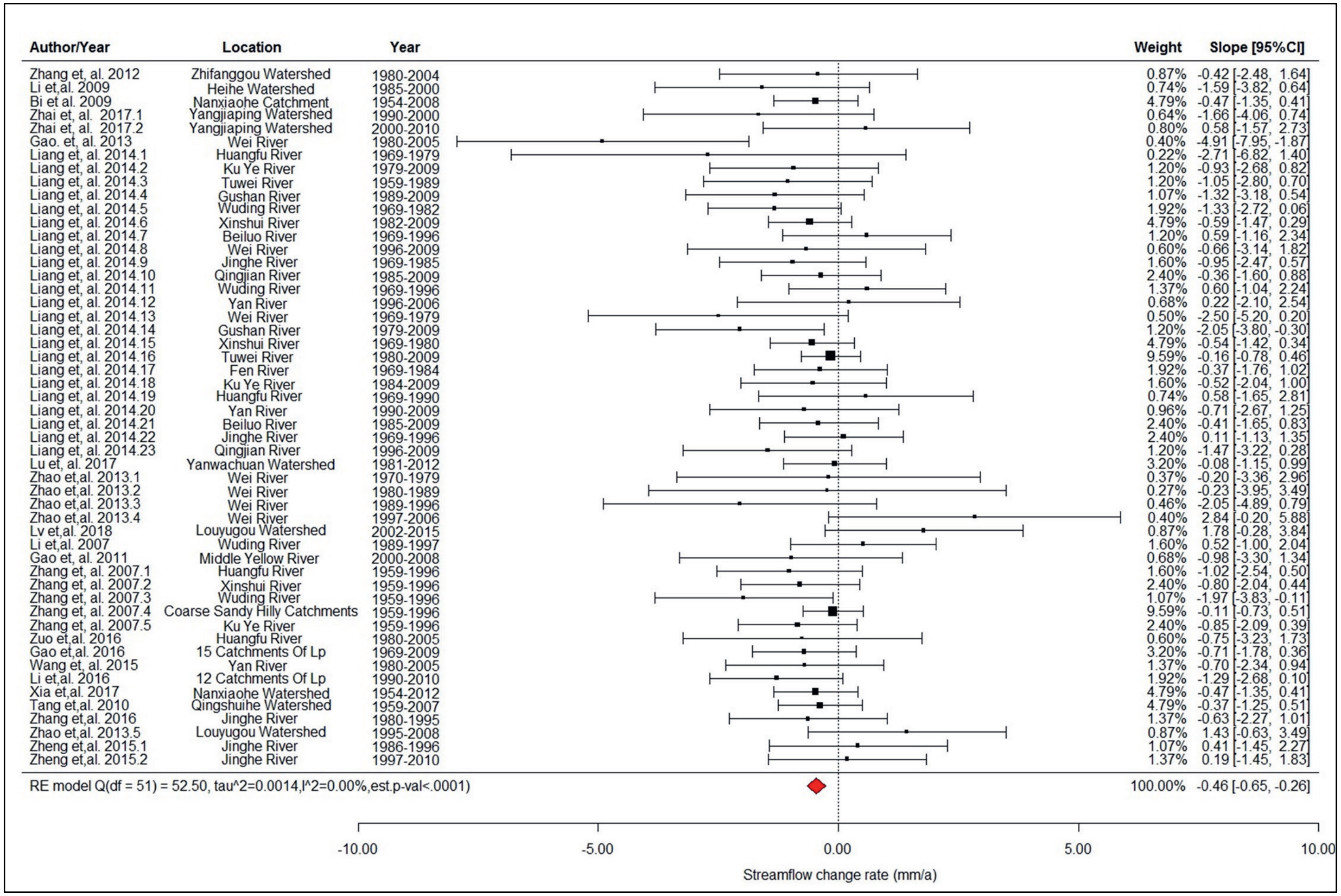


Figure 2.8 Change point of runoff coefficient in watershed case studies. Note: cubes in the figure indicate the significant level (n=18).

2.3.3 Meta-analysis

In order to summarize a general trend of streamflow among all selected watershed studies, a random effect model was conducted. Figure 2.9 presents the result of how streamflow change rates of different watersheds are distributed in the meta-analysis study. Overall, the majority of the streamflow studies show a decreasing trend. Meanwhile the red point indicates the mean effect size of the analysis, illustrating a significant ($p<0.01$) decreasing rate of -0.46mm/year as extracted from the 52 case studies. Thus, from Figure 2.9 we can deduce that in the past decades, the majority of the watersheds in the Loess Plateau experienced a reduction of flow. Compared with the streamflow results, precipitation (*Appendix* 2.4) showed a smaller within study variance, the mean effect size displayed an insignificant trend with value -0.53 mm/year. This indicates that precipitation did not have a certain trend in the studied watersheds. Figure 2.10 is quite revealing in several ways. First, the Z value is relatively concentrated on the negative side, for instance, in Jinghe watershed, a -5.52 Z value was detected from Hongbo Zhang *et al* with 2.33% contribution to the mean effect size. The overall negatives indicate that Rc is decreasing continuously. In general, Figure 2.10 presents a significant decreasing Z value of Rc with -1.40/year. We can deduct from these results that the majority of the watersheds in the Loess Plateau were capturing and storing more precipitation and therefore less runoff was generated.



Author/Year	Location	Year	Weight	Slope [95%CI]
Zhang et, al. 2012	Zhifanggou Watershed	1980-2004	0.87%	-0.42 [-2.48, 1.64]
Li et,al. 2009	Heihe Watershed	1985-2000	0.74%	-1.59 [-3.82, 0.64]
Bi et al. 2009	Nanxiaohe Catchment	1954-2008	4.79%	-0.47 [-1.35, 0.41]
Zhai et, al. 2017.1	Yangjiaping Watershed	1990-2000	0.64%	-1.66 [-4.06, 0.74]
Zhai et, al. 2017.2	Yangjiaping Watershed	2000-2010	0.80%	0.58 [-1.57, 2.73]
Gao. et, al. 2013	Wei River	1980-2005	0.40%	-4.91 [-7.95, -1.87]
Liang et, al. 2014.1	Huangfu River	1969-1979	0.22%	-2.71 [-6.82, 1.40]
Liang et, al. 2014.2	Ku Ye River	1979-2009	1.20%	-0.93 [-2.68, 0.82]
Liang et, al. 2014.3	Tuwei River	1959-1989	1.20%	-1.05 [-2.80, 0.70]
Liang et, al. 2014.4	Gushan River	1989-2009	1.07%	-1.32 [-3.18, 0.54]
Liang et, al. 2014.5	Wuding River	1969-1982	1.92%	-1.33 [-2.72, 0.06]
Liang et, al. 2014.6	Xinshui River	1982-2009	4.79%	-0.59 [-1.47, 0.29]
Liang et, al. 2014.7	Beiluo River	1969-1996	1.20%	0.59 [-1.16, 2.34]
Liang et, al. 2014.8	Wei River	1996-2009	0.60%	-0.66 [-3.14, 1.82]
Liang et, al. 2014.9	Jinghe River	1969-1985	1.60%	-0.95 [-2.47, 0.57]
Liang et, al. 2014.10	Qingjian River	1985-2009	2.40%	-0.36 [-1.60, 0.88]
Liang et, al. 2014.11	Wuding River	1969-1996	1.37%	0.60 [-1.04, 2.24]
Liang et, al. 2014.12	Yan River	1996-2006	0.68%	0.22 [-2.10, 2.54]
Liang et, al. 2014.13	Wei River	1969-1979	0.50%	-2.50 [-5.20, 0.20]
Liang et, al. 2014.14	Gushan River	1979-2009	1.20%	-2.05 [-3.80, -0.30]
Liang et, al. 2014.15	Xinshui River	1969-1980	4.79%	-0.54 [-1.42, 0.34]
Liang et, al. 2014.16	Tuwei River	1980-2009	9.59%	-0.16 [-0.78, 0.46]
Liang et, al. 2014.17	Fen River	1969-1984	1.92%	-0.37 [-1.76, 1.02]
Liang et, al. 2014.18	Ku Ye River	1984-2009	1.60%	-0.52 [-2.04, 1.00]
Liang et, al. 2014.19	Huangfu River	1969-1990	0.74%	0.58 [-1.65, 2.81]
Liang et, al. 2014.20	Yan River	1990-2009	0.96%	-0.71 [-2.67, 1.25]
Liang et, al. 2014.21	Beiluo River	1985-2009	2.40%	-0.41 [-1.65, 0.83]
Liang et, al. 2014.22	Jinghe River	1969-1996	2.40%	0.11 [-1.13, 1.35]
Liang et, al. 2014.23	Qingjian River	1996-2009	1.20%	-1.47 [-3.22, 0.28]
Lu et, al. 2017	Yanwachuan Watershed	1981-2012	3.20%	-0.08 [-1.15, 0.99]
Zhao et,al. 2013.1	Wei River	1970-1979	0.37%	-0.20 [-3.36, 2.96]
Zhao et,al. 2013.2	Wei River	1980-1989	0.27%	-0.23 [-3.95, 3.49]
Zhao et,al. 2013.3	Wei River	1989-1996	0.46%	-2.05 [-4.89, 0.79]
Zhao et,al. 2013.4	Wei River	1997-2006	0.40%	2.84 [-0.20, 5.88]
Lv et,al. 2018	Louyugou Watershed	2002-2015	0.87%	1.78 [-0.28, 3.84]
Li et,al. 2007	Wuding River	1989-1997	1.60%	0.52 [-1.00, 2.04]
Gao et, al. 2011	Middle Yellow River	2000-2008	0.68%	-0.98 [-3.30, 1.34]
Zhang et, al. 2007.1	Huangfu River	1959-1996	1.60%	-1.02 [-2.54, 0.50]
Zhang et, al. 2007.2	Xinshui River	1959-1996	2.40%	-0.80 [-2.04, 0.44]
Zhang et, al. 2007.3	Wuding River	1959-1996	1.07%	-1.97 [-3.83, -0.11]
Zhang et, al. 2007.4	Coarse Sandy Hilly Catchments	1959-1996	9.59%	-0.11 [-0.73, 0.51]
Zhang et, al. 2007.5	Ku Ye River	1959-1996	2.40%	-0.85 [-2.09, 0.39]
Zuo et,al. 2016	Huangfu River	1980-2005	0.60%	-0.75 [-3.23, 1.73]
Gao et,al. 2016	15 Catchments Of Lp	1969-2009	3.20%	-0.71 [-1.78, 0.36]
Wang et, al. 2015	Yan River	1980-2005	1.37%	-0.70 [-2.34, 0.94]
Li et,al. 2016	12 Catchments Of Lp	1990-2010	1.92%	-1.29 [-2.68, 0.10]
Xia et,al. 2017	Nanxiaohe Watershed	1954-2012	4.79%	-0.47 [-1.35, 0.41]
Tang et,al. 2010	Qingshuihe Watershed	1959-2007	4.79%	-0.37 [-1.25, 0.51]
Zhang et,al. 2016	Jinghe River	1980-1995	1.37%	-0.63 [-2.27, 1.01]
Zhao et,al. 2013.5	Louyugou Watershed	1995-2008	0.87%	1.43 [-0.63, 3.49]
Zheng et,al. 2015.1	Jinghe River	1986-1996	1.07%	0.41 [-1.45, 2.27]
Zheng et,al. 2015.2	Jinghe River	1997-2010	1.37%	0.19 [-1.45, 1.83]
RE model Q(df = 51) = 52.50, tau^2=0.0014,I^2=0.00%,est.p-val<.0001)			100.00%	-0.46 [-0.65, -0.26]

Figure 2.9 Result of meta-analysis of streamflow depth change rate.

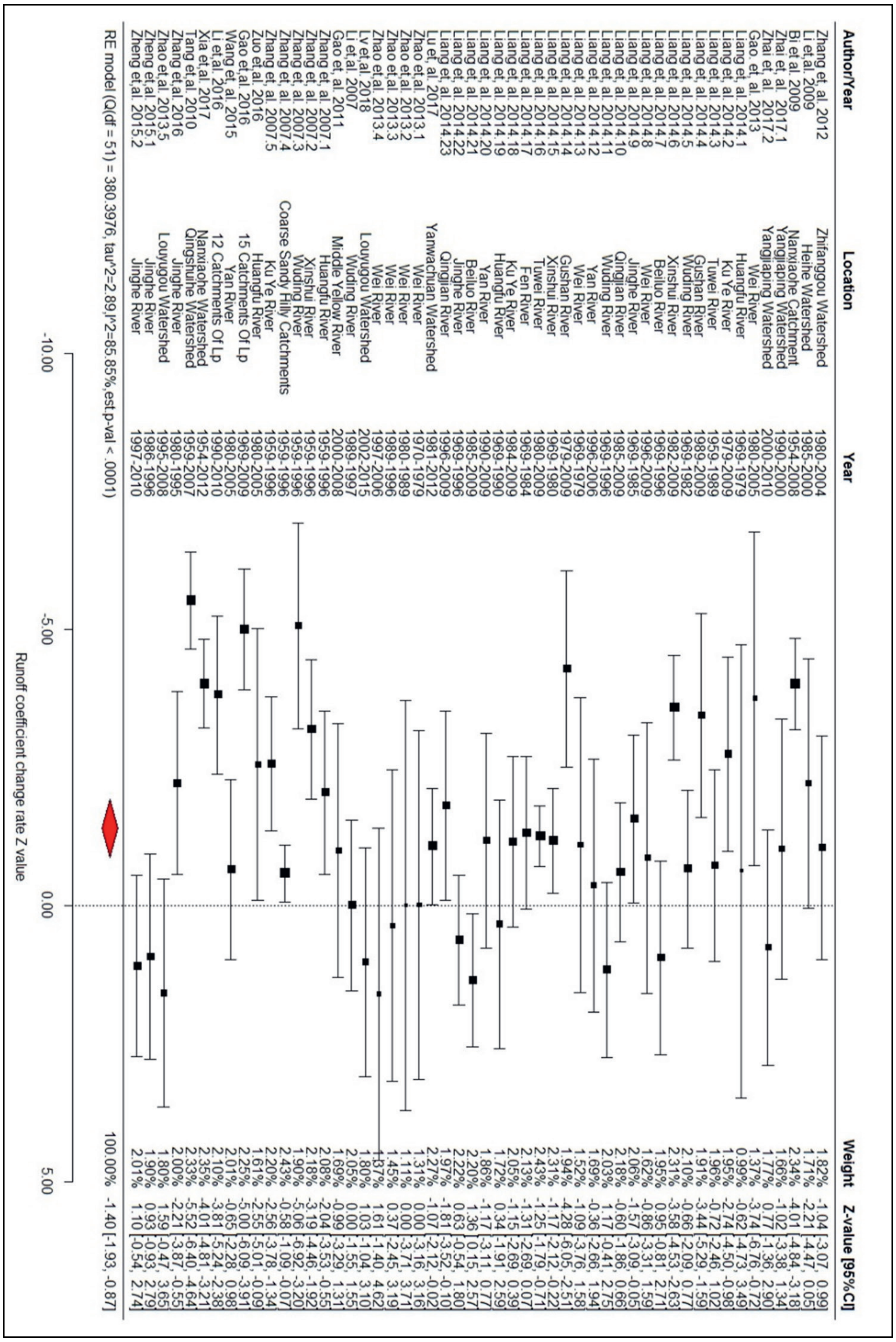


Figure 2.10 Result of meta-analysis of runoff coefficient change rate.

2.3.4 Land use change impacts

Land use change impacts on the streamflow were obtained from two resources: a) directly collected from selected articles; b) estimated using the approach of Huang and Zhang (2004) from streamflow and precipitation time series data. Total land use change and climate change impact index values collected are displayed in Figure 2.11. The average value of land use change impacts is 58.56% with a standard deviation of 21.20% whereas the average of climate change impacts is 41.44%. This result illustrates that overall land cover change had stronger influences on the streamflow change compare to climate change in the Loess Plateau. On the basis of the results from M-K and Pettitt's test, 1999 seems to be a change point of streamflow quantity in the Loess Plateau. Thus, we categorized the impact index according to the time period of study years, followed by conducting a meta-analysis based on the land use impact index. A climate change impact meta-analysis was not conducted, because it is assumed the sum of land use and climate change impact index is 100%. It is apparent from Figure 2.12 that compared to studies after 1999, land use impact index of earlier studies has a wider between-study variance. Wider between-study variance illustrates that there is a larger difference in land use impact index between different watersheds. However, after 1999, the impact of land use on streamflow increased from 55% to 68% with weight 57.60%. This sharp increase may be due to the *GGP*'s initiation and the dramatic land cover change it caused. Overall, the mean effect size of a total of 61 case studies indicates land use change impacts account for 63.52% of the total streamflow change whereas climate change accounts for the rest (i.e., 36.48%).

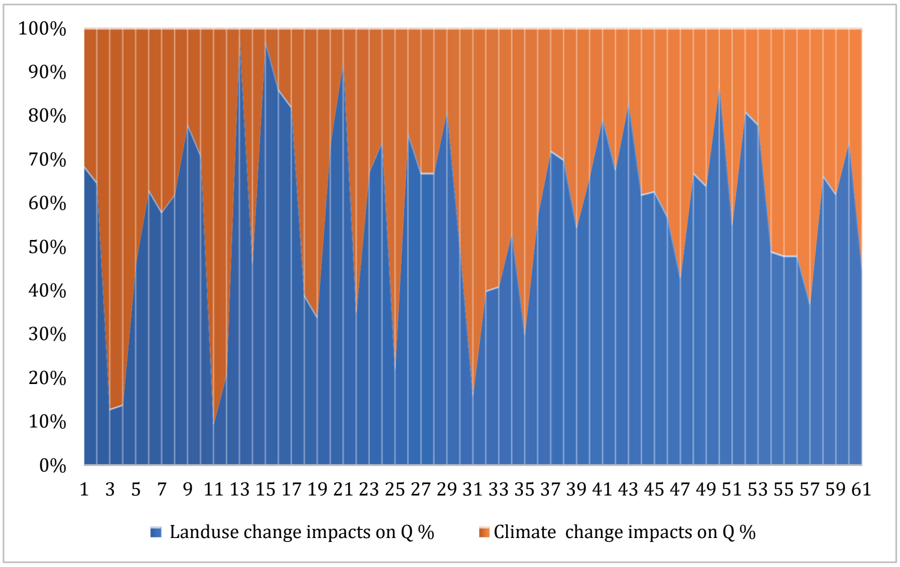


Figure 2.11 Land use change and climate change impacts on the streamflow change (n=61) Note: Watershed name, author and research period are listed in *Appendix* 2.5.

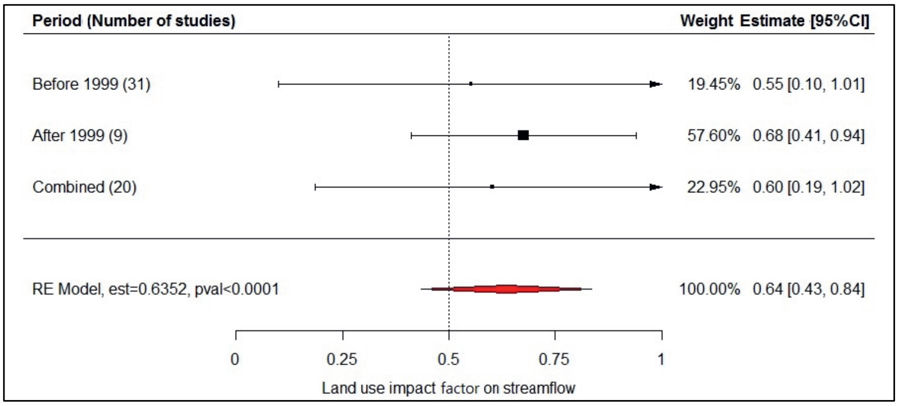


Figure 2.12 Land use impact factor on streamflow depth on the Loess Plateau in different periods.

2.3.5 Impact of soil and water conservation measures

Figure 2.13 presents the meta-regression results between streamflow change rate and SWC separately (a-d), as well as for the total net SWC area (e). Blue circles in the figure represent watershed case studies, whereby the diameter of the blue circle is inversely related with within study variance of streamflow change. For example, in Figure 2.13-b, the two big blue dots in the middle indicate two studies with smaller variance compare to other studies. The solid red lines are the regression line between SWC change area and water flow change quantity, the dotted red line is the confidence interval of the meta-regression. Generally, there is no strong correlation between the four different SWC measures and streamflow change rate. Afforestation (a) and terracing (d) show a slight stimulation effect on streamflow reduction whereas grass planting (b) and dam building (c) are restraining the streamflow. Besides, compared to afforestation and grass planting, in the majority of the watersheds, terrace and dam area increased very slowly and concentrate on the left edge close to 0 %/year. However, when considering the total net SWC area change rate (e), overall, we observe that the increase in the SWC area causes a decrease of streamflow.

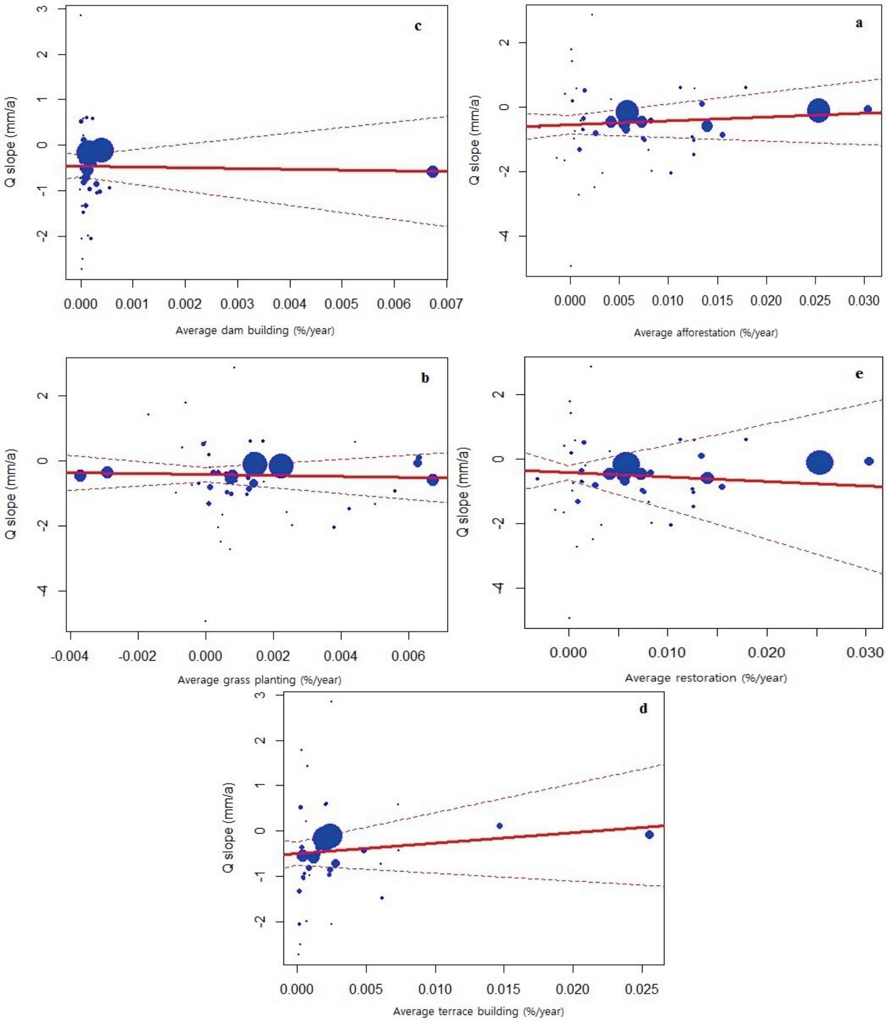
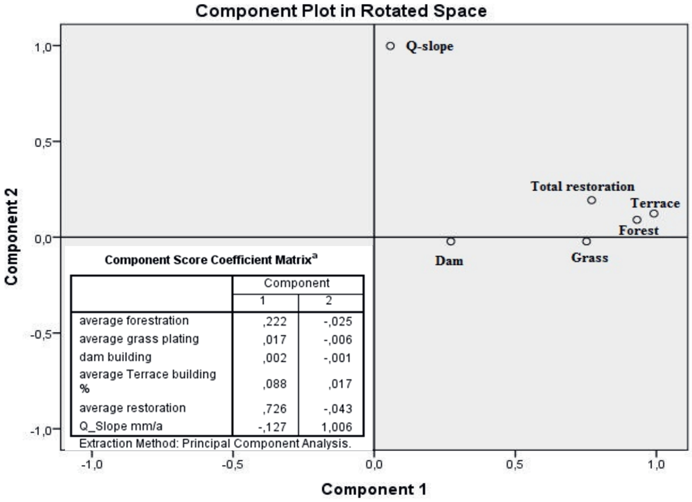


Figure 2.13 Meta-regression between streamflow depth and SWC area change rates.

Figure 2.14 shows the results of a categorical principal components analysis (PCA) performed to determine the relationships between land use change (SWC) and streamflow change. The proportion of variance accounted for in the first and second component is 61.68% and 32.83% respectively, meaning that the sum of the component's variance accounts for a considerable proportion (94.50%). From the PCA plot we observe that principal component (PC) 1 was affected by terrace building and afforestation while (PC) 2 was strongly influenced by streamflow change. In line with the results from meta-regression, streamflow change and SWC change area displayed an angle close to 90 degree, which indicates a low correlation between them. However, Figure 2.12 illustrates that the level of influence of the SWC area on streamflow change was following the order: total restoration area > terrace building > afforestation > grass planting > dam building.



Component Score Coefficient Matrix[a]

	Component	
	1	2
average forestration	,222	-,025
average grass plating	,017	-,006
dam building	,002	-,001
average Terrace building %	,088	,017
average restoration	,726	-,043
Q_Slope mm/a	-,127	1,006

Extraction Method: Principal Component Analysis.

Figure 2.14 Principal component analysis between streamflow depth change and soil and water conservation measures.

2.4 Discussion

Many recent studies show evidence that many rivers in the Loess Plateau are experiencing a streamflow reduction in recent decades (Tian *et al*. 2019; Wu *et al*. 2017; Miao *et al*. 2011). We have found similar results in this study. By using a meta-analysis, we calculated a -0.46 mm year^{-1} streamflow depth reduction from the selected watersheds from different time scales ranging from 1959 till 2015. We found that land use change caused 63.25% of the streamflow decrease from hydrological modelling studies, while Hu et al. (2017b) found that ecological restoration accounts for 72.18% of annual runoff reduction based on a meta-analysis from field experimental studies. The difference may be caused by indicator diversity, scale variety and methodological differences. In this study, total land use change on a watershed scale was considered in the hydrological models, whereas field experiments only considered ecological restoration impacts on a plot scale. Based on our results, precipitation change trend was found to be insignificant, however climate variability still accounts for 36.48% influence on streamflow. Selection of the indicators may cause this difference, as potential evapotranspiration (PET) and temperature data were excluded from the climatic indicators due to insufficient data from literature. For example, Zhao et al. (2014) found that climate change is causing 87% of flow reduction in Beiluo river by using precipitation, PET and temperature as indicators, while in our study the precipitation change is found insignificant in Beiluo river in the same period.

A meta-analysis provides a new method to summarize a general meteorology trend from regional scale, for example, Jiang et al. (2017) found that annual precipitation was decreased by -1.52 mm/year from 1959-1999 and increased from 2000-2012 by 3.47 mm/year in the entire Loess Plateau, while our meta-analysis displayed a different result that no significant precipitation change trend was found. The results of Jiang et al. (2017) were based on the mean value of 49 weather stations from the whole Loess Plateau whereas our results were estimated from each watershed study. The Loess Plateau covers an area of 640,000 km^2 of land thus precipitation various from region to region (Ma *et al.* 2019), therefore, we think it is more representative to derive the precipitation trend for this regional scale level from multiple watershed studies instead of using the mean value from 49 distant stations. The main objective of this study was to describe the streamflow dynamics of the Loess Plateau based on different watershed-level analyses in previous studies. Through results in the same watershed from different publications at similar periods of time, we recognize differences among the results. For example, results from Gao et al. 2013 showed a decrease of streamflow depth of -4.91 mm/year in Wei river between 1980-2005 whereas results from Zhao et al. 2013 presented an increase of 2.84 mm/year in Wei river between 1997-2006. Thus, it is necessary to include all the watershed studies from various research periods by different authors to describe a more comprehensive overview of the streamflow change in the Loess Plateau.

In a meta-analysis, since published studies are more likely to be considered than unpublished data, any bias in the literature is possibly reflected in the meta-analysis as well; this issue is generally known as publication bias (Borenstein et al. 2011). Non-significant studies have been estimated 61-86% less likely to be published than significant studies; therefore results of these non-significant studies may be ignored by the literature reviewers (Chan *et al.* 2004). Additionally, it is likely that some studies were missed using our searching criteria. In order to identify the publication bias in this study, funnel plots (Figure 2.15) were created. Funnel plots display the relation between variance and effect size. In a funnel plot, studies are expected to show symmetry at the top, few studies missing in the middle, and more studies missing near the bottom (Borenstein et al. 2011). From the funnel plot of streamflow (Fig. 2.15; left) we can deduce some studies with lower significance of streamflow change are likely to be missing, whereas in the precipitation funnel plot (Fig. 2.15, right) some studies with higher significance of precipitation change are missing on the top. Overall, the funnel plots indicate the meta-analysis of streamflow change is more reliable than the results of precipitation due to less publication bias. To some extent, this deduction could explain why the climate index accounts for 36.48% of the streamflow reduction and few significant trends were found in the precipitation change.

In this study, a significant reduction of streamflow is observed while an expansion of forest and grassland occurred at the same time. A complicated relationships may exist between trade-off and synergies of these ecosystem services changes. Similar results were found by (Lü *et al*, 2012) that runoff decreased by 10.3 mm/year whereas forest and grassland area increased by 4.9% and 6.6% respectively in the whole Loess Plateau in 2002-2008. GGP is found to be the primary driving factor for this vegetation increase (Feng *et al.* 2013). One argument to explain this trade-off between water yield reduction and SWC area increase is the increased water consumption from land restoration. A higher evapotranspiration rate from the restored vegetation is found to be a crucial reason for runoff-coefficient reduction (Li et al. 2016). Meanwhile soil moisture content decrease significantly after land use conversion, deep soil moisture decreased more than 35% after land use conversion and a soil moisture deficit appeared in all types of new restored land (Yang et al. 2012; Su and Shangguan 2019). According to the findings from this and previous studies, a negative effect of land restoration is exposed, a long-term monitoring process is required to assess the streamflow reduction degree.

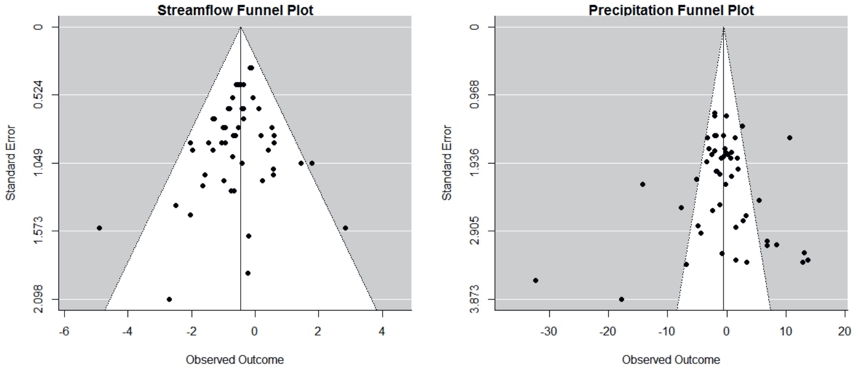
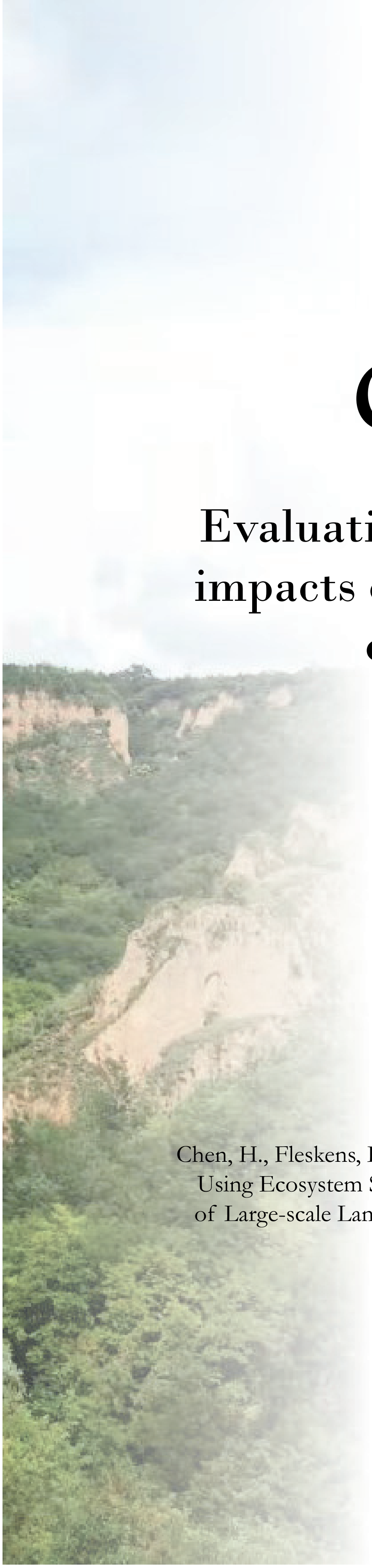


Figure 2.15 Meta-analysis funnel plots.

Starting from 2010, there was a tremendous increase of meta-analysis researches, however, the quality of the meta-analysis various from one to another (Gurevitch et al. 2018). In this study, we conducted a meta-analysis with regular methods including process of literature selection, set up effect size, meta-regression and publication bias analyzes, is considered to be a completed meta-analysis (Borenstein et al. 2011). Further improvements for this study could be achieved; for instance, this study processed the statistics based on annual data, seasonal and event data could be used to investigate the impacts of precipitation on the streamflow more precisely, e.g. for low flow and flood conditions (Gai *et al.* 2019). In some selected watersheds, hydrological models were used to simulate scenarios in different land cover and climate conditions, a meta-analysis can compare the results from different scenarios on the condition that data is available and complete.

2.5 Conclusions

This is the first study that estimates streamflow dynamics among various watershed case studies on the entire Loess Plateau. The streamflow depth of the watershed case studies in the Loess Plateau shows a significant decreasing trend of -0.46mm/year ranging from 1959 till 2015, while no significant change was found in the precipitation data. From the meta-analysis, we identified that land cover change accounts for 63.52% of the streamflow change whereas climate variability accounts for 36.48%. There was a small negative correlation between streamflow change and SWC area net change. The level of influence of different SWC measures on streamflow reduction is in the order of: restoration area > terrace building > afforestation > grass planting > dam building.



Chapter 3

Evaluation of spatial and temporal impacts of landscape restoration on ecosystem services[3]

[3] This chapter is based on:
Chen, H., Fleskens, L., Schild, J., Wang, F., Moolenaar, S., & Ritsema, C. J. (2021). Using Ecosystem Service Bundles to Evaluate Spatial and Temporal Impacts of Large-scale Landscape Restoration on Ecosystem Services on the Chinese Loess Plateau. *Landscape Ecology*.

Abstract:

From 1999 onwards, China has initiated a large-scale landscape restoration project on the Chinese Loess Plateau, which has had profound but variable impacts on the local ecosystem services supply. In this study, we evaluate the spatial and temporal dynamics in 11 ecosystem services in the Yan'an area on the Chinese Loess Plateau from 1990 to 2018 based on the InVEST model and statistical yearbook data. To consider trade-offs and synergies between ecosystem services, the concept of ecosystem service bundles was used to understand the dynamics of ecosystem services. A significant increase of fruit production, sediment retention, habitat quality, aesthetic landscape value as well as learning and inspiration value was found over time in Yan'an area, while a decrease of timber production and water yield was also observed. Synergistic relations were found between sediment retention, carbon sequestration, habitat quality and outdoor recreation, while trade-offs were observed between timber production and water yield. The majority of ecosystem services bundles of Yan'an area were transformed from having a focus on timber production to aesthetic landscape value. The dynamics of ecosystem services change by land restoration was discovered, to start with increasing regulating services at expense of provisioning services, cultural services exceeding regulating services and occupied the main proportion subsequently. The most obvious change was observed in 2000, coinciding with the start of large-scale restoration activities. The implementation of the large-scale restoration project is recognized as a key driving force inducing these changes. Based on the results, it is recommended that the Yan'an government pays attention to local water resource management and timber supply.

3.1 Introduction

Over 40% of the world's land surface are arid and semi-arid areas, which are ecologically vulnerable, sensitive to erosion and facing deterioration risks (Allan et al. 2013). In order to manage and address land degradation and ecological deterioration issues, a number of large-scale land restoration programs have been implemented worldwide, which have significantly altered land use and ecosystem services (Benayas et al. 2009). China is no exception: especially the Chinese Loess Plateau, one of the most severely eroded regions in the world, has been given a lot of attention in land restoration policies (Sun et al. 2014). Starting from the 1970s, the Chinese government has implemented several small-scale land restoration programs on the Chinese Loess Plateau to rehabilitate vegetation cover, combat desertification and reduce soil and water loss (Chen et al. 2015). In 1998, Wuqi county in Yan'an area on the Chinese Loess Plateau started a pioneer land restoration program to reverse the ecological degradation by stopping cultivation of steep slopes and converting cropland and bare land to forest and grassland. One year later, based on the experiences in 1999, one of the world's largest-scale land restoration projects, the Grain for Green project (GGP), was initiated nationally covering more than 20 million hectares of cropland and bare land (Persson et al. 2013). One of the main purposes of the GGP is to maintain soil fertility and combat soil and water losses (Deng et al. 2019). The GGP brought a dramatic alteration of land use and a transformation in ecosystem services delivery (Chen et al. 2015).

Ecosystem services are defined as flows of materials, energy and information which are directly or indirectly provided by ecosystems to human society, including provisioning, regulating, cultural and supporting services (Costanza et al. 1997). Provisioning services include goods and products that we physically obtain from ecosystems, for example, food, water, raw materials etc; Regulating services are necessary services to maintain the ecosystem functions, for instance, erosion control, sediment retention, habitat quality etc; Cultural services like aesthetic landscape value provide spiritual pleasures to human beings (MEA 2005). Multiple ecosystem services can be provided by an ecosystem at the same time, but some ecosystem services cannot be supplied to society simultaneously (Peng et al. 2019). Any of these ecosystem services is associated with other services as either "trade-offs" or "synergies" (Bennett & Balvanera, 2007). Trade-offs between ecosystem services can be comprehended as an increase of a (set of) specific ecosystem service(s) at the expense of other ecosystem services (Raudsepp-Hearne et al. 2010). Synergies, which are the opposite to trade-offs, are characterized as ecosystem services that either increase or decrease jointly (Bennett et al. 2009). Meanwhile trade-offs and synergies may appear diversely in one ecosystem at different temporal and spatial scales (Power, 2010). Understanding the dynamics of ecosystem services is thus essential to comprehend the possible formation of trade-offs and synergies (Dade et al. 2019).

Ignoring dynamics may increase the risk of unexpected changes in ecosystem services (Gordon et al. 2008). Human activity is a major factor affecting ecosystem service trade-offs and synergies through changing land use , by scale, type and intensity (Tolessa et al. 2017; Chen et al. 2019). For example, urbanization, ecological engineering and landscape restoration are often accompanied by a shift in land use for the purpose of (re-) generating a single or multiple ecosystem services. The implementation of these land use changing activities could cause ecological degradation if the trade-offs among other ecosystem services are ignored (Groot et al. 2011). Many previous studies were focused on simple trade-off and synergy relations between ecosystem services and ignore exploration of drivers and mechanisms. The application of the ecosystem services bundles concept is helpful to understand the provisioning mechanisms of ES and the dynamics among multiple ecosystem services. Ecosystem service bundles are defined as a mix of correlated ES provided at the same location and at the same time, though they may not have any direct causal relationships (Renard et al. 2015).

Impacts of the GGP on trade-offs and synergies between multiple ecosystem services have been investigated in multiple scientific studies. Many previous studies have analyzed ecosystem services supply on the Chinese Loess Plateau, and several address the dynamics and relations between different ecosystem services. For example, Lü et al. (2012) discovered that the entire Chinese Loess Plateau was transformed from a carbon source to a carbon sink by mapping carbon sequestration dynamics from 2000 to 2008. Feng et al. (2017) found out that vegetation coverage and types are the main factors that affect soil erosion control, soil moisture conservation and carbon sequestration based on field experiments in 2014. However, the majority of previous studies mainly put emphasis on single trade-off and synergy relations between regulating services, such as soil retention, water retention and water purification, ignoring the changes of other ecosystem services and the driving forces behind such changes. Meanwhile, some researchers focus on comparing ecosystem services after a certain time period against a baseline, but neglect the dynamics during that time span (Yuanxin Liu et al. 2019). For example, Li et al. (2019) mapped changes of ecosystem services in the entire Loess Plateau from year 2000 to 2015, without describing the fluctuation of ecosystem services within these 15 years. Besides, cultural services, which are defined as the nonmaterial benefits people obtained from the ecosystem, were not taken into account in the studies on the Loess Plateau. Furthermore, due to vegetation growth and continuance of GGP, there is a lack of research considering the most recent impacts of GGP on the ecosystem services on the Loess Plateau. Thus, in order to monitor the dynamic impacts of the GGP across various categories of ecosystem services, we considered the time period 1990-2018 (including ex-ante and ex-post phases of the GGP project) and selected 11 ecosystem services covering four provisioning, four regulating and three cultural services.

The implementation of the GGP is expected to have affected a range of ecosystem services on the Loess Plateau. The GGP proposed a reduction in cultivated area in return for an increase in forest and grassland area. Provisioning services, such as grain, livestock, fruit and timber were assessed in order to quantify the impacts from GGP land restoration measures. The main goal of the GGP is to prevent soil and water loss and maintain soil quality, thus, we included sediment retention and carbon sequestration as ecosystem indicators in our analysis. Additionally, it has been found that land restoration plays an important role in the reduction of surface streamflow on the Chinese Loess Plateau (Chen et al. 2020). Therefore, seasonal water yield, as an indicator for water supply, was also considered in this study. Furthermore, a primary goal of restoration is the protection of biodiversity, including genes, species, populations, habitats and ecosystems (Hector & Bagchi, 2007), therefore, habitat quality is also quantified. Here, we define habitat as "the resources and conditions present in an area that produce occupancy – including survival and reproduction – by a given organism" (Hall et al. 1997, p. 175). Cultural services, like all other ecosystem services, must demonstrate unique relations between ecosystem structures and meeting the satisfaction of human needs (Daniel et al. 2012). Cultural services, including outdoor recreation, aesthetic value of the landscape and learning and inspiration values were considered.

The main objectives of this study are a) to analyze the spatial and temporal dynamics in ecosystem services before and after the implementation of the GGP using ecosystem service bundles; and b) to understand trade-offs and synergies between multiple ecosystem services.

3.2 Methods

3.2.1 Study area

The study area of Yan'an is located in the northern Shaanxi province on the south-central part of the Chinese Loess Plateau at latitude 35°21'-37°31' N and longitude 107°41'-110°31' E. Yan'an is a prefectural-level municipality covering an area of 37,030 km^2. It is a typical hilly area on the Loess Plateau that consist of multiple deeply incised valleys. The main soil type is *Calcareous Cinnamon Soil* (Xu et al. 2020). The terrain of Yan'an is higher in the northwest (highest point: 1795 m) and lower in the southeast (lowest point: 353 m), having an average elevation of around 1200 m (Figure 3.1). Yan'an belongs to a semi-humid, warm temperate climate zone with continental monsoon circulation. The average annual temperature is 9.9 °C and annual precipitation is 510.7 mm. In 1998, Yan'an area was selected as the first experimental site to start the GGP land restoration project in its northwestern Wuqi county. Up to now, Yan'an has implemented vegetation restoration for nearly 20 years and restored around 7200 km^2 of degraded land (Guo & Gong, 2016).

3.2.2 Data sources

Land use and land cover (LULC) data of Yan'an area at a 30 m resolution for the years 1990, 1995, 2000, 2005, 2010, 2015 and 2018 was provided by the Data Center for Resources and Environmental Sciences of the Chinese Academy of Science (http://www.resdc.cn). This data was extracted from remote sensing data of Landsat-TM/ETM and Landsat 8. LULC data was classified into six classes: cropland, forest, grassland, water body, urban land and bare land. Meteorological data from 1990-2018, including precipitation, solar radiation, temperature, humidity and evapotranspiration, was obtained from the National Meteorological Administration of China (http://data.cma.cn) for meteorological stations (see Figure 3.1). A 30 m resolution DEM of Yan'an was obtained from the ASTER Global Digital Elevation Model (ASTER GDEM) from the Geospatial Data Cloud site of the Computer Network Center of the Chinese Academy of Science (http://www.gscloud.com). A soil erodibility map of Shaanxi province was obtained from the National Earth System Science Data Center (http://geodata.cn) and a world rainfall erosivity index map was acquired from the European Soil Data Center (ESDAC); http://esdac.jr.ec.europa.eu). Additionally, world soil group data was obtained from EARTHDATA from NASA (http://earthdata.nasa.gov). Statistical data of the 13 counties in Yan'an was derived from the Statistical Yearbook of Yan'an from the Yan'an Statistical Bureau (http://tjj.yanan.gov.cn/).

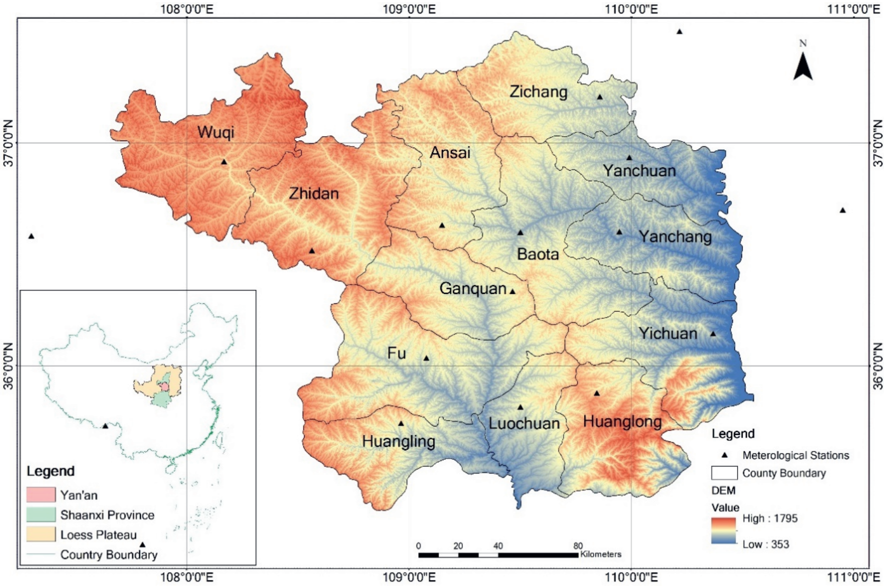


Figure 3.1 Location of the study area Yan'an, including county boundary, meteorological stations and elevation.

3.2.3 Quantification of ecosystem services

Eleven ecosystem services were selected to monitor the impacts of the GGP land restoration project in the 13 counties of Yan'an area (Table 3.1). Each ES was quantified in a biophysical way for the 13 individual counties of Yan'an area over a time period of 28 years split into seven time intervals from 1990 up to 2018.

Indicators for the four provisioning services were derived from the statistical yearbook. As an indicator for grain production, the average yield of wheat and corn of each county (in t/km^2) was used. Apple yield (t/km^2) was used as an indicator for fruit production. Livestock production was indicated by pork, beef and mutton meat productivity (t/km^2). Timber production was indicated by the weight of timber produced per hectare (t/km^2). Four regulating services, including carbon sequestration (Mg/ha), sediment retention (t/ha), seasonal water yield (mm of base flow) and habitat quality (index from 0-1), were assessed by the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model (Nelson et al. 2018), which is explained in detail in sections 2.3.1-2.3.4. Indicators for the three cultural services were obtained from the statistical yearbook and the LULC map, respectively. Terrace area (%) was used as an indicator for the aesthetic value of the landscape, forest area (%) offered an underpinning for outdoor recreation and the number of local cultural institutes (n/1000 km^2) for entertainment and cultural education as an indicator for learning and inspiration. Additionally, the gross value of agriculture, industry and forestry (in USD/km^2) as well as population density (in person/km^2) were calculated from the statistical yearbook as covariables.

Table. 3.1 Ecosystem services and covariables quantified from 1990 to 2018.

Ecosystem services	Indicators/Units	Data sources
Provisioning		
Grain production (GAP)	t/km^2	Statistical yearbook of Yan'an
Fruit production (FUP)	t/km^2	
Livestock production (LVP)	t/km^2	
Timber production (TBP)	t/km^2	
Regulating services		
Carbon sequestration (CAS)	Mg/ha	InVEST Model
Seasonal water yield (SWY)	mm of base flow	
Sediment retention (SDR)	t/ha	
Habitat quality (HBQ)	index from 0-1	
Cultural services		
Aesthetic value of landscape (AVL)	% terraced land	Statistical yearbook of Yan'an
Learning and inspiration (LAI)	n/1000 km^2	
Outdoor recreation (OR)	% of forest area	LULC map

Covariables		
Gross agricultural value (GAV)	USD/km^2	Statistical yearbook of Yan'an
Gross industrial value (GIV)	USD/km^2	
Gross forestry value (GFV)	USD/km^2	
Population density (POD)	person/km2	

3.2.4 Carbon sequestration

Carbon sequestration (CAS) was calculated based on the carbon storage and sequestration model from InVEST (version 3.7.0). This model is composed of three parts to calculate the carbon storage (eq. 1): 1) carbon from plants including aboveground biomass and belowground biomass; 2) carbon from soil; 3) carbon from dead litter. Based on this calculation, land use and land cover change contribute mostly to changes in carbon storage due to changes in vegetation types.

$$C_{carbon} = C_{above} + C_{below} + C_{soil} + C_{dead} \tag{3.1}$$

To run this model, land use maps and carbon pools which indicate carbon storage values of different land use types are required. In this study, carbon sink data is based on experimental field data collected in Yan'an area: aboveground biomass data was obtained from Xiao et al. (2016), belowground biomass from Feng et al. (2017), soil carbon content from Zhang et al. (2019) and dead litter from Zhang et al. (2001).

3.2.5 Seasonal water yield

Because Yan'an has a typical seasonal climate where precipitation is usually concentrated between July and September (S. Yang et al. 2018), the seasonal water yield model from InVEST was used to estimate water yield of the 13 counties in Yan'an. This model represents seasonal water yield (SWY) using two indices: quick flow and base flow. Quick flow indicates the generation of streamflow of hours to days, whereas base flow is defined as the generation of streamflow of months to years (Nelson et al. 2018). In order to monitor yearly water yield and reducing the climate variability impacts from fluctuating precipitations, base flow (in mm) was used while quick flow was excluded in this study.

The SWY model requires a series of monthly evapotranspiration (ET_1-ET_{12}) maps, monthly precipitation (P_1-P_{12}) maps, DEM, LULC maps, soil groups and integer Curve Numbers (CN). Monthly evapotranspiration was calculated with the R-package *evapotranspiration* (version 3.6.2) using meteorological data. Raster maps for monthly evapotranspiration and precipitation were created using the *kriging* tool in ArcGIS (version 10.5), based on the locations of the meteorological stations within and surrounding the Yan'an area. CN data was obtained from the Hydrology Nation Engineering Handbook of United States Department of Agricultural (https://directives.sc.egov.usda.gov/17758.wba).

3.2.6 Sediment retention

Sediment retention (SDR) in Yan'an area was calculated using the sediment delivery ratio model from InVEST. This model is a spatially explicit model based on the spatial resolution of the input DEM raster map. The calculation of the sediment delivery ratio consists of two parts (Nelson et al. 2018). The first part computes the annual soil loss from each pixel in the raster map based on the Revised Universal Soil Loss Equation model (RUSLE; Renard 1997). The second part generates the portion of soil loss that eventually reaches the stream and accounted for the final water yield results (Bhattarai & Dutta, 2007), the RUSEL model is explained as below:

$$usle_i = R_i * K_i * LS_i * C_i * P_i \tag{3.2}$$

where $usle_i$ is the amount of annual soil loss in one pixel, R_i is the rainfall erosivity which is derived from the world erosivity map, K_i is derived from the soil erodibility map, LS_i is the length-gradient factor (calculated from the DEM), and C_i and P_i are the crop management and support practice factors, respectively, which were obtained from Fu et al. (2005).

3.2.7 Habitat quality

Habitat quality (HBQ) was quantified using the InVEST habitat quality model. This model combines information from the LULC map and disturbances to biodiversity to generate a habitat quality map (on an indexed scale between 0-1, 1 indicates a perfect habitat to live). Both the impacts from biodiversity disturbances and the distance between the habitat and the threat sources are considered in the model. Biodiversity disturbances of both negative and positive induced sources were accounted, negative sources include mining areas, roads, railways, urban areas and other populated areas, positive sources contain natural reserves and national parks. The dynamics in biodiversity threats over the 1990-2018 time period were presented by threats maps that varied over time. Additionally, the threats' maps were obtained from the Worldmap dataset of Harvard University (https://worldmap.harvard.edu/).

3.2.8 Statistical methods

Based on the above models and statistical data, we quantified 11 ES, including four provisioning services, three regulating services and four cultural services. In order to understand the spatial and temporal dynamics of each ES, we used the Space-Time Interaction (STI) method from Legendre, Cáceres, and Borcard (2010). This method tests space-time interactions in repeated ecological data, where there are no replications at the level of individual sampling units. In STI, variables of time and space were coded by principal coordinates of neighbor matrices into a two-way analysis of variance (ANOVA) model (Renard et al. 2015). A significant result of STI ($p<0.01$) indicates that the spatial distribution of an ES has changed over time. In our study, STI was processed using the package *adespatial* in R (version 3.6.3), setting each STI test at 999 permutations.

Each ES was calculated based on its mean ± SD across all 13 counties and taking the average value based on county area. Synergies and trade-offs between various ecosystem services were analyzed using Pearson correlation analysis in R (version 3.6.1). For every research year, the average value of each ecosystem service was defined at county level and each ecosystem service was standardized to a comparable unit scale from -1 to 1. Correlations between different ES were determined for the study period 1990 to 2018. Ecosystem service bundles were subsequently defined to assess the dynamics of multiple ecosystem services jointly. Ecosystem service bundles were analyzed using k-means cluster analysis from the package *cluster* in R (version 3.6.3). Maps with ecosystem service bundles were visualized using ArcGIS (version 10.5). Additionally, in order to understand the dominant patterns of ecosystem services values among different temporal and spatial scales, principal component analysis (PCA) was applied through R package *ggplot* (Wold et al. 1987).

3.3 Results

3.3.1 Spatial and temporal dynamics in ecosystem services

In Figure 3.2, the spatial and temporal dynamics of the 11 ES are presented that resulted from the STI analysis. For provisioning services, an obvious increase in fruit production was observed from 2005 to 2015. Results from the STI analysis ($p < 0.001$) indicate that this increase only happened in a few specific counties. Livestock production almost doubled from 1990 to 2018 and this increase occurred across all counties. Grain production fluctuated in all counties during the research period. A drop in grain production was observed in 2000, followed by an increase. In contrast, timber production showed a clear drop starting from 1995 up until 2005. During this time period, timber production decreased with almost 80%. After 2005, the production level tended to stabilize.

For regulating services, a gradual increase was generally observed in sediment retention, carbon sequestration and habitat quality. This gradual increase was not covering all counties, but took place in several specific counties (see Appendix 3.1-3.3); a significant $p < 0.001^*$ from STI test results was found for three regulating services (CAS, SDR and HBQ). Meanwhile the highest increase was determined in 2005 in both regulating services CAS and HBQ. Trends for water yield were fluctuating. Water yield dropped in 1995 and increased again in 2010 and 2018. These fluctuations in seasonal water yield occurred in all counties from 1990 to 2018 as was illustrated by the STI test results (p value = 0.052; see Appendix 3.4).

Cultural services, such as habitat quality and outdoor recreation, showed similar increasing trends as the three regulating services. The values for outdoor recreation, aesthetic landscape value, and learning and inspiration all increased from 1990 to 2018. Results from the STI test (p value < 0.001*) indicate that changes in outdoor recreation and aesthetic value of the landscape only occurred in specific counties of Yan'an area (see Appendix 3.5 for outdoor recreation), while learning and inspiration improved in all 13 counties. Overall, the spatial and temporal dynamics of the 11 ecosystem services indicated that the majority of the selected services showed an increasing trend. Only trends for timber production decreased clearly, while water yield decreased from 1990 to 1995 and increased after 2005 onwards.

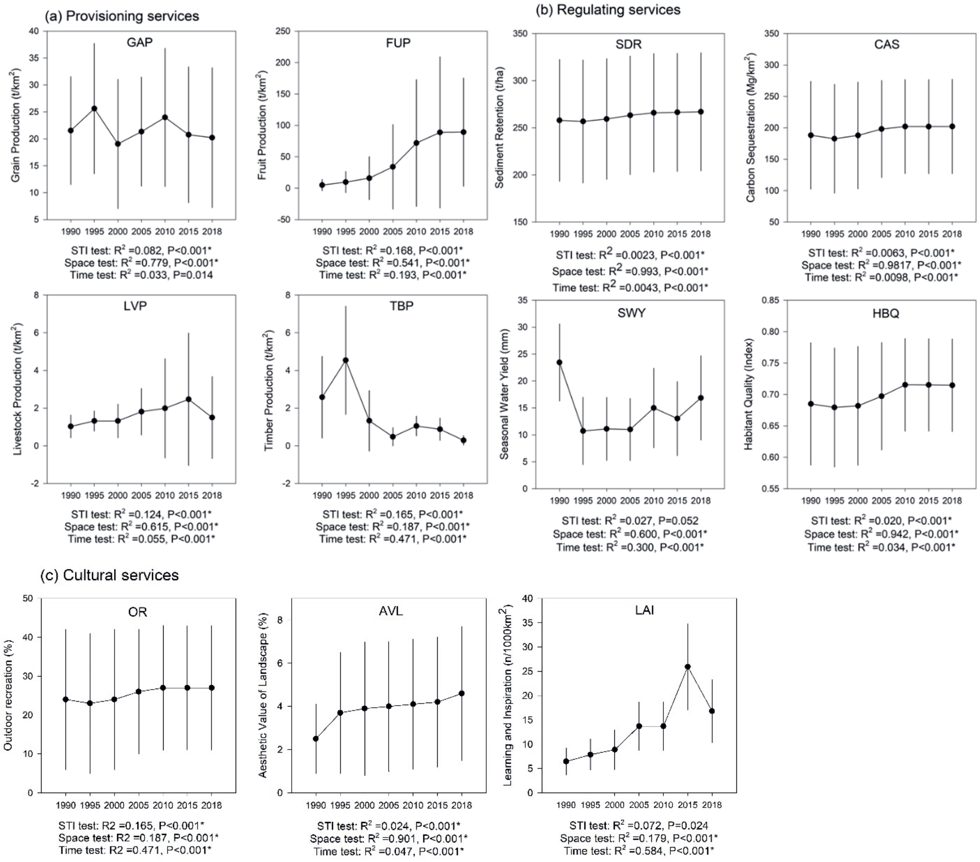


Figure 3.2 Space and Time Interaction (STI) test results for 11 ecosystem services across the 13 counties in Yan'an from 1990 to 2018. Note: error bars indicate standard deviation, calculated based on the average value of ecosystem services from 13 counties in one specific year. GAP: grain production; FUP: fruit production; LVP: livestock production; TBP: Timber production; SDR: sediment retention; CAS: carbon sequestration; HBQ: habitat quality; SWY:

seasonal water yield; OR: outdoor recreation; AVL: aesthetic landscape value; LAI: learning and inspiration.

3.3.2 Trade-offs and synergies between ecosystem services

In the trade-offs and synergies analysis of the ecosystem services, we found that the majority of ecosystem services showed synergistic relations. We used the average value of 11 ecosystem services in each research year at county scale. In Figure 3.3, linear correlations between all ecosystem services are displayed, ordered by size of the Pearson correlation coefficient (*r*). Positive correlations indicate a synergy between services ($0 < r < 1$; displayed in blue color in Figure 3.3), while negative correlations indicate a trade-off between services ($-1 < r < 0$; displayed in red color in Figure 3.3). In general, the figure shows that the majority of the correlations are positive, indicating synergies between those ecosystem services. For instance, there are strong synergies between aesthetic landscape value, learning and inspiration, livestock production, carbon sequestration, outdoor recreation, fruit production, sediment retention and habitat quality.

For provisioning services, fruit production showed a strong synergy with the majority of other ecosystem services, except for a trade-off with timber production. Also, livestock production had a trade-off with timber production. Timber production had trade-offs with the majority of the other services, except for a synergy with grain production. Grain production showed no significant correlation with majority of other services, besides a slight synergy with timber production. Regulating services, including carbon sequestration, habitat quality and sediment retention had synergies between each other. Water yield showed trade-off correlations with the aesthetic landscape value and livestock production. As for cultural services, outdoor recreation showed synergies with the majority of the regulating services, while trade-offs with provisioning services were observed. Learning and inspiration and aesthetic landscape value had similar correlations with other ecosystem services. Additionally, the aesthetic value of the landscape had trade-offs with water yield and timber production, while learning and inspiration only showed a significant trade-off with timber production. The highest synergy was found between carbon sequestration and outdoor recreation ($r = 0.99$), and between sediment retention and habitat quality ($r = 0.98$). Additionally, carbon sequestration showed very strong synergies with sediment retention and habitat quality ($r = 0.98$ and $r = 0.97$, respectively). Highest trade-offs were found between timber production and outdoor recreation ($r = -0.89$), followed by timber production and carbon sequestration ($r = -0.85$).

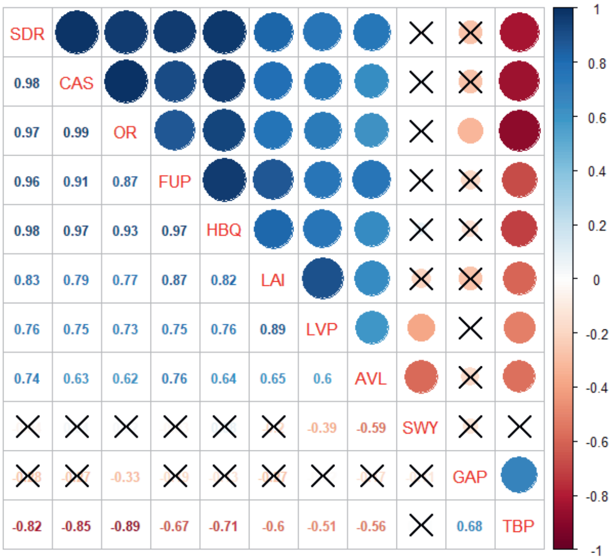


Figure 3.3 Correlations between different ecosystem services. Numbers illustrate the Pearson correlation coefficient (*r*) of linear correlations. Blue dots indicate a synergy, while red dots indicate a trade-off. The color depth indicates the strength of the correlation. Crosses indicate an insignificant result (p > 0.05). Abbreviations can be found in Figure 3.2.

3.3.3 Principal component analysis between ecosystem services

By a combined analysis of a PCA and the Pearson correlations, the internal structure and explained variance of the trade-offs and synergies between different ecosystem services was investigated. The result of the PCA can be found in Figure 3.4 component 1 (PC1) explained 70.1% of the total variance while component 2 (PC2) explained 11.4%, apparently the summed variance of PC1 and PC2 had met the 60% threshold. PC1 occupied a major portion of the PCA test. Within PC1, besides timber production, gross forestry value shows negative correlation to other ecosystem services as well. Additionally, in PC2, we found a negative correlation between water yield and grain production, which was not observed in the Pearson correlation test.

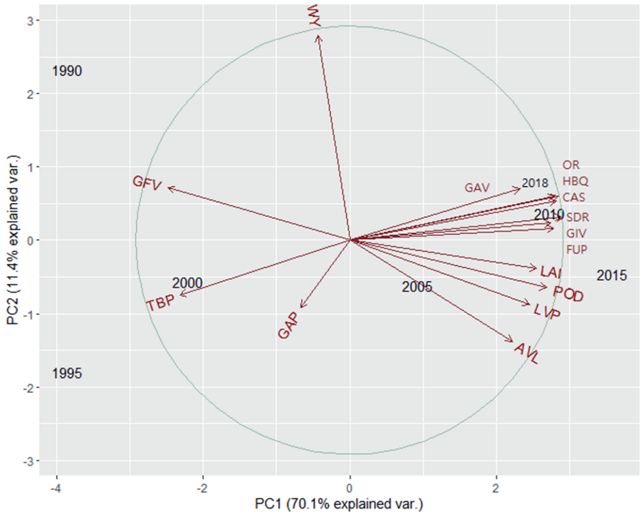


Figure 3.4 Principal Component Analysis of ecosystem services.

3.3.4 Ecosystem services bundles

In the results of ecosystem services bundles, seven time intervals in 13 counties of Yan'an area were considered in the calculation. Based on k-means clusters results with standardized ecosystem services values, the 11 ecosystem services from one specific year and county were considered as an entity, 7 time intervals and 13 counties (91 in total) of the ecosystem services group were categorized into 5 clusters of ecosystem service bundles. In Figure 3.5, the specific components of five ecosystem service bundles are displayed. For each bundle, the dominant ecosystem services were used to name the bundles. The five bundles are identified as food production, sediment retention, forest habitat, landscape value and timber production. These five ecosystem service bundles indicate the value distribution of 11 ecosystem services specifically at county-level and in a certain research year. According to the value of ecosystem services in each bundle, bundle 1 Food production was dominated by provisioning services, led by fruit production, followed by grain and livestock production. Bundle 2 Sediment retention had the highest sediment retention value while the remaining 10 ecosystem services were fluctuated amongst each other. Carbon sequestration, habitat quality and outdoor recreation were the focal ecosystem services in bundle 3. The cultural services aesthetic landscape value and learning and inspiration were well represented in bundle 4 labeled as landscape value. Bundle 5 was led by timber production, followed by water yield and grain production.

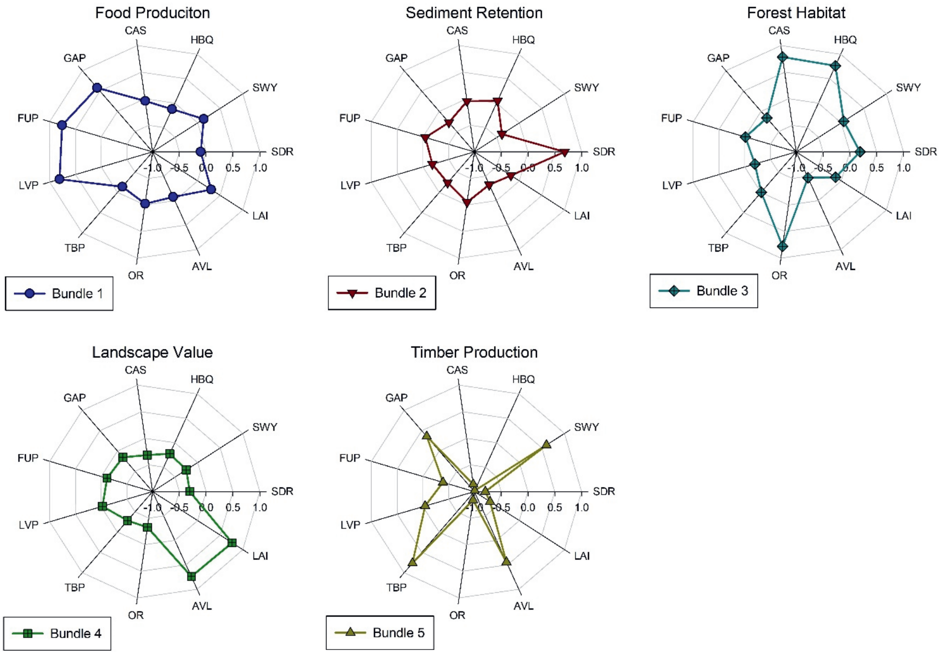


Figure 3.5 Ecosystem service bundles. Note: 1. Food production, 2. Sediment retention, 3. Forest and Habitat, 4. Landscape value, 5. Timber production.

In Figure 3.6 the spatial and temporal distribution of the five ecosystem service bundles in 13 counties across 7 time intervals is displayed. In general, we can observe a change of overall color from 1990 to 2018: in 1990 the dominant color was yellow while in 2010 this color turned to be red and changed to green in 2018 eventually. These color changes indicate that the dominant ecosystem service bundles of Yan'an area altered from Timber Production to Sediment Retention from 1990 to 2010, and moved towards Landscape Value in 2018. Starting from 1990, in the Northern part of Yan'an area, Timber production was the major ecosystem service bundle. In 1995, the distribution of the ecosystem service bundles almost remained the same. However, from 2000 we observe a transformation from Timber production to Sediment retention in Wuqi, Baota and Yichuan, and to Landscape value in Zhidan county. The distribution of ecosystem service bundles remained the same in the years 2005 and 2010, but starting in 2015 there are 7 Landscape value bundles covering the Yan'an area. Luochuan was the only remaining county with a Food production bundle, while Huangling and Huanlong kept a Habitat quality bundle during the whole research period. A summary of changes in ecosystem service bundles numbers can be found in Table 3.2.

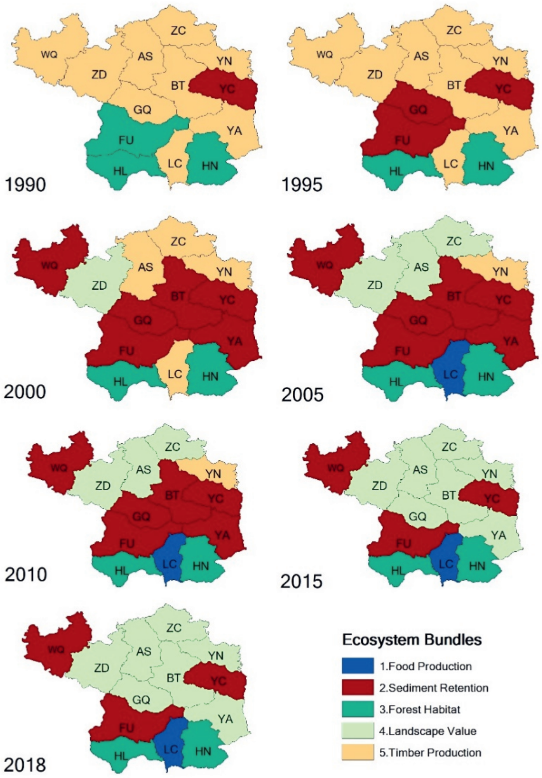


Figure 3.6 Spatial and temporal distribution of five ecosystem service bundles in Yan'an area. Note: WQ: Wuqing; ZD: Zhidan; AS: Ansai; ZC: Zichang; YN: Yanchuan; YC:Yanchang; BT: Baota; GQ: Ganquan; YA: Yichuan; HL: Huangling; LC: Luochuan; HN: Huanglong.

Table 3.2 Temporal variation in ecosystem service bundles (count data represent the number of counties (n=13) where the concerning bundle was dominant).

ES bundles	1990	1995	2000	2005	2010	2015	2018
1. Food Production	0	0	0	1	1	1	1
2. Sediment Retention	1	3	6	6	6	3	3
3. Habitat Quality	3	2	2	2	3	2	2
4. Landscape Value	0	0	1	3	3	7	7
5. Timber Production	9	8	4	1	1	0	0

3.4 Discussion

Eleven ecosystem services in Yan'an area were quantified and their spatial and temporal changes were estimated. The trade-offs and synergies between these ESs were analyzed, and ecosystem service bundles were assessed. Based on the results, we observed increases in the majority of the ecosystem services from 1990 to 2018, and particularly dramatic increases of fruit production, habitat quality, carbon sequestration, learning and inspiration and outdoor recreation that occurred since 2000. Correlation analysis revealed relations between specific ecosystem services, both trade-offs and synergies were observed. Synergies were found between sediment retention, carbon sequestration, outdoor recreation, fruit production, habitat quality, learning and inspiration, livestock production and aesthetic value of landscape, while a trade-off was found between timber production and water yield. The ecosystem services bundles results showed an obvious change since 2000, as the majority of the ecosystem bundles changed from timber production to landscape value.

The results of ES quantification were similar to previous studies on the Loess Plateau, and confirm that there were increasing trends of sediment retention and carbon sequestration during the implementation of the GGP (Yang et al. 2018). In the results of sediment retention and carbon sequestration in Figure 3.2, we observe a drop from 1990 to 1995. This indicates an ordinary trend in the Yan'an area before restoration implementation, representing a general degradation trend on the Loess Plateau. Shortly after, the implementation of the GGP started and since 2000 both of these regulating services slightly increased. From the collected 4 carbon input indices (carbon in above-ground biomass, below-ground biomass, litter biomass and carbon in soil), we observe huge differences in aboveground and belowground biomass between cropland and forest: forest contains 10 times higher biomass values than cropland on the Loess Plateau (Xiao et al. 2016; Feng et al. 2017). Due to the traditional practice of removing crop residues after harvest, in the Carbon model the carbon content of the litter layer of cropland was set at 0. Hence the introduction of the GGP, through an increase of forest and reduction of cropland, has increased the local carbon storage of the Yan'an area. We observed a dramatic drop of water yield in 1995, and the value kept being consistently low compared to 1990 until the end of the assessment period in 2018.

According to the observational evidence from many regions in the world, land use and climate change are recognized to be two majors drivers affecting baseflow (Price, 2011). On the Chinese Loess Plateau, the newly planted forest and grassland have caused an increase of both evapotranspiration and net primary productivity (Feng et al. 2016). Additionally, in recent decades a significant increase of extreme warm surface temperature and a decrease of average daily precipitation were observed on the Chinese Loess Plateau (Sun et al. 2016). Wang et al. (2015) initiated a research of human activity impacts on runoff and sediment transportation in Yan River, which is the main river in the Yan'an area, and concluded that human activity is a main reason of runoff decline by changing the land cover. Meanwhile, according to the algorithm of the Seasonal water yield model, decline of precipitation and increase of temperature and evapotranspiration could be a main reason to cause a decrease in water yield. HBQ increased around 7% from 2000 to 2010 and showed a slight decreasing trend between 2010 to 2018. Habitat quality from the InVEST model is calculated based on distance and the area of disturbances from the habitat, as well as sensitivity of land cover type to threats. In comparison, forest is less sensitive to threats than cropland and grassland (Nelson et al. 2018). From the land use change table in Appendix 3.6 we found that the urban area expanded more than two times by 2018 compared to 1990, while forest land continually increased from 1995 to 2010 and maintained almost the same value after 2010. This trend could be explained as land restoration leading to an expansion of forest area and increase of HBQ from 2000 to 2010; after 2010, reforestation stagnated while urban area expansion caused a slight decrease of HBQ.

Cultural services often relate to spiritual significance and landscape aesthetics (Daniel et al. 2012). It's hard to quantify and monitor the cultural services especially when crossing a huge time span, due to the difficulties of understanding human emotions from the past. However, in this study, despite data deficiency about cultural services, we quantified the amount and monitored the dynamics of cultural services in terms of outdoor recreation, aesthetic landscape value and learning and inspiration on the Loess Plateau. In previous publications researching ecosystem services' dynamics on the Loess Plateau region, cultural services were frequently neglected (Feng et al. 2017; Yang et al. 2018). Only a few studies have investigated dynamics of cultural services during the implementation of the GGP. Hou et al. (2017) only recorded a slight increase of recreation capacity from 2000 till 2010 in Baota distinct in Yan'an area. Similar results of outdoor recreation have been found in our study while, additionally, a decrease in 1995 had been observed. Tourism is one essential indicator of cultural services indicating the attractiveness of a landscape, which has been studied by many ecosystem research (Raudsepp-Hearne et al. 2010; Remme et al. 2015). In this study, there is insufficient tourism data when tracing back to 1990; however, it is believed that in Yan'an area tourism coincides with outdoor recreation. According to the tourist numbers from the recent five years, Huanglong and Huangling counties received the most tourists among other counties and had the highest forest cover, suggesting that outdoor recreation is correlated with forest cover. An increase of aesthetic landscape value was observed from 1990 till 2018 indicating an expansion of terrace area. Terraces not only bring unique scenery to the local landscape, but also stimulate crop yield. A field experiment on the Loess Plateau found that the yield of a 3-year-old terraced land was 27% higher than sloping farmlands (X. Liu et al. 2011). Based on the dramatic increase of learning and inspiration value from 1990 to 2015, we can speculate local people had paid more attention to their indigenous cultural learning and entertainment.

Results of ecosystem service bundles displayed the temporal and spatial dynamics of ecosystem services before and after GGP implementation. From Figure 3.6, it can be observed that starting from 2000, there was a transformation of ecosystem service bundles from Timber production to Sediment retention and landscape value in northern Yan'an (particularly in Wuqi, Zhidan, Ansai, Baota, Zichang, Guanquan and Yanchang counties). After 2015, since the GGP policy in Yan'an area had altered from mainly reforesting land to maintaining the reforested land, change of land use types was minimized. From the ecosystem service bundles maps, we observe the general process of ecosystem services components change by land restoration in the Loess Plateau. In the first 10 years of the GGP from 2000 to 2010, there was an increase of regulating services at the expense of provisioning services. After 2010, cultural services surpassed regulating services to occupy the majority of the ecosystem services bundles. While during 2010–2018, based on Figure 3.2, regulating services were not decreasing, it was the proportion of cultural services in ecosystem services bundle that increased. Meanwhile we observe that the ecosystem service bundles became stable after 2015 since there was no change in ecosystem service bundles between 2015 and 2018.

According to the land use change map from Appendix 3.7, it can be observed that the majority of the land use change occurred in the northern part of Yan'an while Huanglong and Huangling counties feature much less land use changes. During the GGP implementation, there was a decrease in cultivated land and an increase in grassland and forest area in return (Appendix 3.6 and 3.7). Therefore, it could be expected that grain production would be reduced due to the shrinkage of cropland. However, according to the results in Figure 3.3 there was an increase of average grain production from 2000 to 2010. One explanation is that there has been an increase of grain productivity due to the improvement of agricultural technology as well as the terrace expansion; for instance, there has been an increased utilization of fertilizer on the Loess Plateau (Fan et al. 2005), and from 2000 till 2008, grain yields increased from 3.0 t/ha to 3.9 t/ha on the Chinese Loess Plateau (Lü et al. 2012b).

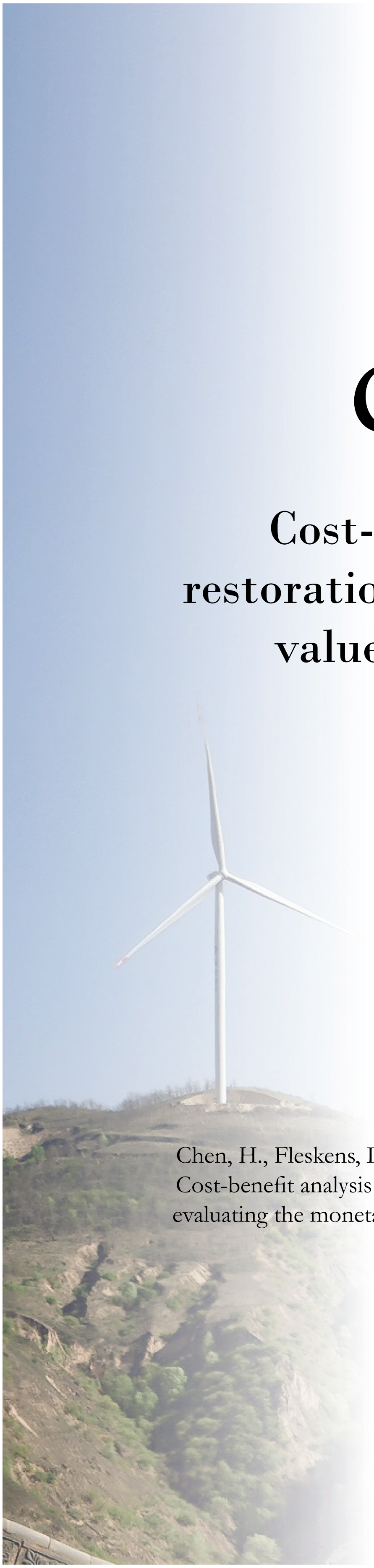
Changes of economic factors in terms of gross agricultural value (GAV), gross industrial value (GIV) and gross forestry value (GFV) as well as population density (POD) were also included in the STI test (Appendix 3.8). Timber production plummeted after 1995 and was almost 5 times lower in 2005. This change may be due to the introduction of GGP policy that banned all tree felling activities, thereupon triggering a decrease of GFV from 1990 to 2005. Meanwhile, the fruit industry has blossomed from 2000 in parts of Yan'an area, especially in Luochuan county, which is famous for its high quality and quantity of apple production (Y. J. Ma et al. 2015). Additionally, according to the GGP strategy there were two types of forests restored from cropland and bare land: economic forest and ecological forest. Economic forest contains various species of fruit trees, nut trees and paper trees which support local farmers' income, for instance, apple, pear, red dates and walnuts, whereas for ecological forest restoration usually drought-enduring trees and shrubs are selected, such as *Robinia pseudoacacia*, *Hippophae rhamnoides* and *Platycladus orientalis* (Deng et al. 2014). Therefore, an increasing area of restored economic forest expanded the fruit tree area simultaneously and improved fruit production as a result.

To sum up, implementation of the Chinese land restoration project GGP not only improved the majority of ecosystem services on the Chinese Loess Plateau, but also led to local economic growth through subsidies and agricultural products. Results of this study are coherent with the "4 Returns approach", since landscape restoration is expected to enhance and restore ecosystem functions which leads to improved delivery of ecosystem services and the returns of natural capital, social capital, financial capital and the return of inspiration (Moolenaar, 2016). According to the guidelines of the ESP (Ecosystem Services Partnership), impact assessment and integrated cost-benefit analysis of land restoration are essential procedures to achieve sustainable landscape management and support land use planning (Groot et al. 2018). For instance, Groot et al. (2020) undertook an integrated cost-benefit analysis of large-scale landscape restoration in Spain. It is therefore suggested to apply an integrated cost-benefit analysis to GGP to unravel the social-economic and environmental impacts of land restoration on the Chinese Loess Plateau in a structured and coherent way.

This research covered an area of 37,000 km^2 and considered an assessment period of almost 30 years. Therefore, there are many factors that could change ecosystem services, for instance, population increase, urban expansion, climate change, etc. However, according to the discussion above, the GGP is understood as a major driver that changed the land cover and ecosystem services simultaneously. Overall, the GGP implementation has had positive impacts on enhancing a majority of provisioning, regulating and cultural services, while the GGP shows negative impacts on timber production and water yield. Decrease of timber production was mainly due to land management policy but may not be a severe issue, as it could be managed by timber import from other provinces. Another concern is the decrease of water yield, although due to the shrinkage of cropland area by the GGP project, the demand for agricultural water use had decreased at the same time. Liang et al. (2018) reported a decline of soil moisture after GGP implementation, with forest featuring lower moisture content than cropland and grassland, while revegetation on the Loess Plateau is considered as a main driver for the moisture decrease. Clearly, forest expansion had brought more pressure on water supply than grassland on the Loess Plateau with an average annual precipitation from 250 mm ~ 600 mm. In order to maintain local water supply, it is recommended that further landscape restoration plans balance the revegetation area of forest and grassland.

3.5 Conclusion

In this study, the dynamics of 11 ecosystem services in 13 counties from Yan'an area were quantified within a time range from 1990 to 2018. An increasing trend was found in the majority of the provisioning, regulating and cultural services including fruit production, livestock production, sediment retention, carbon sequestration, habitat quality, aesthetic landscape value, learning and inspiration and outdoor recreation while seasonal water yield and timber production showed decreasing trends. We observed synergies between regulating and cultural services, including SDR, CAS, HBQ and OR, while both trade-offs and synergies were found in provisioning services. TBP was negatively correlated with CAS, SDR, OR, HBQ and LAI whereas GAP showed synergies. Ecosystem service bundles revealed temporal differences from 2000 until 2015 as well as spatial differences between northern and southern Yan'an. The process of ecosystem services components change by GGP was discovered, to start with increasing regulating services at expense of provisioning services, followed by cultural services exceeding regulating services and occupied the main proportion. Implementation of the GGP is recognized as a key factor changing the land use and affecting ecosystem service bundles. To conclude, GGP implementation had improved the majority of regulating and cultural services whereas it constrained timber production and local water yields. This study reveals the dynamics of ecosystem services while land restoration occurred; this knowledge supports future land use planning and helps to maintain a balance between different ecosystem services. From this study, it is suggested for the Yan'an government to pay attention to local timber products balance, as well as balancing forest and grassland area to maintain sustainable water supply.



Chapter 4

Cost-benefit analysis of land restoration: evaluating the monetary value of ecosystem services[4]

[4] This chapter is based on:
Chen, H., Fleskens, L., Schild, J., Wang, F., Moolenaar, S., & Ritsema, C. J. (2021).
Cost-benefit analysis of large-scale land restoration in the Chinese Loess Plateau:
evaluating the monetary value of ecosystem services. *Ecological Economics, submitted.*

Abstract:

The large-scale Grain for Green (GGP) land restoration program in the Chinese Loess Plateau brought about a strong alteration in land use, dramatically transforming the delivery of ecosystem services. This study aims to understand the dynamics of the monetary value of ecosystem services during the GGP implementation process and in the future, as well as unravel its net economic benefit. Next to using observed land use change effects, we used the CLUE-S model to simulate land cover of Yan'an area in the Chinese Loess Plateau over the period 2000-2020 for a non-GGP scenario (2020 NoGGP), quantify the ecosystem services using the InVEST model and statistical data, and assess the monetary value of ecosystem services by using market prices, replacement cost and benefit transfer. The total monetary value of the ecosystem services increases from 2000 to 2020. The net present value of the GGP over the period 2000-2020 is calculated on the basis of the difference between the actual GGP outcome in 2020 and the 2020 NoGGP scenario, and amounts to 19.41 billion RMB. Trade-offs in monetary values are found between provisioning and regulating services between 2020 and 2020 NoGGP. Net present value of ecosystem services results illustrate that the introduction of the land restoration project enhanced local ecosystem services and augmented monetary benefits. However, a lower return on investment is projected if land restoration continues to expand until 2030. It is recommended to consider more social-environmental factors to support future decision making.

4.1 Introduction

Arid and semi-arid areas cover over 40% of the land surface on this planet; they are considered ecologically vulnerable and sensitive to erosion and face land degradation risks (Kosmas et al. 2014). To address land degradation and desertification issues, multiple land restoration projects have been implemented worldwide (Palmer, 2009). The Chinese Loess Plateau region is an arid area that has experienced severe soil erosion and land degradation due to strongly dissected landscapes, high soil erodibility, intensive rainfall and human activities (Tsunekawa et al. 2014). As one of the most severely eroded regions in the world, the Chinese Loess Plateau has been given a lot of attention in terms of land restoration policies by the national government (Cao et al. 2009). In 1999, one of the world's largest land restoration projects, the Grain for Green project (GGP) was first initiated in the Loess Plateau, aiming to convert sloping cultivated land and bare land into forest and grassland to reduce soil erosion (Persson et al. 2013). With the GGP implementation, around 28 million hectares of cropland and bare land were converted into grassland and forest from 1999 to 2009 (Zhou et al. 2012). The GGP brought a dramatic alteration of land use and, thus, a transformation in ecosystem services delivery (Chen et al. 2015).

During the last few years, various frameworks and approaches were suggested to identify, specify and quantify ecosystem values (Verdone 2015; Saarikoski et al. 2016). For instance, Cordier et al. (2014) introduced a hybrid Input-Output model as a guiding framework to integrate monetary valuation techniques. Schwilch et al. (2016) developed a framework suitable for practical application to the prevention and remediation of soil degradation as well as for the estimation of ecosystem values. As the attention to ecosystem services valuation continues to grow, further development of ecosystem services monetizing methods is expected. It is believed that economic valuation not only helps to obtain the full picture of nature's societal value, but also solves the shortcomings of traditional conservation (Gómez-Baggethun et al. 2011). Monetizing techniques are widely applied for evaluating the effects of changes of ecosystem services on components of human wellbeing as these techniques are regarded as ways to guide decision making processes (Winkler, 2006). For example, Plummer (2009) promoted the benefit transfer method to valuate ecosystem services for conservation planning and ecosystem-based management. Cost-benefit analysis (CBA) has been applied to support policy formulation and decision making in many land restoration cases (Wainaina et al. 2020; Chadourne et al. 2012), and there is an increasing tendency in the use of CBA to evaluate projects and policies which affect ecosystem services, and to promote policies that maximize net benefit flow to the society (Wegner & Pascual, 2011).

Plenty of previous studies have investigated the monetary value of ecosystem services and conducted CBA of ecosystem services at different spatial scales (Saarikoski et al. 2016; Verdone 2015; Sofia et al. 2020). Schild et al. (2018) performed a meta-analysis about the monetary value of dryland ecosystem services at a global scale, pointing out the necessity of improving monetary valuation methods for decision making. Meanwhile, costs and benefits of landscape restoration have been studied by multiple researchers recently. For example, an increase in monetary value of ecosystem services initiated by landscape restoration was determined in a case study in Emscher, Germany in which market value, non-use value and costs were explicitly considered (Gerner et al. 2018). Birch et al. (2010) performed a cost-benefit analysis of conserved areas and pointed out that active restoration was generally outweighed by passive forest restoration due to the high costs involved in active restoration. Many evaluation systems were developed for CBA of landscape restoration; for instance, Verdone (2015) provided a CBA framework supporting forest landscape restoration decision making. Also in China, there has been a rise of research carrying out CBA of large-scale restoration projects, for instance, Ma et al. (2020) conducted a CBA of China's Natural Forest Conservation program, and concluded that natural vegetation supplied the highest net benefit. However, despite being one of the world's largest land restoration projects, the GGP received scanty attention of monetary valuation of ecosystem service change and lacks a cost-benefit analysis to guide future decision making. The majority of studies focused on quantification of ecosystem services during the GGP implementation (Yang et al. 2018), and while Li et al. (2016) plotted the ecosystem services value of the whole of China from 1990 to 2010, the impacts of land restoration and temporal dynamics of ecosystem services value were not considered.

This paper seeks to understand the monetary value dynamics of ecosystem services during the GGP implementation process and unravel the net economic benefit of this land restoration program by conducting a cost-benefit analysis. Ten ecosystem services were selected to estimate the monetary value of ecosystem services in terms of provisioning, regulating and cultural services. Meanwhile to determine the impacts from the current GGP, a counterfactual land use scenario was built to represent the case that the GGP is not implemented, in order to compare the total monetary value differences. The main objectives of this study are to: a) analyse the monetary value of ecosystem services before, after and for a possible future phase of the GGP; b) calculate the net economic benefit of the GGP by conducting a CBA; and (c) provide recommendations for future policy making.

4.2 Methods

4.2.1 Framework

In order to conduct a CBA of the GGP based on the monetary value of ecosystem services in the Chinese Loess Plateau, we built a "2020 NoGGP" scenario assuming the Grain for Green project was not implemented in the Yan'an area. The differences in estimated NPV between the 2020 case and 2020 NoGGP case then determines the cost-benefit analysis result of the GGP. To arrive at this result, the following steps were taken: 1) Build land use scenarios for the GGP; 2) Estimation of the GGP cost; 3) Monetary valuation of ecosystem services; 4) Cost-benefit analysis. The framework of this study is displayed in Figure 4.1. Land use scenario 2020 NoGGP was developed using the CLUE-S model (Verburg and Overmars 2009). Based on the restored cropland area, the investment of the GGP was estimated. The land cover in different years of GGP implementation will affect ecosystem functioning, and change ecosystem services eventually. The quantification of ecosystem services was achieved with the aid of the InVEST model (Nelson et al. 2018) and statistical yearbook data. After the values of quantified ecosystem services (ES) were assessed by different monetary methods, the net present value (NPV) of ES was calculated based on accumulated yearly benefits and costs in the different land use scenarios.

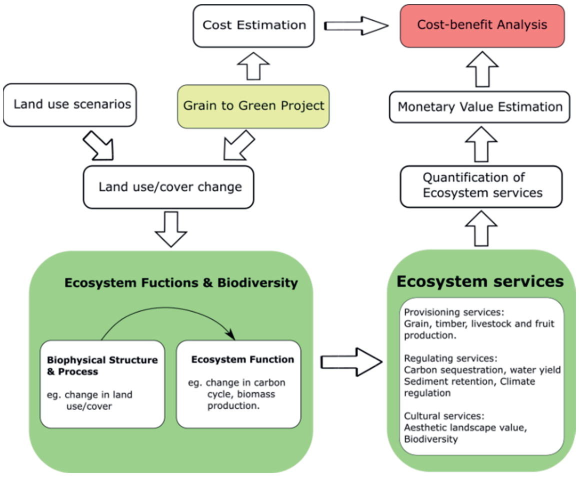


Figure 4.1 Cost-benefit analysis framework for the GGP. In the figure, the yellow box indicates human induced activities, the green boxes indicate natural processes, and the red box indicates the final result.

4.2.2 Study area

The study area of Yan'an is located in the northern Shaanxi province on the south-central part of the Chinese Loess Plateau between latitudes 35°21'-37°31' N and longitudes 107°41’-110°31’ E. Yan’an is a prefectural-level municipality covering an area of 37,030 km^2. It is a typical hilly area in the Loess Plateau that consists of multiple deeply incised valleys. The main soil type is Calcareous Cinnamon Soil (Xu et al. 2020). Yan’an has a semi-humid, warm temperate climate with continental monsoon circulation. The average annual temperature is 9.9 °C and annual precipitation is 510.7 mm. The population of Yan’an area is around 2.3 million, while the Gross Domestic Product (GDP) of Yan’an in 2018 was 156 billion RMB. In 1998, Yan’an area was selected as the first experimental site to start the GGP land restoration project – in its north-western Wuqi county. Up to now, Yan’an has implemented vegetation restoration for nearly 20 years and restored around 7200 km^2 of degraded land (Guo & Gong, 2016).

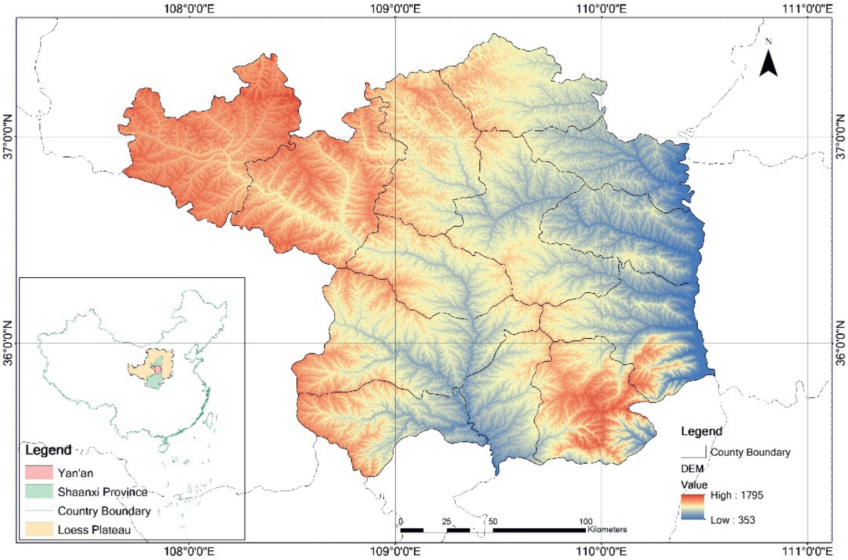


Figure 4.2 Map of study area in the Chinese Loess Plateau.

4.2.3 Land use scenarios

To understand the net economic benefit from the GGP and its future continuation, we simulated two land cover scenarios. To distinguish the impacts of the GGP from only the land cover change perspectives, we introduced the scenario of “2020 NoGGP”. In this scenario, land cover in 2020 was simulated based on a projection of the land use change tendency from 1990 to 2000. By comparing the net present value of the scenario 2020 NoGGP and the value from the real year 2020, a cost-benefit analysis of GGP implementation can be estimated. Additionally, we introduced a scenario “2030”, to estimate the land cover in 2030 assuming land restoration continues to expand for another ten years. We applied the CLUE-S model to simulate the land cover for the two scenarios. The CLUE-S model has been applied in many geographical and environmental studies globally (Kucsicsa et al. 2019; Huang et al. 2019; Zare et al. 2017). This model contains four different modules to predict future land use change, along with policy restrictions and designer demands (Verburg and Overmars 2009). The allocation procedure of the four modules consists of :

$$Ptot_{i,t,lu} = Ploc_{i,t,lu} + Pnbh_{i,t,lu} + elas_{lu} + comp_{t,lu} \qquad (4.1)$$

Where i, t, lu are indicators for time, location and land cover respectively, $Ptot$ is the highest total probability of a certain land use type, it is the sum of $Ploc$ (location suitability), $Pnbh$ (neighbor suitability), $elas$ (conversion elasticity) and $comp$ (competitive advantage). The location suitability was calculated based on logistic regression relations between existing land use type and location factors. In our study, we selected seven location factors influencing land use types (Table 4.1). Moreover, we applied Receiver Operating Characteristic (ROC) curves to measure the goodness of a fit of logistic regression models. A completely random model gives a ROC value of 0.5 whereas a perfect fit results in a value of 1.0; usually an acceptable logistic regression model is regarded as having a ROC value higher than 0.75 (Gil Pontius Jr & Schneider, 2001). Furthermore, the CLUE-S model was calibrated by performing a land cover simulation covering the period from 1990 to 2000 and comparing to the actual land cover in 2000. The Kappa index between the simulated land cover map of the year 2000 and the real 2000 land cover map was 96.03%. According to the results of ROC and Kappa index, it was determined that results of the CLUE-S model are trustable.

Table 4.1 ROC and logistic regression values of location factors in CLUE-S model.

	ROC	DEM	Slope	Distance to river	Distance to railway	Distance to city	Distance to nature area	Distance to road
Crop	0.768	-7.42E-04	-0.0321	-1.69E-05	-5.08E-06	-0.1416	1.15E-05	-1.03E-06
Forest	0.805	2.48E-03	0.0293	1.61E-05	-5.27E-06	0.2729	-2.06E-05	1.23E-05
Grassland	0.777	-7.42E-04	0.0198	-1.31E-06	5.89E-06	-6.12E-03	9.53E-07	-5.36E-06
Water	0.873	-5.07E-03	-0.0567	-1.23E-04	2.83E-06	-0.2820	9.35E-06	-7.00E-05
Urban	0.947	-1.42E-03	-0.1269	-5.36E-06	-5.24E-06	-13.200	-2.05E-07	-6.19E-05
Bare	0.856	9.87E-03	-0.0145	-1.94E-04	-7.91E-05	-0.881	1.60E-05	-2.18E-04

4.2.4 Data sources

Land use and land cover (LULC) data of Yan'an area at a 30 m resolution for the years 2000, 2005, 2010, 2015 and 2020 was obtained from the Data Centre for Resources and Environmental Sciences of the Chinese Academy of Science (http://www.resdc.cn). Land use and cover data was extracted from remote sensing data of Landsat-TM/ETM and Landsat 8. LULC data was classified into six classes: cropland, forest, grassland, water body, urban land and bare land. A 30 m resolution DEM of Yan'an was obtained from the ASTER Global Digital Elevation Model (ASTER GDEM) from the Geospatial Data Cloud site of the Computer Network Centre of the Chinese Academy of Science (http://www.gscloud.com). Statistical data of the Yan'an area was derived from the Statistical Yearbook of Yan'an of the Yan'an Statistical Bureau (http://tjj.yanan.gov.cn/). Additionally, the

Shaanxi Statistical Price Yearbook provided unit price and Consumer Price Index (CPI) information to support monetization of ecosystem services.

4.2.5 Ecosystem services and valuation methods

In this study, ten ecosystem services were selected, including four provisioning services, four regulating services and two cultural services. The selected provisioning services provide information about the physical material supply of ecosystem services. In terms of regulating services as non-material supply, we included sediment retention and carbon sequestration as the main goal of the GGP is to prevent soil and water loss and improve soil quality. Besides, it has been found that land restoration plays an important role in the reduction of surface streamflow on the Chinese Loess Plateau (Chen et al. 2020). Therefore, seasonal water yield, as an indicator for water regulation, was also considered in this study. Land use and cover change are the major drivers of global ecological change and strongly influence regional climate (West et al. 2011); thus, climate regulation was considered as one of the regulating services. Cultural services have been frequently neglected by previous studies. In this study, we included aesthetic landscape value and biodiversity as indicators.

Table 4.2 Quantification and valuation methods for ecosystem services.

Ecosystem services	Quantification method	Monetary method
Grain production (GAP)	Statistical yearbook	Market price
Timber production (TBP)		
Livestock production (LVP)		
Fruit production (FUP)		
Carbon sequestration (CAS)	InVEST model	Carbon tax
Seasonal water yield (SWY)		Replacement cost
Sediment retention (SDR)		
Climate regulation (CLR)	Land use type	Benefit transfer
Aesthetic landscape value (AVL)		
Biodiversity (BIO)		

Grain production of year 2000 and 2020 was obtained from the Yan'an Statistical Yearbook, while grain production of the 2030 and 2020 NoGGP scenarios was determined based on estimated crop yield and crop area from simulated land cover maps. In 2020 NoGGP, the crop yield in 2020 was estimated from the result of a linear regression model based on extrapolation of the crop yield trend from 1990 to 2000; in 2030 the crop yield was estimated based on the crop yield trend from 2000 to 2020. The value of the grain production could be calculated according to the grain price in the specific research year. Fruit and livestock production of year 2000 to 2020 were obtained from Yan'an Statistical Yearbooks. Production in the 2020 NoGGP scenario was calculated by the same estimation method as used for grain production. Fruit and livestock values were calculated based on average fruit and livestock meat prices according to the China Price yearbook in the specific year concerned. Timber production was calculated from timber production in different research years. In the NoGGP scenario, timber production was assumed according to timber production in the years before the GGP. We used 10 years of timber production data from 1990 to 2000 to create a linear regression and predict the timber production in 2020 without GGP. The timber price was based on the price of *Pinus tabuliformis Carr*, as the most commonly harvested tree species. To estimate the projected GGP implementation cost beyond 2020 the price of nursery seedlings of 15 RMB/plant in 2020 was used.

The amount of carbon storage (in t/ha) was calculated based on the Carbon Storage model from InVEST. The value of the carbon sequestration is subsequently estimated by multiplying by the carbon price:

$$U_c = AP_c \tag{4.2}$$

Where U_c is the value of the sequestrated carbon (RMB/ha), A is the unit amount of the sequestrated carbon (t/ha), and P_c is the price of carbon (RMB/t). China has not included a carbon price in its ETS (Emission Trading System); however, China is planning to apply a carbon tax nationally after 2020. According to the impacts of carbon tax on CO_2 emission from Dong et al. (2017), the feasible carbon tax in China in 2020 is estimated to be less than 391 RMB/t (50 EUR/t). Additionally, based on the designed Chinese Environmental tax, the CO_2 tax is estimated to be 50 RMB/t in 2020. The carbon weight ratio in CO_2 is 12:44, thus in our study, we applied a carbon tax of 13.6 RMB/t in 2020.

The monetary value of regulating services can be assessed by calculating the replacement cost. Water yield from different land use scenarios was determined by the base flow amount, which was calculated by the Seasonal Water Yield (SWY) model from InVEST. The input data for the water yield model included precipitation, potential evapotranspiration (PET) and land use data. Precipitation data was collected from the meteorological stations covering in Yan'an area, PET was calculated based on the meteorological data. In the water yield model, the base flow was first calculated (mm), and then the value of water yield was calculated according to the replaced reservoir construction capacity price for storing the water (RMB/m^3):

$$U_W = 10BP_d \tag{4.3}$$

Where U_W is the value of the water yield (RMB), B is the amount of base flow generated from the catchment (mm), P_d is the reservoir construction price (RMB/m^3). According to the China Hydrology yearbook, the average price of reservoir construction based on the average capacity in 2005 was 5.77 RMB/m^3.

Sediment retention of all research years and scenario cases were calculated by applying the Sediment Retention model from InVEST, with results of sediment retention presented in t/ha. The monetary value of sediment retention was determined by the replacement cost of sediment check dams (RMB/m^3):

$$U_s = AP_s \times \rho \tag{4.4}$$

where U_s is the value of the sediment retention (RMB/ha), A is the unit amount of sediment being retained (t/ha), P_s is the construction price of sediment check dam (RMB/m^3), ρ is the bulk density of sediment (t/m^3). The price of the check dams was obtained according to the China Hydrology yearbook. In 2000, the construction price of check dam price was 6.11 RMB/m^3. The bulk density of the sediment from Yan'an area was obtained from field experiment results by Yali et al. (2020) with value 1.25 t/m^3.

To estimate the monetary value of biodiversity, aesthetic landscape and climate regulation, we applied the benefit transfer method by valuing the ecosystem services based on the land cover area. Jianping et al. (2004) estimated the value of biodiversity by the willingness-to-pay method in Shaanxi province. Gaodi et al. (2008) investigated ecosystem services valuation methods by a questionnaire among 700 ecologists, providing benefit transfer values for aesthetic landscape value, climate regulation and biodiversity base on different land use types. These values were improved in Gaodi et al. (2015). Additionally, Yuanjie et al. (2020) adjusted the benefit transfer value of ecosystem services based on previous studies, and provided ecosystem services value coefficients of different land use types especially for the northern Shaanxi area. These previous studies provided benefit transfer coefficients to accomplish secondary valuation of ecosystem services in this study, for biodiversity, climate regulation and aesthetic landscape value (Table 4.3). We applied these benefit transfer coefficients on our study area Yan'an, which is part of the northern Shaanxi province.

Table 4.3 Transferred ecosystem services value coefficients of different land use types in northern Shaanxi of 2020. Numbers indicate the transferred value of listed ecosystem services in each km^2.

Ecosystem services value (RMB/km^2)	Crop	Forest	Grass	Water	Urban	Bare
Biodiversity	88626	391865	162481	221564	29542	6082
Aesthetic value	14771	180727	75593	164218	104266	2607
Climate regulation	84281	353634	135545	463113	0	4344

4.2.6 Assumptions and regulations

In the ecosystem services valuation and cost-benefit analysis calculation processes, many models and calculation methods were involved. In order to keep the consistency of valuation for different scenarios and control variables, our analysis was based on the following assumptions and regulations:

(i) Impacts from climate change were not included. As the land cover change may alter the surface PET and precipitation, and change the water yield as a result, we assume land cover is the only factor driving changes in base flow.

(ii) All the monetary values of different research periods were transferred to current year's price based on the Consumer Price Index (CPI) of the corresponding research year from the Statistical Price Yearbook.

(iii) Grain for Green is the only driver of land cover change from 2000 to 2020, and the governmental cost of land restoration is corresponding to this land use change.

(iv) Land cover change in different scenarios is equally distributed over the research period, so that the accumulated NPV can be calculated.

4.2.7 Cost-benefit analysis

Investments in the GGP were mainly supported by the central government, consisting of four parts: 1) Labor costs for vegetation planting and terrace building; 2) Farmers' subsidy; 3) Plants, seeds and equipment; 4) Administration and maintenance of restored land. According to the financial report from the Yan'an GGP office in 2020, the labor cost was estimated to be 52.94 RMB/Chinese mu/year (79,410 RMB/km^2/year), while costs of pesticides, herbicides and fertilizers were 4.24 RMB/Chinese mu/year (6,360 RMB/km^2/year) (Z. Wang et al. 2018). In 2017, the research team investigated six villages in Ansai county: based on results of interviews with local farmers and village secretaries, the GGP subsidy was applied for 16 years for the restored cropland. Precisely as 160 RMB/Chinese mu/year for the first eight years and 90 RMB/Chinese mu/year for the remaining eight years including a maintenance fee of 20 RMB/Chinese mu/year. Therefore, the unit price of governmental investments in the GGP is estimated to be 3.086 million RMB/km^2 overall.

Table 4.4 Constituents of GGP's unit area cost. The subsidy was offered over two periods, the first eight years at 140 RMB/mu/year, and the next eight years at 70 RMB/mu/year.

Cost	Price (RMB/Chinese mu/year)		Duration (Year)	Subtotal (RMB/km^2)	
Labor	¥	52.94	1	¥	79,410.00
Pesticides	¥	4.24	1	¥	6,360.00
Maintenance	¥	20.00	16	¥	480,000.00
Subsidy	¥	140(70)	16 (8+8)	¥	2,520,000.00
Total				**¥**	**3,085,770.00**

Cost-benefit analysis of the GGP is achieved by calculating the difference between net present value (NPV) of year 2020 and 2020 NoGGP scenario:

$$\mathrm{NPV} = \sum_{t=i}^{T} \frac{(B_i - C_i)}{(1 + r)^t} \tag{4.5}$$

Where C_i is the total cost of the GGP in year i , r indicates the discount rate, and B_i is the benefit of GGP, which is the total monetary value of year i minus the total monetary value in year i without the GGP influence. According to the discount rate data for China from *Economic Research* (https://fred.stlouisfed.org/series/INTDSRCNM193N), the average discount rate for China from 2000 to 2020 is 3.10%. The NPV results of the GGP restoration program in Yan'an area for different research periods were visualized by ArcMap 10.5. The monetary value maps were made by raster calculator, based on the ecosystem services amount and distribution from InVEST model results and values obtained from monetary valuation methods. Boxplots of the total monetary value were derived from R 3.6.2.

4.3 Results

4.3.1 Land use scenarios

In Figure 4.3, land use simulation results from the CLUE-S model are displayed. In the 2020 NoGGP scenario, the GGP was assumed not to have been implemented in Yan'an area, and instead to have evolved following the land use change tendency from 1990 to 2000. As a result, after 20 years of GGP implementation, there is an obvious expansion of grassland in the northern part of Yan'an area compared to year 2000, while urban development is concentrated in the middle part. In the 2020 NoGGP simulation map, we observe an expansion of crop area in the middle and northern part of Yan'an area that is in contrast with 2020, while the forest area remained similar to year 2000.

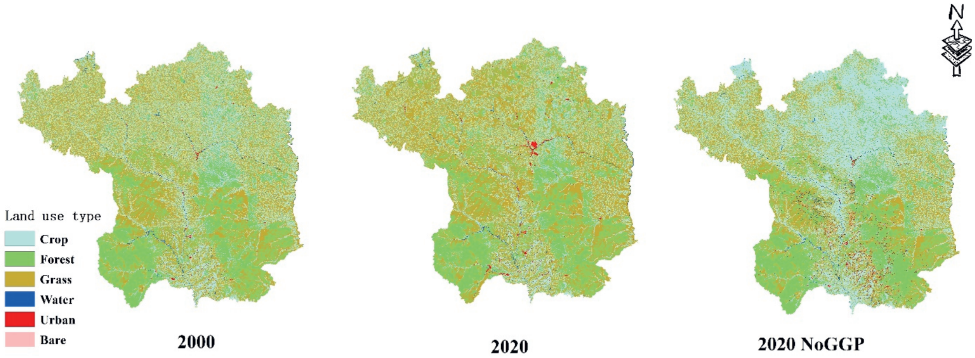


Figure 4.3 Land use maps of different scenarios.

In Figure 4.4, the specific land use area of different research years is presented. We observe that the cropland area in 2020 is reduced by 20.90% compared to 2020, while forest and grass area increased by 8.46% and 10.02% respectively, and urban area expands by 83.51%. In the 2020 NoGGP scenario, cropland area increases by 38.74% compared to 2000, forest and grass areas shrink by 7.37% and 27.08% respectively, while urban area expands by 130.19%. The differences between land cover maps indicate that the GGP has altered the change rate between crop, forest and grass area over the period from 2000 to 2020: the expansion of crop area was reversed and replaced by an enlargement of grass and forest land area.

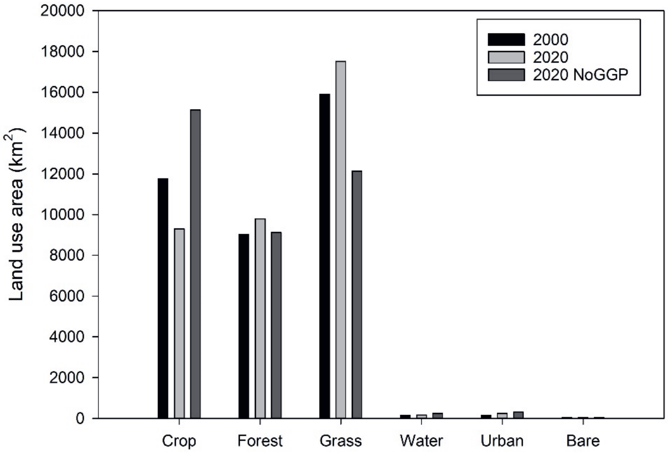


Figure 4.4 Land use area bar plot for different years (2000; 2020; 2020 NoGGP).

4.3.2 Quantifications of ecosystem services

A quantification of ecosystem services was made after obtaining the land use maps for different scenarios. In Table 4.5, the quantified ecosystem services are displayed. Values of biodiversity, climate regulation and aesthetic landscape value are missing as they were transferred directly from the land cover maps. In general, between 2000 and 2020, the grain and livestock production remain at similar value while fruit production increases dramatically by a factor eight. Meanwhile a decrease in timber production was found in 2020. Three regulating services increase progressively from 2000 to 2020. In the 2020 NoGGP scenario, quantity of ecosystem services is obviously different: compared to 2000, grain, fruit and livestock production almost double while timber production decreases. Reduction of regulating services in the 2020 NoGGP case shows an opposite tendency compared to year 2020.

Table 4.5 Quantification of ecosystem services across the Yan'an area for different years.

Ecosystem service and unit	2000	2005	2010	2015	2020	2020 NoGGP
Grain production (t)	666,023	744,870	820,376	721,900	768,610	1,279,884
Fruit production (t)	467,899	1,014,649	2,316,808	2,846,474	3,623,619	1,240,177
Livestock production (t)	42,536	62,793	61,937	52,786	52,295	115,339
Timber production (plants)	13,440,000	3,360,000	6,210,000	10,500,000	8,294,100	8,420,100
Carbon sequestration (t)	153,789,089	161,906,667	165,125,767	165,175,734	164,140,647	147,442,110
Sediment retention (t)	498,710,910	499,431,948	500,676,768	500,697,626	732,427,563	407,134,039
Seasonal water yield (t)	402,611,205	403,654,268	531,548,208	469,585,482	613,603,222	390,947,448

4.3.3 Total monetary value of different scenarios

After having quantified the ecosystem services in different research years, we made an estimation of the total monetary value (TMV) of ecosystem services for seven research years: 2000, 2005, 2010, 2015, 2020 and 2020 NoGGP. The monetary value results of different research years are displayed in Figure 4.5. Different colors in the histogram indicate the monetary value of different ecosystem services, while the red line determines total monetary value change compared to the previous research period.

In Figure 4.5, we discover a general increasing trend of ecosystem services values reaching from 45 billion RMB in 2000 to 112 billion RMB in 2020. Over this period, the TMV of ecosystem services had increased almost 60 billion RMB; the highest increase of TMV was found between 2005 and 2010 with an incremental value of around 30 billion RMB. However, in the 2020 NoGGP case, the monetary value is observed to be 39 billion RMB lower than 2020. Generally, in the constituent ES values of the TMV, water yield contributes the biggest share of TMV among all research years. Meanwhile we observe obvious changes in the components of TMV from 2000 to 2020; for example, the value of fruit production rises significantly whereas less value is found in the 2020 NoGGP case.

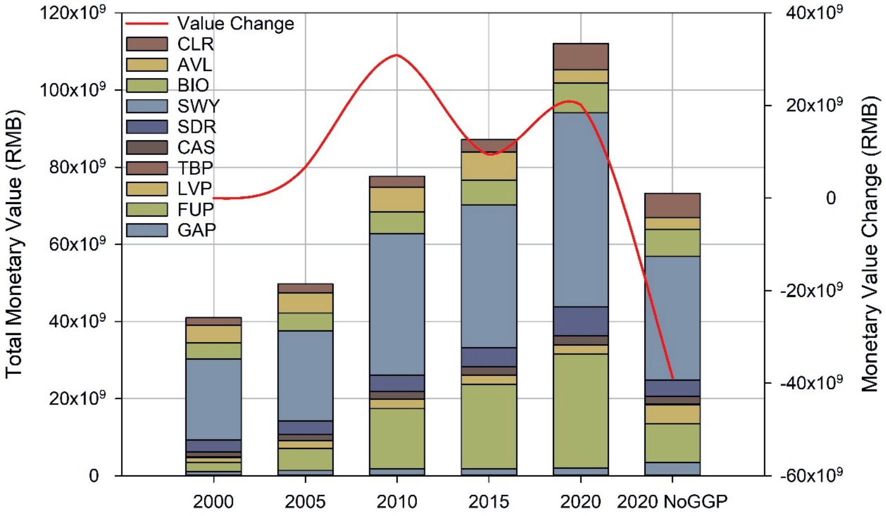


Figure 4.5 Total monetary value of Yan'an area in different research years. Abbreviations can be found in Table 4.2.

In Figure 4.6, the distribution of TMV in six research years is mapped, ecosystem service values are transformed to 10,000 RMB/pixel[5]. Over all six maps, higher TMV are concentrated in the southern part of Yan'an area correlated to the forest area, while grass and cropland area represent a comparably lower monetary value. Several blue and red (high TMV value) points in the TMV map usually correspond to water and urban area. From 2000 to 2020, TMV value increases in the southern part of Yan'an, while higher monetary value expansion is also apparent in the northern area. The most obvious change of TMV happened between 2005 and 2010, which is coherent with the result in Figure 4.5. In the NoGGP case of 2020, less monetary value is observed compared to year 2020, especially in the southern part of Yan'an area. As a result, the implementation of the GGP has brought more value to the Yan'an ecosystem services, with a more equally distributed TMV. Until present, the average monetary value of ecosystem services in Yan'an area has increased from 12,141 to 30,291 RMB/ha from 2000 to 2020, while in the 2020 No GGP scenario case, the average TMV was 19,804 RMB/ha.

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[5] The resolution of the map is 30 m, the area of each pixel is 900 m^2.

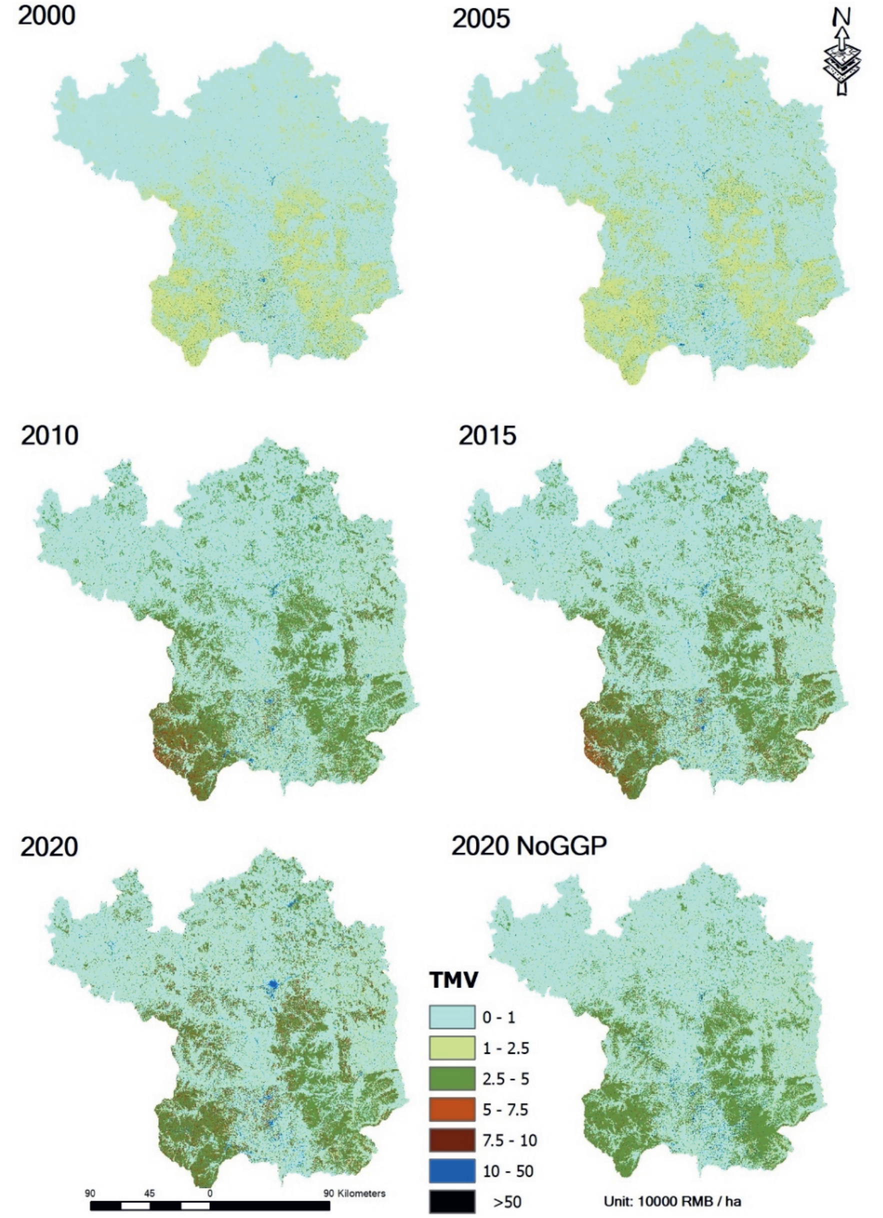

Figure 4.6 Total monetary value across Yan'an area (in RMB 10,000/pixel) in different research years.

4.3.4 Cost-benefit analysis

To conduct a CBA for the GGP, the cost of the GGP is first calculated and presented in Table 4.6. From the table, the biggest increase of restored cropland occurs between 2005 and 2010, with a corresponding cost of the GGP of 4.3 billion RMB.

The expansion of the GGP was decelerated after 2010 according to the land cover maps. By 2020, a total of 2358 km^2 of cropland was restored, representing a 7.3 billion RMB investment. In the NoGGP scenario, 4097 km^2 of forest and grass areas degrade and as no restoration action takes place the relevant restoration cost is assumed to be 0.

The result of the NPV estimation is displayed in Table 4.7. The benefit and cost of the GGP in each research year were calculated based on the initiation of previous research period (detailed NPV table in Appendix 4.1). The highest NPV of GGP in Yan'an area is found in year 2020, with an incremental value of 43.19 billion RMB. However, the biggest increase of NPV is found between 2005 and 2010 with a 17.70 billion RMB raise, while the lowest increase of NPV is 6.37 billion RMB from 2010 to 2015. The highest TMV benefit is determined from 2005 to 2010, coinciding with the biggest investment of land restoration that took place at the same time.

Table 4.6 Accumulated cost of the GGP for the Yan'an area.

Year	Accumulated restored cropland (km^2)	Unit price (RMB/km^2)	Cost (RMB)	Accumulated cost (RMB)
2005	877.37	3,085,770	2,707,354,928	2,707,354,928
2010	2264.74		4,281,117,994	6,988,472,921
2015	2267.82		9,506,332	6,997,979,253
2020	2357.55		276,891,696	7,274,870,949
2020 NoGGP	-4096.80		0	0

Finally, the NPV of the 2020 NoGGP scenario is calculated (See Appendix 4.2) and the cost-benefit analysis is conducted between the GGP implementation case in 2020 and without GGP case in 2020. The result is presented in Table 4.7 and Figure 4.7. While the GGP has a negative NPV until 2006 due to the cost of restoration, the NPV turns positive after 2007 and increases constantly. The internal rate of return (IRR) is negative in 2006 and in 2007 the IRR is 19.6%, exceeding the annual discount rate of 3.1%, illustrating the GGP started to have a net benefit compared the non-GGP case after 2007. The Benefit/Cost ratio (B/C) of the GGP is larger than 1.00 in 2006 and its value constantly increases from 2005 to 2020, indicating that the GGP becomes gradually more beneficial as benefits rise faster than incremental investment. Eventually, over the assessment period 2000–2020, the implementation of the GGP brings 19.41 billion RMB extra net benefit for Yan'an ecosystem services compared to the NoGGP case in 2020.

Table 4.7 Cost-benefit analysis result and investment criteria.

Year	Project Years	Cumulative Discounted benefit	Cumulative Discounted cost	Net Present Value	IRR	B/C
2005	5	¥ 8,007,169,397.84	¥ 10,457,372,126.95	¥ -2,450,202,729.11	N/A	0.77
2006	6	¥ 12,657,744,529.91	¥ 12,691,613,567.33	¥ -33,869,037.42	-0.45%	1.00
2007	7	¥ 17,168,486,656.06	¥ 14,858,676,070.12	¥ 2,309,810,585.94	19.61%	1.16
2008	8	¥ 21,543,600,260.47	¥ 16,960,579,564.58	¥ 4,583,020,695.89	28.51%	1.27
2009	9	¥ 25,787,163,407.34	¥ 18,999,283,244.95	¥ 6,787,880,162.39	33.23%	1.36
2010	10	¥ 29,903,131,542.02	¥ 20,976,687,396.62	¥ 8,926,444,145.40	35.94%	1.43
2015	15	¥ 36,282,697,055.18	¥ 26,413,103,782.14	¥ 9,869,593,273.04	36.42%	1.37
2020	20	¥ 50,681,971,488.65	¥ 31,273,012,166.51	¥ 19,408,959,322.14	37.33%	1.62

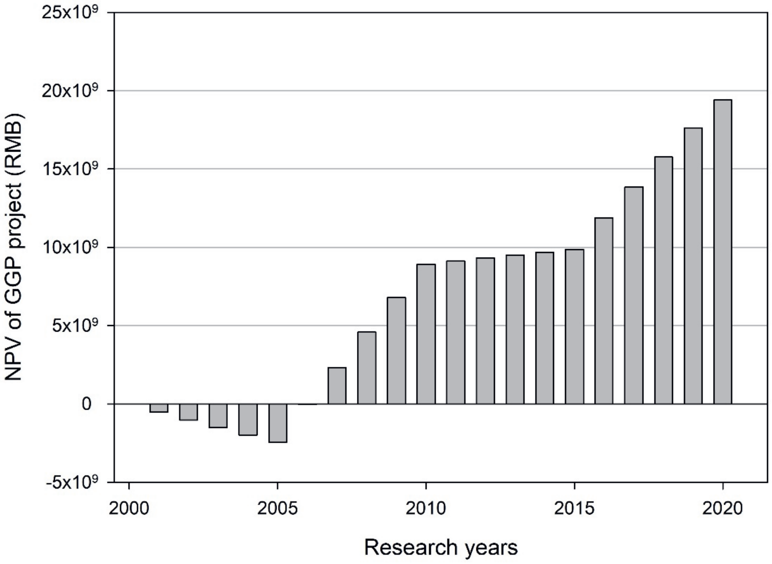

Figure 4.7 Evolution of the NPV of the GGP between 2000 and 2020.

4.4 Discussion

4.4.1 Influences of variables

Discounting the future is essential for sustainable decision making, but as the discount rate is changing over time, this creates uncertainty when conducting cost-benefit analysis (Costanza et al. 2021). In this study, we used a constant discount rate of 3.1% for NPV calculation. In Figure 4.8 we present the result of sensitivity analysis in which we applied different discount rates for estimating the GGP project's NPV at different assessment periods. Increasing the discount rate from 2% to 10% leads to a lower NPV, and this reduction is most pronounced in year 2020. As the GGP has an IRR of 19.6% in 2007, which is higher than the maximum discount rate used in the sensitivity analysis, the moment that the project turns beneficial is not affected.

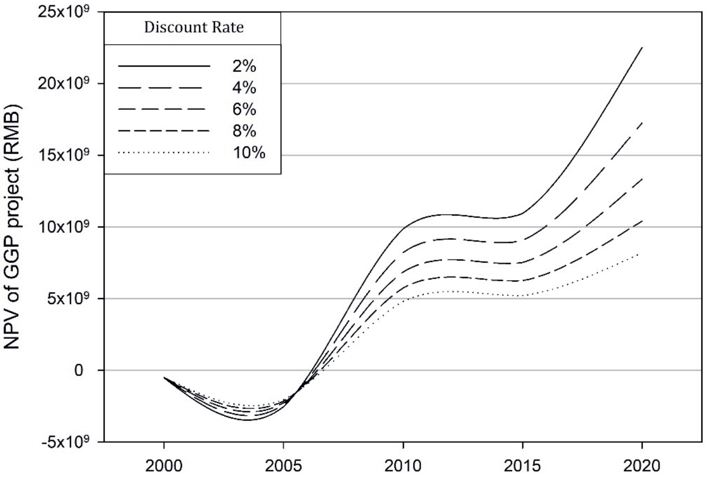

Figure 4.8 Sensitivity of the NPV of the GGP project to the discount rate applied.

According to Figure 4.7 and Table 4.7, at the initial stage of restoration, the benefit is usually negative. However, there was an obvious increase of NPV from 2015 to 2020 while the corresponding incremental cost of restoration is low. This situation may illustrate that the benefit of a restoration project is hysteretic: in the initial stage, forest and grassland is restored with high investment while the monetary value of ecosystem services is low; after several years of growing period for the restored plants, the restored land constantly provides higher value of ecosystem services year after year while corresponding maintenance cost is low.

Furthermore, in Figure 4.9, we used boxplots to understand the distribution of total monetary value of ten ecosystem services among all research years. Cultural services, namely biodiversity and aesthetic landscape value have similar and relatively constant economic value while the economic value of provisioning services and regulating services show big differences. According to the plot, water yield occupies the biggest portion of total monetary value, with an average value of 40 billion RMB for each research year. Fruit production contributes the highest use value to local farmers. Fruit production is distinguished as a major agricultural enterprise, with good market prices. Grain production, timber production and carbon sequestration have relatively small values compared to other services, while according to Chen et al. (2021), these services were not influenced by the GGP significantly.

The Grain for Green project is considered as an essential land restoration program to improve the eco-environmental quality of China since the 20th century (Bryan et al. 2018). Trade-offs and synergies between the provisioning of different ecosystem services induced by the GGP were revealed by many previous studies in the Chinese Loess Plateau.

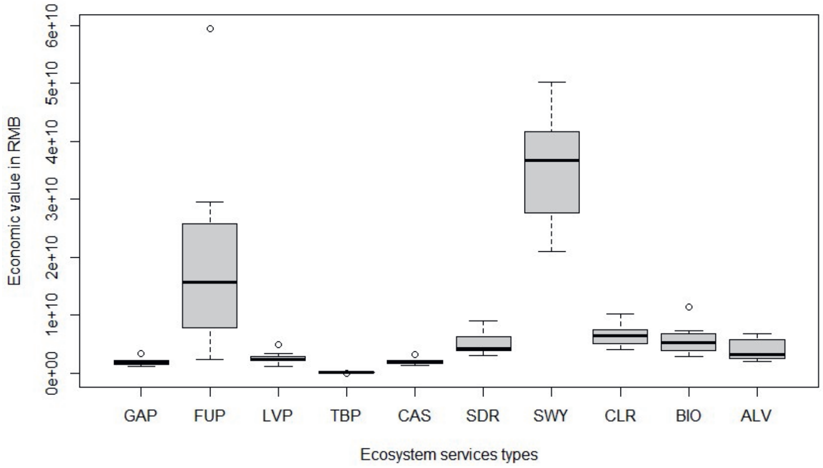

Figure 4.9 Boxplot of monetized ecosystem services across all research years (2000-2020).

It was commonly found that the majority of the ecosystem services were improved while there were trade-offs between provisioning services and regulating services (Li et al. 2019). However, has the GGP improved the economic value of ecosystem services simultaneously? In this study, we compare the monetary value of the year 2020 and 2020 NoGGP scenario to assess the impacts of GGP implementation on individual ecosystem services (Fig. 4.10). Trade-offs in the monetary value of ecosystem services are found between provisioning, regulating and cultural services. Reductions of monetary value occur in the case of grain production, livestock production and (slightly) in timber production, while the rest of the monetary values of ecosystem services increase, especially for fruit production, sediment retention and water yield.

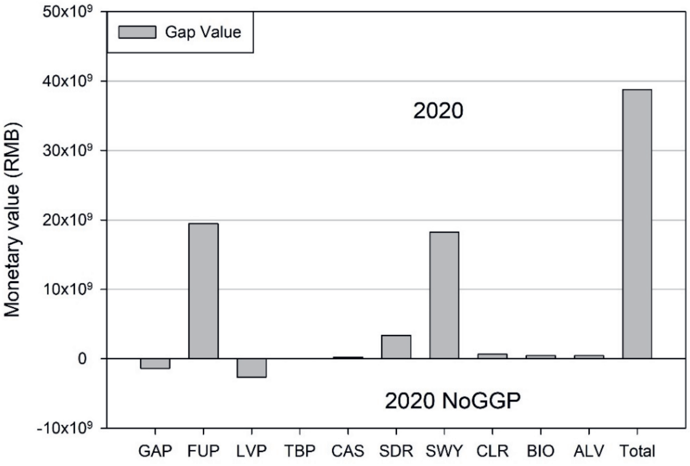

Figure 4.10 Comparison of monetary value between year 2020 and 2020 NoGGP.

4.4.2 A future GGP 2030 scenario

We built a future scenario for 2030 to estimate the land cover of Yan'an assuming the GGP continues for another 10 years with a similar land cover change rate as observed between 2000 and 2020. In Figure 4.11, the future land cover generated by the CLUE-S model for 2030 is displayed. Details of specific land cover values can be found in Appendix 4.3. When extrapolating the average cropland reduction rate by the GGP from 2000 to 2020, in 2030 the total restored cropland is estimated to be 3818 km^2 with 11.8 billion RMB investments. In general, the estimated expansion of GGP until 2030 brings an additional 1461 km^2 of restored forest and grassland compared to 2020, accompanied with urbanization in the main city area.

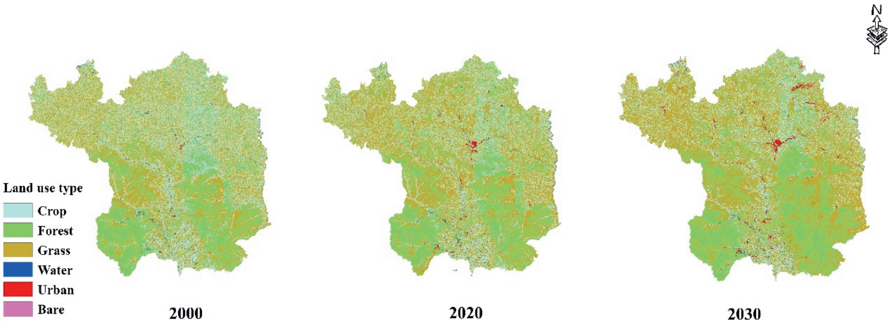

Figure 4.11 Land cover of a future continuation of GGP scenario to 2030.

In 2030, the monetary value of ecosystem services is estimated to be 56.78 billion RMB, i.e. a 13.60 billion increase compared to 2020 (Figure 4.12). However, the associated cost of restoration increases to 1.13 billion RMB per year, reaching the highest investment amount in the history of the GGP. The increase of the investment is mainly due to the expansion of restored forest area according to the model. Consequently, the increase rate of the NPV declines from an average of 2.11 billion RMB/year in the period 2000–2020 to 1.36 billion RMB/year in 2020–2030. In Figure 4.13, the B/C ratio at different discount rates is presented. The B/C ratio reaches its highest point in year 2025 at all discount rates, and then drops to similar values as for 2020 in year 2030. As the TMV calculation is based on a projected current year's price of CPI which is increasing every year, the increased investment and lower BC ratio illustrates that the continuous expansion of the GGP with the same strategy may not bring a constant economic value return.

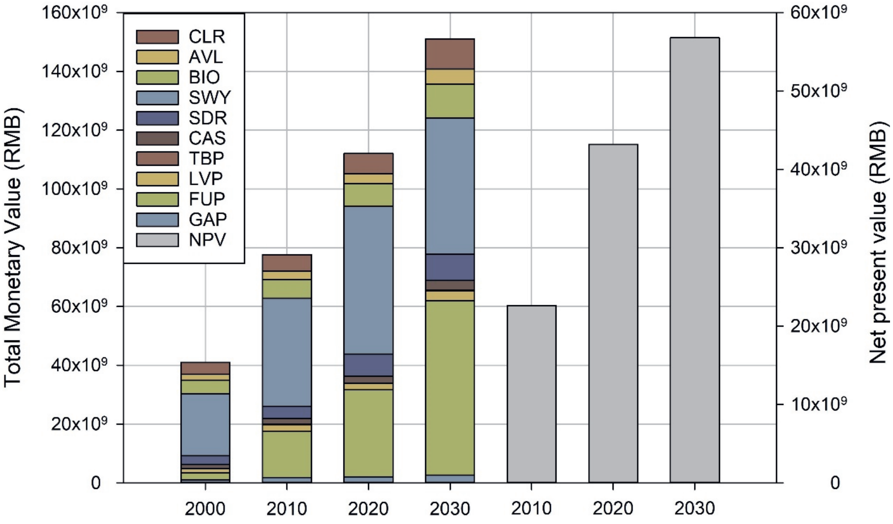

Figure 4.12 Annual TMV and overall project NPV value of the GGP at different years, including future continuation of GGP scenario to 2030.

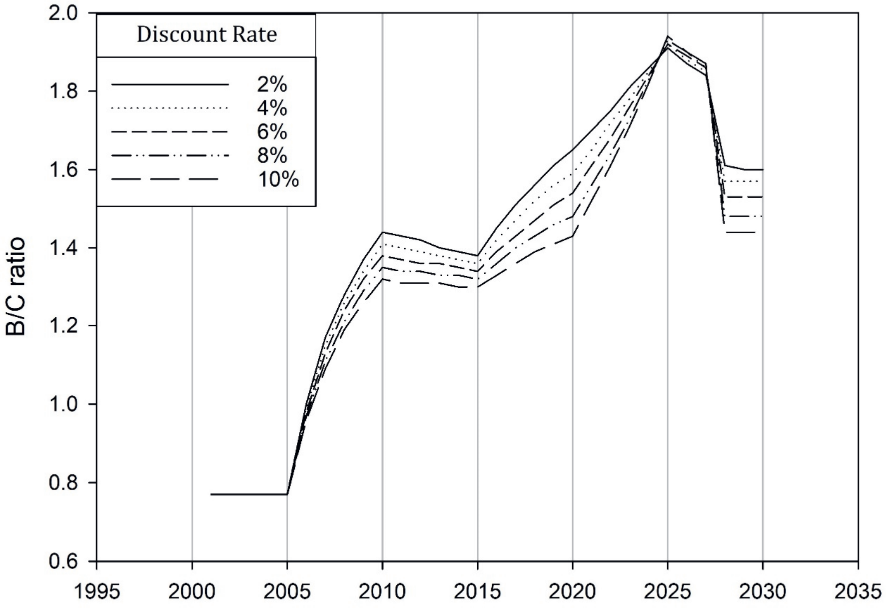

Figure 4.13 Evolution of the B/C ratio of the GGP (including future continuation to 2030), at different discount rates.

4.4.3 Implications from previous studies

Two land use scenarios were built and ten ecosystem services were quantified and their total monetary value was estimated, followed by a cost-benefit analysis to calculate the net present value of the GGP from 2000 to 2020. There have been several previous studies that simulated land cover change due to the Grain for Green project in the Loess Plateau; Zeng et al. (2020) simulated hundreds of land use scenarios based on Bayesian belief networks considering farmland reduction, slope and population distribution to estimate ecosystem services changes in the Chinese Loess Plateau. Peng et al. (2019) used the CLUE-S model to simulate different levels of forest restoration by the Grain for Green project and its impacts on ecosystem services in Yun'nan province, China. In our study, we applied the CLUE-S model considering seven influential factors including elevation, slope, distance to road, river, railway, city and nature area; the model was validated against the land cover map of 2000 and considered credible. The difference between the land cover map 2020 and 2020 NoGGP scenario illustrates that implementation of the GGP had significantly increased the vegetation cover while cropland was reduced. As the results determined, changes in the land cover of the Chinese Loess Plateau induced by the Grain for Green project led to an increase of monetary value of ecosystem services. A similar result was found by Li et al. (2016), who plotted the economic value of ecosystem services of China from 1990 to 2010, and identified the Loess Plateau as having increased economic value since 2000 while the ecosystem service value in coastal areas gradually deteriorated.

While the CLUE-S model provides the possibility to create dynamic and regionally defined land use scenarios, this model requires a set of variables to define the elasticity of land use conversions. This model is very sensitive to the change of parameters, therefore it is essential to carefully define the setting of the parameters. In this study, the model validation showed trustworthy results, however, there are still social, economic and environmental factors that should be considered. For instance, the emigration of local population due to urbanization and variation of ecosystem services due to climate change can be included in the CLUE-S model and ecosystem services quantification models. Model results should not be the only reference for decision making; although the GGP is estimated to be beneficial in 2030, the willingness of stakeholders to continue to participate and maintain the restored forest and grassland need to be investigated.

4.5 Conclusion

This study simulates the land cover of Yan'an area in 2020 with the CLUE-S model to establish a counterfactual scenario for the case without restoration intervention in order to conduct a cost benefit analysis of the Grain for Green project. The change of monetary value of ecosystem services and net present value due to the GGP was studied for different research periods. In general, the total monetary value of the ecosystem services increases constantly from 2000 to 2020, i.e. the monetary value with GGP implementation is higher than that of the 2020 NoGGP scenario. The result of cost-benefit analysis based on the GGP and NoGGP scenario indicates that the implementation of the GGP created a cumulative net present value of 19.41 billion RMB. Trade-offs of monetary value are found in provisioning and regulating services between the 2020 and 2020 NoGGP scenario. The monetary value distribution maps indicate that forest contributes a higher monetary value of ecosystem services and show a concentration in the south of Yan'an area. The future case of 2030 illustrates that the continuation of the GGP in the future may bring lower economic return.

Chapter 5

Stakeholders' perception towards land restoration and its impacts on ecosystem services[6]

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[6] This chapter is based on:
Chen, H., Fleskens, L., Wang, F., Moolenaar, S., & Ritsema, C. J. (2021).
Stakeholders' perceptions towards land restoration and its impacts on ecosystem services: a case study in the Chinese Loess Plateau. *Land Use Policy*, *submitted.*

Abstract:

To combat land degradation and deterioration issues the Grain for Green project (GGP) was implemented on the Chinese Loess Plateau in 1999 and substantially altered the land cover and reduced soil and water losses. This study aims to understand how local stakeholders perceive the current land restoration process and what their expectations are for future land restoration policy, as well as how stakeholders assess the GGP impacts on local ecosystem services changes. We investigated the perspectives of 150 stakeholders representing five stakeholder groups including farmers, governmental officers, citizens, tourism operators and forestry practitioners by questionnaires administered in 2021 in the Yan'an area of the Chinese Loess Plateau. The survey results indicate a 72% support rate of stakeholders for the current GGP, with government officers reporting the highest value and tourism operators the lowest. The support rate for future land restoration decreased to 51%. While the majority of the stakeholders considered that the GGP had stimulated regulation and cultural ecosystem services, they however perceived negative impacts on grain production, livestock production, water yield and water quantity. Factors influencing farmers' decision making on recultivating the restored forest are found to be mainly economic. We recommend policy makers to adjust the compensation standards and durations for farmers, increase the diversity of restoration tree species, and create stronger stakeholder involvement by using a participatory process for future land restoration policy making.

5.1 Introduction

Due to a strongly dissected landscape, high soil erodibility, intensive rainfall and human activities, the Chinese Loess Plateau experienced severe soil erosion and land degradation issues (Tsunekawa et al. 2014; Feng et al. 2010). To manage these issues, many land restoration programs at different scales have been implemented on the Chinese Loess Plateau starting from the 1970s (Bryan et al. 2018). In 1999, one of the world's largest-scale land restoration projects, the Grain for Green project (GGP), was initiated nationally in China to reverse the ecological degradation by stopping slope cultivation and restoring arable land to forest and grassland (Deng et al. 2019; Chen et al. 2015). As an incentive-based program, the GGP provided financial incentives to those who supplied ecosystem services, so-called payments for ecosystem services (PES) (Redford 2009). Subsidies were given to farmers by local GGP offices as compensations for the restoration. This GGP-exploited PES scheme has directly engaged millions of rural households as core agents for the project implementation (Lü et al. 2012a).

During the implementation process of landscape restoration, participatory approaches are being increasingly adopted by environmental authorities worldwide (Westberg et al. 2010). To effectively achieve sustainable land management, it is very important that stakeholders in the land restoration program are fully involved, including in the decision making, project framing and the implementation process phases (Reed, 2008). Moreover, the science-policy agreements such as Inter-governmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) had conducted ecological assessments with indigenous and local knowledge (ILK), emphasizing the importance of knowledge from key stakeholders and encouraging stakeholders involvement during the ecological policy making process (Peterson et al. 2018).

Stakeholders are individuals or groups of people that affect or are affected by the actions and results of an initiative (Mcwilliams, 2014). Benefits of involving stakeholders can be summarized as obtaining a better understanding of the situation through different points of view, integrating local knowledge and enabling the empowerment of the local population and avoiding top-down approaches (Stringer et al. 2006). Farmers are very essential stakeholders for carrying out ecological restorations, as they are directly engaged in the land restoration program, including by making changes in the management of their own land and through subsidies affecting their household income (Sherbinin et al. 2008). Ignoring local people's interests and excluding them from the planning, management and decision making process of the restoration has been found to be a main source of conflicts between people and the environment (Lewis 1996; Nepal 2002). The stakeholders' perception and willingness in achieving landscape restoration is essential for governmental policy making and landscape management (Cao et al. 2009).

To better achieve sustainable land restoration and eliminate the conflicts between stakeholders and restoration policy makers, many previous research studied the perception of farmers on the Grain for Green program. One of these investigations, conducted by Cao et al. (2009), discovered that 63.8% of the participating farmers supported the GGP at the time of interviewing (2007). Due to the introduction of the GGP, farmers' income sources, living styles, and environment awareness had been altered; meanwhile some farmers were alleviated from poverty (Shu and Ximing 2018; Dong et al. 2021; Feng et al. 2015). Farmers, however, are not the only stakeholders in the GGP. In previous studies, less attention has been drawn to the other stakeholders in the landscape restoration. The GGP itself is of huge societal importance for every citizen in the Loess Plateau, and their opinion and knowledge are essential for the local land restoration. Local residents have interacted with and experienced surrounding environments for centuries and have built ecological knowledge and practices facilitating land restoration in the process (Berkes et al. 2000).

Hence, it's essential to understand stakeholders' perceptions toward current landscape restoration, their personal interests on ecosystem services and what their opinions are of GGP impacts on local ecosystem services, as well as their expectations for future land management policy. Currently, a continued expansion of the restoration forest in the Chinese Loess Plateau is envisioned in the future. When a restoration activity is planned, the full range of points of view and knowledge of stakeholders needs to be considered to limit the risk of failure (Couix et al. 2015). Besides, at beginning of the GGP, Uchida et al. (2005) found that there remained uncertainties whether farmers will reconvert the restored land back to cultivation after the program ends. Cao et al. (2009) surveyed 2000 GGP participant farmers in Shaanxi province, China and 37.2% of them planned to recommence cultivation once the subsidy ended in 2018. It is therefore important to understand the current willingness of farmers to recultivate their restored forest. Therefore, the main objectives of this study are to: a) Understand stakeholders' perceptions towards current and future land restoration policy and their future preferences; b) Discover factors influencing farmers' decision making on recultivating the restored forest; c) Investigate stakeholders' perceptions of GGP impacts on local ecosystem services change.

5.2 Methodology

5.2.1 Framework

In this study, we applied the framework from Figure 5.1 to determine stakeholders' perceptions towards the current and future Grain for Green project in Yan'an area.

Activities comprised: 1) Stakeholder identification; 2) Questionnaire design; 3) Interviews; 4) Statistical analysis. Five stakeholder groups were identified, and two questionnaire formats were designed, one for farmers and the other for other stakeholders. In total, 157 interviews were conducted, and we applied Kruskal-Wallis tests and Binary logistic regression to determine the perception variances between different stakeholder groups.

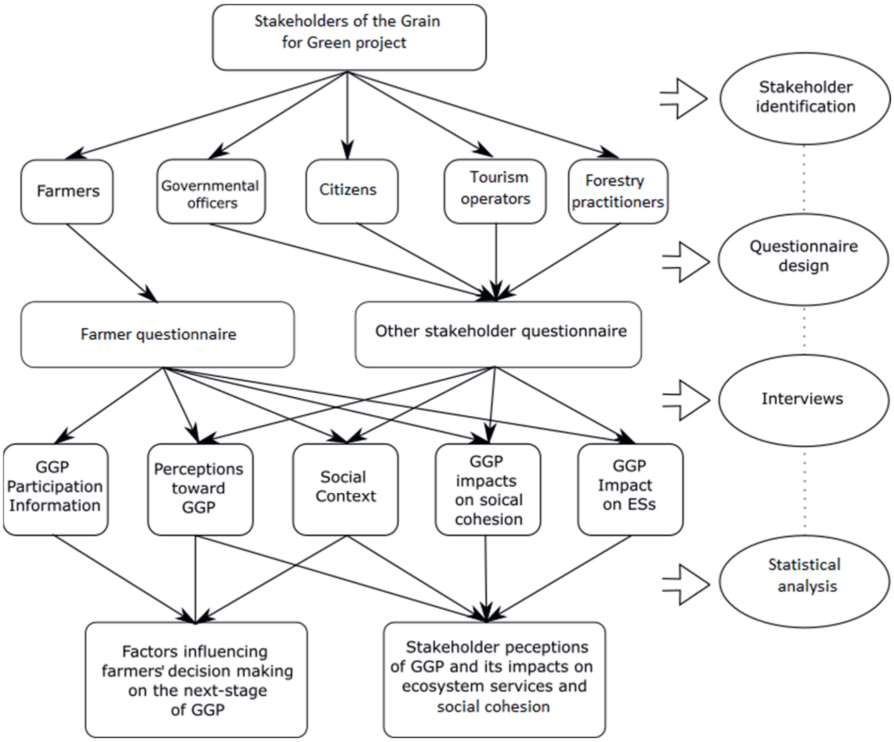


Figure 5.1 Framework of the social investigation.

5.2.2 Study area

The study area of Yan'an (Figure 5.2) is located in the northern Shaanxi province on the south-central part of the Chinese Loess Plateau between latitudes 35°21'-37°31' N and longitudes 107°41'-110°31' E. Yan'an is a prefectural-level municipality covering an area of 37,030 km^2. It is a typical hilly area in the Loess Plateau that consists of multiple deeply incised valleys. The main soil type is Calcareous Cinnamon Soil (Xu et al. 2020). Yan'an belongs to a semi-humid, warm temperate climate zone with continental monsoon circulation. The average annual temperature is 9.9 °C and annual precipitation is 510.7 mm. The population of Yan'an area is around 2.3 million, and the Gross Domestic Product (GDP) of Yan'an in 2018 was 156 billion RMB. In 1998, Yan'an area was selected as the first experimental site to start the national GGP land restoration project in its north-western Wuqi county. The Grain for Green project officially initiated in 1999 nationally and covered all 13 counties of Yan'an area. Yan'an has implemented vegetation restoration for nearly 20 years and increased the vegetation cover from 33% to 52% (Guo & Gong, 2016).

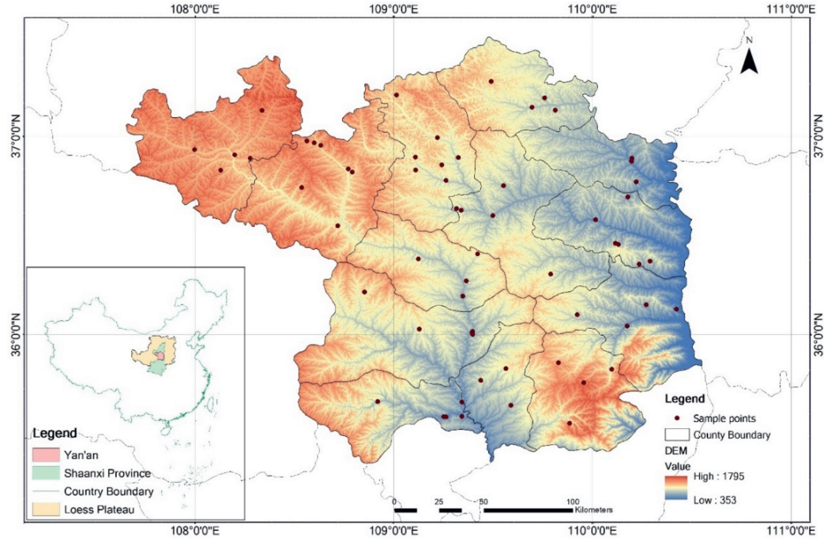


Figure 5.2 Questionnaire sites in the Yan'an area.

5.2.3 Data collection

(i) Identification of key stakeholder groups

A pre-investigation was conducted in March 2018 at Ansai county of Yan'an area, in order to identify the key stakeholder groups regarding the GGP implementation impacts. The primary data contained 52 interview surveys and meetings with different stakeholders from urban as well as rural areas. According to our primary data collection, we identified five stakeholder groups to be investigated based on their involvements in the GGP: farmers, government officers, citizens, tourism operators, and forestry practitioners. Farmers were directly involved in the GGP implementation, government officers were the policy makers and executors of the GGP policy, while citizens, tourism operators and forestry practitioners were passively influenced by the GGP due to ecosystem services and policy change.

(ii) Questionnaire design

As farmers directly participated in the GGP and were involved in more policy interventions compared to other stakeholders, for instance, subsidies, land rights, and restoration maintenance, the questionnaires were designed into two formats, one for farmers and one for other stakeholders. The farmers' questionnaire contained 48 items and was divided into five sections. The first section was designed to collect basic information about farmers' GGP participation, including the participation year, restoration area, and subsidy amount received. The second section was semi-structured and aimed to elicit farmers' perceptions toward the current and future GGP implementation. The third section listed 13 ecosystem services including four provisioning services, five regulating services and three cultural services. Ecosystem services were described in a comprehensible way for easier understanding, and subsequently farmers were asked to state their impression of impacts of the GGP on the listed services on a five-point scale: obvious increase, increase, not sure, decrease and obvious decrease. The fourth section aimed to understand impacts of the GGP on farmers' household income and social cohesion. The fifth section recorded the social context of farmers with regard to sex, education years, household size, family income and etc. The questionnaire for other stakeholders was simplified from the farmers' questionnaire, and consisted of part of the second, third, fourth and fifth sections of the farmers' questionnaire.

(iii) Stakeholder interviews

The data collection took place in March 2021. All stakeholders were randomly surveyed in each county of the Yan'an area. Farmers were investigated in the rural area randomly in randomly selected villages while other stakeholders were surveyed in the urban area. As the majority of the farmers were low educated, we collected the farmers' questionnaire through oral communication. Each farmer interview took around half to one hour. Thirteen GGP offices in each county of Yan'an area were visited; we interviewed the officers about local GGP implementation information with open questions regarding the existing problems and future plans. Citizens were randomly selected in the urban area; tourism operators were interviewed at tourist attractions and travel agencies in town, while forestry practitioners interviewed were mainly nursery owners and employees of local forest fire bureaus.

5.2.4 Statistical methods

We applied Kruskal-Wallis one-way analysis of variance (ANOVA) to compare the variances between stakeholder groups. In the ANOVA result, the null hypothesis is that the variances between populations are the same, while a significant ($p < 0.05$) Kruskal-Wallis test rejects the null hypothesis and indicates that at least one sample stochastically differs from other samples. When significant ANOVA results were determined, the Duncan's Post hoc test was utilized to determine which sample was distinct from others. In this study, the survey results of social context, perceptions towards the GGP and its impacts on the ecosystem services and social cohesion were analyzed by the Kruskal-Wallis test. Furthermore, we used binary logistic regression to determine the factors influencing farmers' willingness to recultivate their restored land. Additionally, the stakeholder perception of GGP impacts on local ecosystem services change were compared with ecosystem services quantity change by model results from Chen et al. (2021) by Pearson linear regression. The Kruskal-Wallis one-way ANOVA and binary logistic regression were conducted by SPSS 25.0 for Windows. Figures were drawn by

SigmaPlot 14.0 and Pearson linear regression was executed by using the package *tidyverse* from R 4.0.5.

5.2.5 Social context of the stakeholders

Collectively, we investigated stakeholders from 60 locations and collected 150 effective questionnaires out of 157 (effective rate 95.54%), including 103 farmer questionnaires, and 47 from other stakeholders: 15 from citizens, 13 from government officers, and 11 and 8 from tourism operators and forestry practitioners respectively (Table 5.1). Approximately 57% of the respondents were male. According to the Kruskal-Wallis ANOVA test, there was a significant difference between the age of farmers and other stakeholders. Other stakeholders were on average almost 13 years younger than farmers; other respondents' age was concentrated between 31-50 years whereas farmers' age was usually between 51-70 years. Furthermore, there was an obvious gap between the education level of farmers and other stakeholders: most other stakeholders had senior high school or college education while farmers tended to be illiterate or with primary school education. The average income of stakeholders was 3920 RMB (around 7.8 RMB equals 1 Euro), and it again differed significantly between farmers and other stakeholders. In summary, farmers were older, with lower education level and less income compared to other stakeholders.

Table 5.1 Social contexts of the survey participants.

Basic information	Total	Farmers	Other stakeholders	p-value
Participants	150	103	47	
Male	57%	55%	60%	
Female	43%	45%	40%	
Age (years)	54±11	58±10	45±8	0.001
below 30	2%	1%	4%	
31-50	36%	19%	72%	
51-70	57%	73%	23%	
above 70	5%	7%	0%	
Education level (years)	8±5	6±4	12±4	0.001
illiteracy	19%	27%	0%	
primary school	24%	30%	11%	
junior high school	26%	26%	26%	
senior high school	20%	17%	28%	
college	11%	0%	34%	
master	1%	0%	2%	
Family monthly income (RMB)	3920±4996	2728±3092	6531±7035	0.001
below 1,000 RMB	23%	32%	4%	
1,000-3,000 RMB	35%	41%	21%	
3,000-5,000 RMB	24%	17%	40%	
5,000-10,000 RMB	11%	7%	21%	
10,000-20,000 RMB	5%	4%	6%	
above 20,000 RMB	2%	0%	6%	

5.3 Results

5.3.1 Stakeholders' perception of the GGP

Results of stakeholders' perception towards current and future land restoration is displayed in Figure 5.3. According to the farmers' survey results, 65% of the farmers support the current GGP policy, around 15% farmers remained neutral and approximately 20% of farmers oppose the land restoration. Meanwhile the main reasons for farmers' attitudes towards the GGP were answered in open questions. For those supporting the GGP, 23% of the 103 farmers responded that the yield of previous slope farming was very low and 14% of farmers think the GGP reduced the farming labor work. Farmers who opposed GGP mainly did so due to income reasons; 20% of the total number of interviewed farmers pointed out that implementation of the GGP had decreased their household income due to reduced cash crop production while two farmers replied that grazing activities were forbidden. As for other stakeholders, a unanimous response was found among the government officers that all stakeholders support the GGP policy.

Meanwhile, a vast majority of citizens, tourism operators and forestry practitioners showed a supportive attitude towards previous land restoration – the oppose rate was approximately 10%. In the open question section, 55% of respondents claimed land restoration had improved the local ecological environment and reduced soil and water losses, and 15% of stakeholders replied that the air quality had been improved. However, 13% of respondents declared that the GGP had decreased local agricultural acreage, and one tourism practitioner opposed the land restoration due to lack of diversity in the restored plant species.

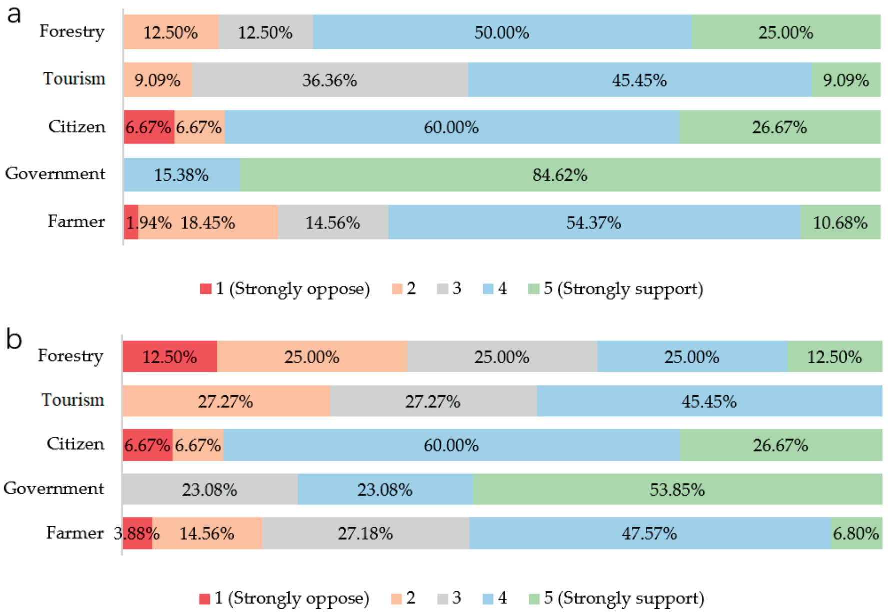


Figure 5.3 Stakeholders' perception towards current (a) and future (b) GGP implementation.

Compared to the stakeholders' perception towards the current GGP, in Figure 5.3 (b) we observe an obvious increase of dissenting opinions from stakeholders towards future land restoration. There were 54% of farmers showing positive attitudes towards future GGP plans, while 27% remained uncertain, and the remaining 18% took a negative stance. As for the reasons, 19% of the farmers claimed that they supported a future GGP but remarked that there was no sloping farmland left for restoration, and 9% of respondents reflected they were too old and not fit for future restoration work. As for government officers, three officers reflected there was still severe soil and water loss existing in their administration area and argued that it is essential to continue restoration for soil retention. Perceptions of citizens towards the current and future GGP remained similar while a more opposite attitude was determined in the tourism group compared to Figure

3 (a). Increased forest fire risk was the main reason raised by forestry practitioners to oppose future land restoration.

Social impacts of land restoration were also determined from the surveys. In Table 5.2, results of stakeholder perception on the six statements are displayed. In general, all stakeholder groups consider that the GGP implementation had positive impacts on improving awareness of environmental protection: government officers strongly agree on these statements while farmer and forestry practitioners had comparably significantly lower values. Stakeholders stayed neutral about relations between the GGP and local job opportunities. Stakeholders recognized that the implementation of the GGP is of high implementation efficiency and the highest value was given by government officers. A majority of stakeholder groups disagree on the statement that the GGP improved their income while only government officers displayed a positive attitude. Meanwhile farmers, government officers and citizens denied the GGP implementation had induced land abandonment, which corresponds to our survey investigation in rural areas where abandonment of arable land was not commonly observed. It was believed by farmers, government officers and citizens that the introduction of land restoration caused a population out-migration issue; the reduced farmland in the rural area might be the cause of outmigration due to lack of income source.

Table 5.2 Stakeholders' perception on the social impacts of the GGP. Note: values ranging from 1 to 5 indicated opinions from "strongly disagree" to "strongly agree". All values are mean ± SD; same letters behind values indicate a significant variance between each other.

Statements	Total	Farmer	Government	Citizen	Tourism practitioner	Forestry practitioner	p-value
GGP improved my environmental protection awareness	3.85±0.7	3.78±0.69 a	4.54±0.52 ab	3.87±0.64	3.91±0.7	3.63±0.74 b	**< 0.01**
GGP stimulated local job opportunities	2.89±0.75	2.84±0.65	3.31±0.85	2.93±1.22	3.09±0.7	2.5±0.53	0.12
GGP Implementation efficiency is high	3.65±0.89	3.61±0.94	4.31±0.63 a	3.4±0.74 a	3.73±0.65	3.38±0.74	**0.05**
GGP improved my income	2.69±1.1	2.7±1.09	3.54±1.05 ab	2.4±1.12 a	2.27±0.79 b	2.25±1.04	**0.02**
GGP induced cultivation land abandonment	2.75±0.84	2.73±0.88	2.15±0.8 ab	2.8±0.56	3.09±0.3 a	3.38±0.92 b	**0.01**
GGP simulated local population out-migration	3.63±0.95	3.75±0.94	3.08±1.12	3.4±0.91	3.64±0.81	3.38±0.92	0.11

5.3.2 Factors influencing farmers' willingness to recultivate the restored forest

Results on factors influencing farmers' decisions on whether to re-cultivate their restored forest are presented in Table 5.3 and 5.4, based on Kruskal-Wallis one-way ANOVA and Binary logistic regression respectively. From Table 5.3, basic information on farmers' participation in the GGP is displayed. On average, 59% of farmer's family cultivation land was restored, farmers received 1495 RMB/mu (equal to 99,667 RMB/ha) subsidy in total and they considered the subsidy standard to be low (average scale = 2.53). While farmers estimated that the GGP implementation had caused a reduction of income by -2861 RMB annually, cultivation is still the main income source of 63% of the surveyed farmers. Overall, 82% (84 of 103) of the interviewed farmers replied they will not recultivate the restored forest, whereas only 18% (19 of 103) respondents still intend to cultivate. We received a response from 24 respondents explaining the reasons for not being interested in recultivating: 14 farmers explained that recultivation is no longer possible as the restored trees had grown up stoutly with big root systems, while five farmers considered themselves too old for additional cultivation work.

Table 5.3 Farmers' participation in the GGP, their willingness to re-cultivate their GGP forest and influencing factors. Note: values ranging from 1-5 indicate participants' opinion ranging from strongly disagree to strongly agree.

Categories	Description	Total	NO	YES	p-value
Farmer willingness	Farmers' willingness to re-cultivate their GGP forest in the future	103	84	19	
Restoration rate	Restored farmland / total land owned	59.35±27.96%	60.87±27.04%	52.66±31.64%	0.250
Support GGP	Degree of support for the current GGP policy (from 1 to 5)	3.53±0.98	3.65±0.88	3±1.2	**< 0.01**
GGP force	Farmers consider themselves forced to join GGP (1 = No, 2 = Yes)	1.30±0.46	1.33±0.47	1.16±0.38	0.135
Tree Species	Satisfaction to restored tree species (from 1 to 5)	2.83±0.94	3.37±1.1	2.70±0.86	**< 0.01**
Support future GGP	Degree of supporting for future GGP policy (from 1 to 5)	2.17±0.6	2.2±0.6	2±0.58	0.182
Average subsidy	Total subsidy received / total farmland restored (RMB/mu)	1494.97±574.75	1561.21±547.46	1202.11±615.54	**< 0.01**
Subsidy standard	The GGP subsidy is high (from 1-5)	2.53±0.81	2.63±0.8	2.11±0.74	**< 0.01**
Maintenance work	The maintenance work is hard (from 1-5)	3.3±0.85	3.33±0.81	3.16±1.01	0.419
Spare time	GGP implementation has increased my spare time (from 1 to 5)	3.79±0.98	3.77±0.97	3.84±1.01	0.785
Social cohesion	GGP implementation has strengthened social cohesion (1-5)	2.83±0.98	2.86±1	2.68±0.95	0.492
Education level	Participants' education years	6.15±4.27	6.29±4.38	5.53±3.78	0.487
Labor ratio	Adult man number / total family number	45.94±15.18%	45.62±14.27%	47.37±19.08%	0.653
Income change	Amount by which family annual income changed by the GGP(RMB)	-2860.58±10938.78	-1875±5519.3	-7217.89±22649.84	**0.049**
Income source	Main income source (cultivation = 1, other = 0)	63.11±48.49%	65.48±47.83%	52.63±51.3%	0.299
Family income	Monthly family income (RMB)	2728.16±3092.35	2779.76±3086.46	2500±3192.87	0.724
Age	Participants' age	57.58±9.85	57.95±10.2	55.95±8.12	0.425
Sex	Ratio of male	55.34%	55.76%	57.89%	0.806

Significant differences were found in the support for the GGP, tree species, average subsidy, subsidy standard and income change between farmers who answered yes and no to recultivating the restored forest. Comparably, farmers who are willing to recultivate restored forest have a lower degree of support for the GGP; however, the main differences between farmers' willingness to recultivate the restored forest were found in the income aspects. Tree species is also an important factor affecting farmers' decision making on recultivation: the less satisfaction a farmer had from the planted trees, the more they would like to recultivate their restored forest. There were 40 interviewed farmers who gave opinions on their preferred restoration tree species; 68 % of the respondents preferred economic forest, for instance apple trees and pepper, while the rest pointed out pine trees and cypresses. Farmers who preferred to recultivate received on average 359 RMB/mu (23,933 RMB/ha) less subsidy compared to farmers who said "No" to recultivation;

meanwhile they consider the GGP subsidy to be low (average scale = 2.11). Additionally, the "Yes" group estimated that the implementation of the GGP had caused an average reduction of their annual household income by -7218 RMB/year while the reduced income for the "No" group was estimated to be -1875 RMB/year. From Table 5.3, it is observed that the negative impact of the GGP on farmer's income was the main reason influencing farmer's decision making to recultivate the restored forest. Results of the binary logistic regression are presented in Table 5.4. Restoration ratio, support for the GGP, tree species, income source and family income are the factors influencing farmers' decision making on whether to recultivate their restored forest.

Table 5.4 Binary logistic regression results of farmers' willingness to re-cultivate their GGP forest.

Statements	B	S.E.	odds ratio	p-value
Restoration rate	0.03	0.02	1.03	**0.05**
Support GGP	0.81	0.40	2.25	**0.04**
GGP force	0.62	0.70	0.78	0.38
Support future GGP	0.47	0.60	1.59	0.43
Tree species	-0.70	2.93	5.65	**0.01**
Average subsidy (RMB/mu)	0.00	0.00	1.00	0.20
Subsidy standard	0.71	0.45	2.04	0.11
Re-plant work	0.49	0.38	1.64	0.19
Spare time	0.12	0.35	1.13	0.73
Social cohesion	-0.32	0.43	0.73	0.46
Education level (years)	-0.05	0.10	0.95	0.62
Labor ratio	0.00	0.02	1.00	0.94
Income change (RMB)	0.00	0.00	1.00	**0.04**
Income source	1.59	0.82	4.91	**0.05**
Monthly family income (RMB)	0.00	0.00	1.00	**0.05**
Age	0.00	0.04	1.00	0.92
Sex	-1.07	0.69	0.34	0.12

5.3.3 Stakeholders' preferences for the future GGP

In this section, we describe the open questions results regarding stakeholders' preferences on the future restoration policy (Figure 5.5). To sum up, the suggestions received by farmers were in decreasing order of frequency: increase the subsidy standard (31%), extend the subsidy period length (27%), no suggestions (21%), free restoration plant selection (15%), technical support on tree planting and others (6%). Apparently, duration and amount of subsidy were of greatest concern to farmers in relation to their preferences for the GGP, while free tree species selection and technical support occupied a small portion of farmers' demands. Other stakeholders put more focus on the tree species diversity, while still a big portion (32%) of responses argued that the farmers' subsidy should be increased. 17% of the other stakeholders agreed on extending the forest restoration subsidies while 13% thought the restored forest area should be reduced. Comparably, regarding to future restoration policy, farmers were most concerned about their income from subsidies, while other stakeholders paid attention to the biodiversity value of future restoration forest.

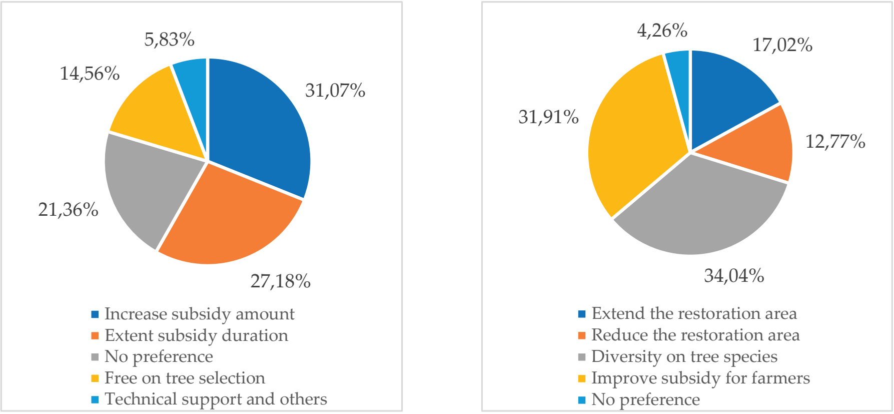


Figure 5.5 Share of farmers' (left) and other stakeholders' (right) preferences on future GGP.

5.3.4 Stakeholders' perception of the GGP impacts on ecosystem services

In this section, GGP impacts on ecosystem services were determined by different stakeholder groups; results are presented in Figure 5.4. In provisioning services, a decrease of grain production was recognized by all stakeholder groups, while an increase of fruit production was found by all stakeholders except farmers. Farmers perceived an obvious decrease of livestock production while tourism operators pointed out an opposite opinion. According to the farmers, grazing is forbidden by the government as goat grazing will destroy the root system of the restored nursery. Additionally, the regular fodder source for household livestock was crops grown on sloping farmland. Due to land restoration, the reduction of cropland had led to lack of fodder for livestock. Therefore, the majority of the farmers chose to sell their household livestock after restoration. Stakeholders declared uncertain attitudes regarding the land restoration impacts on timber production. For regulating services, the improved climate regulation, soil and water conservation and reduced hazard events were recognized by all stakeholders. The biggest divergence was found in water quality and quantity between different stakeholder groups. Government officers believed the water quantity and quality was increased by land restoration while farmers and forestry practitioners believed the water quantity and quality were both getting worse. As for cultural services, the majority of the stakeholders interviewed consider that land restoration had positive impacts on improving the biodiversity and landscape value. Farmers claimed more wild animals were witnessed in the mountain area, including wild birds and chickens, and even wild boars started to appear in the mountain forest after restoration. Tourism operators found a slight positive effects of the GGP on local tourism; however, government officers were obviously more certain about the positive impact.

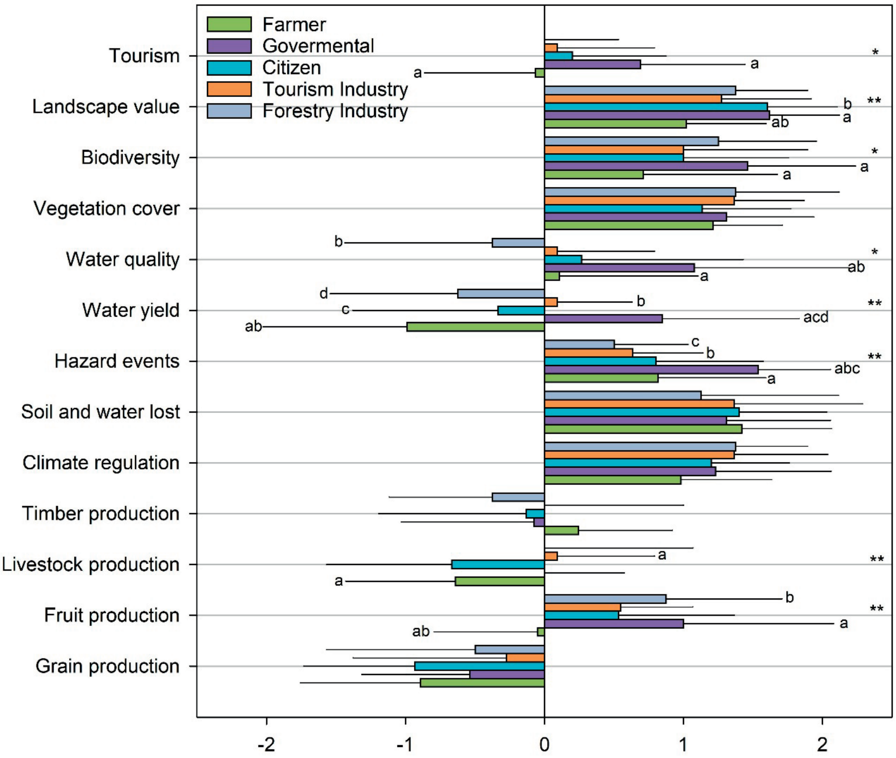


Figure 5.4 Stakeholder perceptions of the GGP impacts on local ecosystem services. Note: in the x-axis, -2 = strongly decrease; -1 = decrease; 0 = not sure; 1 = increase, 2 = strongly increase. Values are mean ± SE. * indicates the significance of Kruskal-Wallis Oneway ANOVA test between different stakeholder groups, * = $p < 0.05$, ** = $p < 0.01$, same alphabet behind value determines a significant difference between group.

5.4 Discussion

In our study, according to the results from the stakeholder questionnaire, we observed that the support rate of stakeholders for the current land restoration policy is 72% (108 support and strongly support the GGD out of 150). For future land restoration policy, government officers report the highest support value while among tourism operators the support rate decreases to 51%. Stakeholders perceive that the implementation of the GGP has increased their environmental protection awareness, that the GGP stimulated local population out-migration and the implementation efficiency of land restoration is high. The majority of the stakeholders consider that the GGP has stimulated the ecosystem services in terms of regulation and cultural services, however, negative impacts are determined on grain production, livestock production, water yield and water quantity. Factors influencing farmers' decision making on recultivating the restored forest are found to be restoration rate, support to GGP, tree species selection, income impact by GGP, income source and monthly income.

5.4.1 Comparison between model results and stakeholder perceptions

In this section, we compare two results of GGP impacts on ecosystem services, one is biophysical changes from ecosystem services models and statistical year books (Chen et al. 2021) and the other is cognitive from stakeholders' interviews. The objective is to understand whether stakeholders' cognitive explanations differ from physical transformation of ecosystem services. We compared correlations between ecosystem services change rates from 2000 to 2020 by biophysical models and average stakeholder perception scales (from 1 to 5) of ecosystem services changes, since the start of the GGP implementation across thirteen counties in the Yan'an area (Figure 5.6a,b). In the Pearson linear regression, every point indicates an average change value of ecosystem services in each county from 2000 to 2020 corresponding to average stakeholder perception of ecosystem service change in their county. In the figure, a positive correlation determines the ecosystem services change from model results is matched with stakeholder perception and vice versa.

According to the figure, significant correlations ($p < 0.05$) are discovered in timber production, livestock production, fruit production, water yield, and sediment retention. For provisioning services: changes in values of grain production, livestock production and timber production obtained from model results are consistent with stakeholder perception as positive correlations are determined. A reduction of grain production is perceived by most of the stakeholders, but actually in some counties the grain production still increased during land restoration according to the statistical yearbooks (Chen et al. 2021). Change in timber production varied between counties, while the stakeholder perceptions are similar to the model results. Livestock production reduction is found in the majority of the counties and stakeholders reflected this in similar scales. Fruit production was found to be dramatically increased after restoration according to models, while in the stakeholders' perception this increase is low.

The majority of regulating and cultural services results are found to be consistent between model results and stakeholder perceptions; the only unmatched case is habitat quality. Water yield is found to be decreased from ecosystem service models from -11% to -52%, and stakeholders determined the water reduction simultaneously on an average scale of -0.12 to -1.36 in different counties. Although the correlations of outdoor recreation and habitat quality are not significant, stakeholders still perceived that land restoration had positive impacts on the landscape and the model results support this point of view. Sediment retention is determined to be enhanced from the model results and stakeholders observed an obvious decrease of soil and water losses on a scale ranging from 0.92 to 1.71. In general, stakeholders are more sensitive to the change to provisioning and regulating services rather than cultural services, as more significant correlations are found. The implementation of the GGP policy has directly reduced the household grain and livestock production as crop area is reduced and grazing is forbidden. Farmers occupied a big portion of stakeholders, and their perception has reflected the GGP impacts on provisioning services precisely. Besides, the consistency between stakeholder perception and model results confirms that the introduction of land restoration has altered the ecological functions from biophysical aspects and that these impacts are acknowledged by local stakeholders.

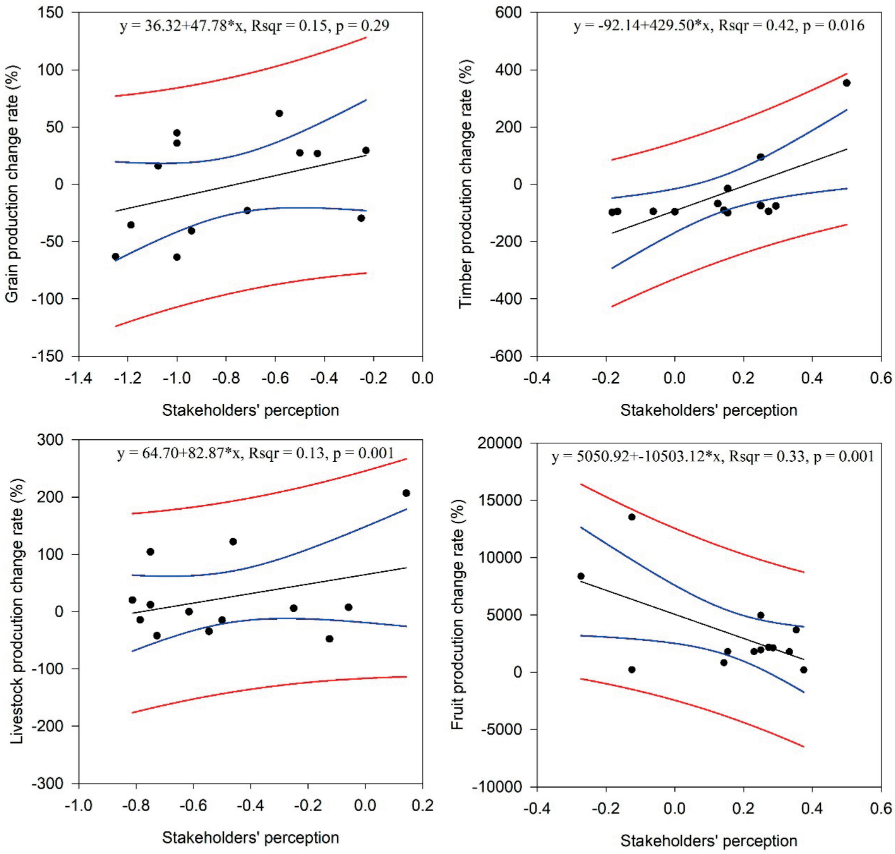


Figure 5.6a Correlations between results of ecosystem service models and stakeholder interviews for provisioning services. Note: x-axis represents average values of stakeholder perception in each county of Yan'an area, y-axis indicates the modelled change of ecosystem services values; blue lines represent the 95% confidence band, red lines the 95% prediction band.

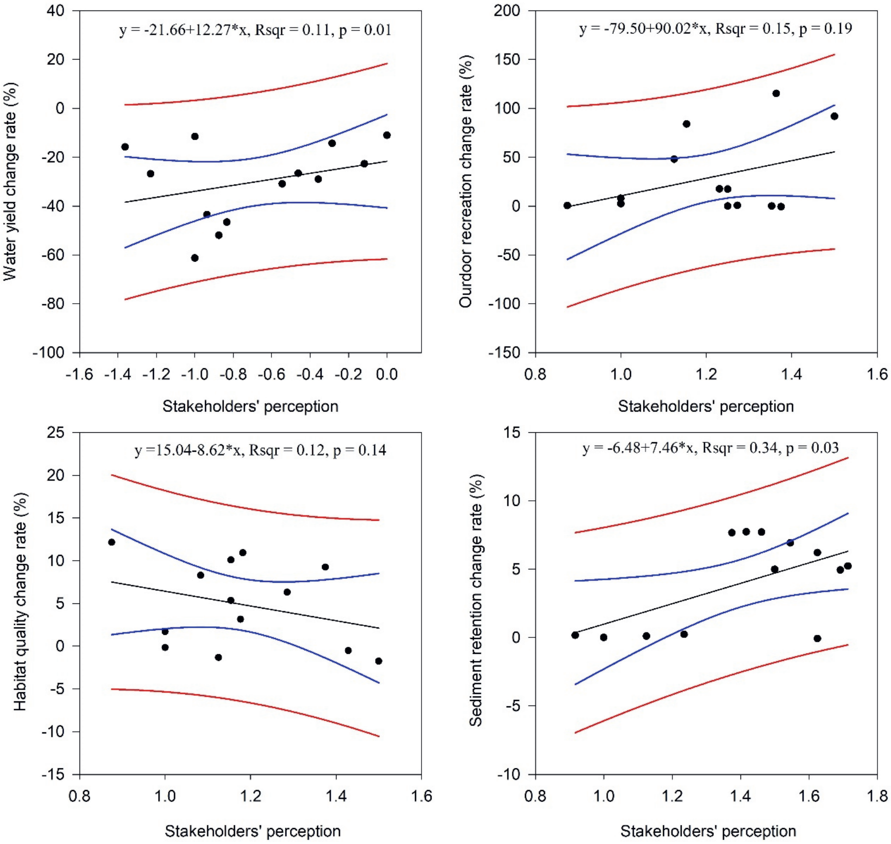


Figure 5.6b Correlations between results of ecosystem service models and stakeholder interviews for selected regulating and cultural services. Note: x-axis represents average values of stakeholder perception in each county of Yan'an area, y-axis indicates the modelled change of ecosystem services values; blue lines represent the 95% confidence band, red lines the 95% prediction band.

5.4.2 Insights from previous studies

Cao et al. (2009) revealed that farmers' support rate of the GGP was 63.8% at Shaanxi Province in 2005, while 37.2% of the farmers planned to recultivate the restored forest when subsidies would end. After 15 years, our results show that although the majority of the subsidies for households already ended, farmers' support rate still remained similar at 66.02%. However, farmers' willingness to recultivate the restored forest had dropped almost by half to 18.45% in 2021. The most direct reason of this drop in willingness reported by farmers is that the restored forest became dense as it had grown for 20 years, and reclaiming land converted to forest has become irrational due to the massive cost. Besides, the average age of the interviewed farmers is almost 58 years and some farmers claimed they are too old for additional agricultural work. A study conducted in the

Three Gorges Reservoir Area near Yangtze river found that 74.4% of the farmers hoped to be liberated from low-income farmland work through a next GGP phase in 2012 (Feng et al. 2015). Meanwhile, it is found that farmers were increasingly shifting their labor endowment from on-farm work to off-farm work (Uchida et al. 2009). Currently, as for 36.89% of the interviewed farmers the main family income source is not cultivation, the diversity of the income sources may encourage farmers to seek for alternative job opportunities rather than stick to cultivation. Furthermore, before land restoration, the major cash crops of slope farming were proso millet, maize and wheat, which were of low economic value in the market. As slopes were under dryland farming and due to a lack of fertilizer and pesticide use, the yield of slope farming is lower than that of flat land farming. Thus, it is believed that the possibility of farmers to recultivate the restored forest is very low as it is economically unattractive.

Regarding environmental perceptions, Liu et al. (2010) compared the environmental attitudes among stakeholder groups and government staff gave the highest scores. Similar results have been found in our study: government officers perceived the most positive impacts of the GGP among all stakeholder groups. In our study, government officers in Yan'an area tended to be overly optimistic in comparison to other stakeholder groups and even ignored common facts. For instance, a significant reduction of water yield had been determined in the Chinese Loess plateau in the past few decades (Chen et al. 2020). Besides, perceptions of local farmers and forestry practitioners responded with similar impressions in the Yan'an area while only government officers considered that the water yield had increased. Farmers claimed there used to be floods and landslides in the previous decades; however, after land restoration the water level decreased obviously while floods disappeared consequently.

5.4.3 Existing issues and recommendations

According to the stakeholder survey results and investigation throughout the Yan'an area, we discovered two main issues of current land restoration policy: a) Insufficient and unsustainable compensation policy for the restored forest; b) fragile ecosystem due to a lack of biodiversity. In 2004, an investigation in the southwest of China claimed that impacts of the GGP on the local food security and farmers' household income were critical issues (Xu et al. 2007). During our investigation after seventeen years in 2021, we discovered a similar issue. After the GGP implementation, farmers' main income source altered from cash crops from slope farming to subsidy from the local GGP office. However, the majority of the farmers participated in the GGP in the early 2000s and the subsidy lasted for sixteen years in total. Farmers reflected that the GGP subsidy had ended, and they now only receive a maintenance fee of around 30 RMB/Chinese mu*year^{-1} (equal to 256 €/ha/year) from the GGP office. Besides, as the majority of the restored forests are ecological forests, farmers can barely obtain economic benefit from the sloping land anymore. Therefore, currently farmers harvest limited returns from their own restored land, either from subsidy or from agroforestry products.

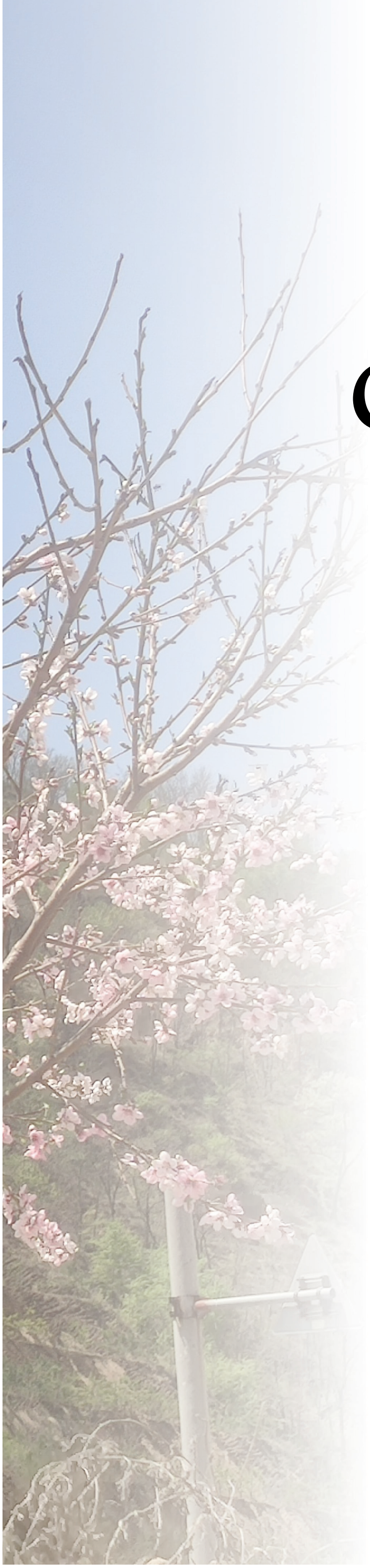
Based on farmers' investigation across 13 counties in the Yan'an area, the restored forest species are mainly robinia (*R. pseudoacacia*), apricot (*Prunus sect. Armeniaca*), hippophae (*Hippophae*) and caragana (*Caragana arborescens*), and usually for a certain area the restored plants are limited to one or two species (46% of the farmers reported the restored plant was only robinia). During our investigation journey, we observed that the landscape of the restored forest was simple, for example in Figure 5.7, the most common species found in the mountain area is robinia. Although all stakeholder groups agree that the GGP had positive impacts on biodiversity (Figure 5.4), improving the diversity of the restored tree species still occupied a big portion of future preferences (Figure 5.5). Wang et al. (2021) claimed that the implementation of the GGP increased the forest cover rather than that it improved habitat availability. According to the farmers, there are increasing observations of wild animals after the restoration; however, the animal species are limited to wild mountain chicken and infrequent wild pigs. Due to farmers' rare visits to the restored forest after restoration, the reduction of human activities might be a reason for the improved wild animal populations. However, lack of biodiversity is commonly perceived by stakeholders and leads to the restored forest being ecologically fragile. From the open questions, local government officers reported that the current issue they are facing are pests and plant diseases. Meanwhile we observed widespread oil wells in the mountain area in northeast Yan'an area, which is damaging the local ecosystem (Figure 5.7, right). Farmers reported that the petroleum industry is a major cause of drinking water pollution.

Figure 5.7 Pictures of restored sloping farmland (left) and oil drills in the mountain area (right).

Based on the meetings with GGP officers from different counties, we understand that the GGP is a top-down policy delivered from central government to province level, and to city, county, town and finally the village level, where village leaders convey the GGP policy to each household. Thus, farmers are passively involved in the land restoration and their voice can hardly be heard. According to the responses from stakeholders, many issues had raised by land restoration policy, such as subsidy standards for the post-restoration stage and lack of biodiversity of the restored forest. It is recommended for policy makers to enable the involvement of local people and understanding the current situation through mobilizing local knowledge held by stakeholders. For instance, local GGP offices are encouraged to organize workshops to understand farmers' requirements in the late stage of restoration, for example to adjust the compensation standard or duration. In the next round of GGP, increasing the diversity of restoration tree species will be essential to help recovering a more stable and sustainable ecosystem. Additionally, science-policy agreements such as IPBES and CBD acknowledge the importance of indigenous and local knowledge in building a diversity of knowledge systems to support the international biodiversity assessment and policy making process (Tengö et al. 2017). Thus, introducing a more participatory policy and increasing the involvement of stakeholders is encouraged for future land restoration policy making processes.

5.5 Conclusions

To conclude, according to the results from the stakeholder survey, we observed that a majority of the stakeholders support the current land restoration whereas almost half of the stakeholders' support expansion of land restoration in the future. Stakeholders perceived that the implementation of the GGP had enhanced their environmental protection awareness and stimulated out-migration of population. With regard to preferences in the future, subsidy duration and amount are the topics of most concern for farmers, while other stakeholders would like to see that more attention is paid to the biodiversity value of future restoration forest. The share of restoration area of the total area of households, degree of support for the GGP, satisfaction with restoration tree species, level of influence of the GGP on farmers' income and household income source are identified as the main factors influencing farmers' decision making on whether to recultivate the restored forest land. A majority of the stakeholders consider that the GGP has stimulated regulating and cultural ecosystem services; however, negative impacts had been observed on grain production, livestock production, water yield and water quantity. We recommend policy makers to adjust the compensation standards and durations for farmers, and increase the diversity of restoration tree species to strengthen the stabilization of the restored ecosystem. Additionally, the development of a participatory process to involve stakeholders is suggested for future policy making in order to integrate diverse points of views from various stakeholders.



Chapter 6

Synthesis

6.1 Review of research objectives and questions

A steadily increasing world population and the expansion of agricultural area are driving an increase in degraded land, threatening the fundamental processes underpinning natural and agricultural ecosystems on earth and the quality of human life (Eswaran et al. 2019). Land restoration is considered to be the antidote for the 21st century's global challenge of land degradation (Abera et al. 2020). Land restoration is considered to be one of the pathways to achieve the targets set out by the Sustainable Development Goals (SDG), the Convention on Biological Diversity (CBD), the United Nations Framework of the Convention on Climate Change (UNFCCC) and the United Nations Convention to Combat Desertification (UNCCD) (Wolff et al. 2018). The United Nations, taking this situation very seriously, has declared 2021-2030 to be the UN Decade on Ecosystem Restoration to catalyze restoration action. To devise successful land restoration actions, portfolios and policies, it is crucial to learn from previous experiences. This thesis took the example of large-scale land restoration on the Chinese Loess Plateau, notably through the Grain for Green (GGP) project, as a case study to assess the impact of restoration.

The current (GGP) and previous land restoration projects brought dramatic changes to the land cover of the Chinese Loess Plateau, especially in terms of increasing vegetation cover and reducing farmland area. However, the impacts of land restoration are not only notable from the geographical perspective in terms of land cover change, but also extend to hydrological, biophysical, economic and societal aspects. These multifaceted impacts of land restoration have not been integrally studied by previous research, thus, in our study, we aimed to investigate the impact of land restoration on the Chinese Loess Plateau by integrating analyses from different disciplinary angles.

The main research question was described as:

What are the integrated impacts of land restoration projects on the Chinese Loess Plateau?

More detailed sub research questions taking different disciplinary angles were:

RQ1: What are the impacts of ecological restoration and climate variability on the surface flow in the Chinese Loess Plateau?
RQ2: What are the spatial and temporal dynamics of ecosystem services before and after the Grain for Green project in the Chinese Loess Plateau?
RQ3: What are the costs and benefits of the Grain for Green project and how does the monetary value of ecosystem services change during the land restoration?

RQ4: What are the stakeholders' perceptions towards landscape restoration actions and impacts on the ecosystem services in the Loess Plateau?

6.2 Main research findings

This thesis highlights the importance of conducting a multifaceted impact assessment of land restoration, considering the fact that the impacts in this case manifested in reduced surface water flow, altered local ecosystem services, improved monetary value of the environment and changing stakeholders' perceptions as is evident from Chapters 2, 3, 4 and 5, and summarized in the following subsections (Figure 6.1).

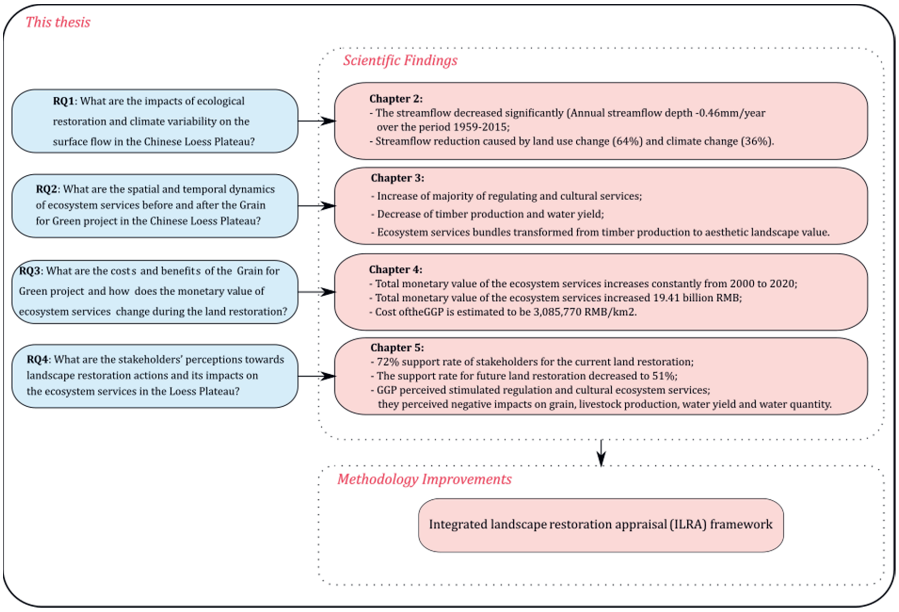


Figure 6.1 Research questions and main scientific outcomes of this thesis.

6.2.1 Land restoration and climatic impacts on surface waterflow

The first research question was "*What are the impacts of ecological restoration and climate variability on the surface flow in the Chinese Loess Plateau?*" To answer this research question, we conducted a systematic literature review by using a meta-analysis of 52 case studies with hydrological modelling results, which was reported in Chapter 2. First, Mann-Kendall tests and Pettitt's tests were applied to analyze the change trends and change year of precipitation and water flow in the previous decades. Subsequently, the meta-analysis yielded the change rate of water flow, as well as the impact ratio from land use and climate change.

The Mann-Kendall test illustrated that the majority (41 of 52) of the studied watersheds showed a decreasing streamflow trend in recent decades and nearly half of them were significant, while none of the increasing trends were found to be significant. However, in the meantime, precipitation levels in the different watersheds did not show a clear increasing or decreasing trend. Additionally, from Pettitt's test results, the most significant streamflow reduction started to appear between 1990 and 2000, mainly concentrated at the end of the 1990s. Meanwhile, the random effect model meta-analysis indicated that the impacts from land use change and climate change on the surface flow change were 64% and 36%, respectively. Additionally, after 1999, the impact of land use on streamflow increased from 55% to 68%, illustrating that the land use change impacts enhanced the streamflow reduction. From the results of the principal component analysis, the level of the impact of soil and water conservation measures on streamflow change followed the order: total restoration area > terrace building > afforestation > grass planting > dam building.

6.2.2 Land restoration impacts on ecosystem services

The second research question was "*What are the spatial and temporal dynamics of ecosystem services before and after the Grain for Green project in the Chinese Loess Plateau?"* In Chapter 3, in order to answer this question, the Yan'an area was selected as the research area for the case study. To monitor environmental change, ecosystem services were subdivided into 11 ecosystem services including four provisioning services, four regulating and three cultural services. The time frame was determined to be from 1990 to 2018 with seven time intervals in between, covering the periods of pre- and post- Grain for Green project implementation to understand the temporal dynamics of ecosystem services by Space-Time Interactions (STI). Meanwhile the spatial dynamics were quantified for the 13 counties in the Yan'an area. The quantification methods comprised reviewing statistical yearbook data and applying InVEST models. Dynamics of ecosystem services were illustrated by mapping changes in ecosystem service bundles over time for the 13 counties in the research area.

The STI results determined an obvious increase in fruit production and livestock production while the grain production and timber production decreased during the research period. Regulating services gradually increased for carbon sequestration, sediment retention and habitat quality. In contrast, a significant drop in water yield was found. All three cultural services including outdoor recreation, aesthetic landscape value and learning and inspiration showed rising trends from 1990 to 2018. Additionally, trade-off and synergistic relationships between different ecosystem services were observed. A synergistic relationship was found between regulating and cultural services while both trade-offs and synergies were determined among provisioning and regulating services. Results of the quantification and correlation analysis of ecosystem services imply that although land restoration had positive impacts on the majority of the regulating and cultural services, the existence of trade-offs indicates that negative impacts of land restoration on specific ecosystem services cannot be avoided. In the Grain for Green project, ecosystem service reduction was found in grain production, timber production and water yield.

Moreover, ecosystem service bundles illustrated temporal and spatial dynamics of clustered ecosystem services during the implementation of the GGP in the Yan'an area from 1990 to 2018. The process of change in ecosystem service components triggered by the GGP was discovered to start with increasing regulating services at the expense of provisioning services, followed by cultural services exceeding regulating services and occupying the main proportion of all ecosystem service bundles. Implementation of the GGP is recognized as a key factor changing land use and affecting ecosystem service bundles.

6.2.3 Land restoration impacts on total monetary value

The third research question was "*What are the costs and benefits of the Grain for Green project and how does the monetary value of ecosystem services change during the land restoration?"* To answer this research question, the approach was to compare the net present value gap between current land restoration and a simulated scenario in which land restoration was not implemented. Yan'an continued to be selected as the case study area, and the research period ranged from 2000 to 2020 with five-year intervals. In order to conduct the cost-benefit analysis, the CLUE-S model was applied to simulate a non-GGP influenced land cover map "2020 non-GGP". The quantification methods used for ecosystem services were the same as in Chapter 3, while market prices, avoided costs and benefit transfer were used as valuation methods to estimate the monetary value of ecosystem services. Costs of land restoration were calculated based on labor cost, subsidy and maintenance investments.

The simulated 2020 non-GGP land use scenario featured an increase in crop area while forest and grassland areas were reduced as compared to the situation in 2020 when the GGP was implemented. From 2000 to 2020, the total monetary value of ecosystem services constantly increased from 45 billion RMB to 112 billion RMB, while the TMV of 2020 non-GGP was estimated to be 39 billion RMB lower than that of the GGP in 2020. This result illustrates that the land restoration project brought more economic value to the ecosystem as compared to the case without land restoration.

Through conducting a cost-benefit analysis, we calculated that the implementation of the GGP had accumulated a net present value of 19.41 billion RMB when subtracting restoration costs from extra net benefits for Yan'an's ecosystem services as compared to the non-GGP case in 2020. During the first six years of the research period, when the GGP was initiated, the non-GGP scenario had a higher monetary value, while after 2007, the GGP started to bring more economic benefit.

Trade-offs in monetary values were also found between provisioning and regulating services between 2020 and the 2020 non-GGP simulation.

6.2.4 Stakeholders' perceptions on land restoration impacts

The fourth research question was "*What are the stakeholders' perceptions towards landscape restoration actions and impacts on the ecosystem services in the Loess Plateau?*" To answer this research question, first, a primary investigation was initiated in Ansai county in the Yan'an area in 2018 to identify the main stakeholder groups. Afterwards, in early 2021, a questionnaire survey was carried out in the Yan'an area and focused on different stakeholder groups in order to understand their attitudes towards current and future land restoration policy, as well as their perceptions of land restoration impacts on local ecosystem services. Additionally, factors influencing a farmer's decision to recultivate restored forest were also studied by applying a binary logistic regression model.

Based on the results from 150 stakeholder respondents, the support rate for the current land restoration policy was 72%, while the support rate for a future GGP was 51%. Government officers supported this policy the most while tourism operators supported it the least. This result reveals that the majority of the stakeholders have positive attitudes toward the current GGP policy, while fewer stakeholders support future land restoration. Factors influencing a farmer's decision to recultivate restored forest lands were restoration rate, support for the GGP, tree species selection, influence of the GGP on income, income source and monthly income. The results of stakeholder perception of GGP impacts on the ecosystem services were similar to the model results reported in Chapter 3. A reduction in grain production, livestock production and water yield were determined by the stakeholders, while most of the stakeholders observed an increase in regulating and cultural services through the impacts of land restoration. To conclude, most stakeholders showed a positive attitude towards GGP policy. Nevertheless, negative impacts of the GGP on farmer's income were found to be the main reason influencing a farmer's decision on whether to recultivate the restored forest once the government subsidy stopped.

6.3 Scientific significance

This thesis provides scientific contributions based on the methodologies and findings. In Chapter 2, with regards to the methodology, although meta-analysis is commonly accepted as a method to synthesize results from previous clinical research and laboratory experiments (Borenstein et al. 2021), it was also adopted in this study to analyze hydrological model results. Findings from Chapter 2 indicate the impact level of land restoration and climate change on streamflow, warning scholars to pay attention to the potential side-effects of land restoration. In Chapter 3, although the quantification methods and ecosystem service bundles were adapted from previous studies (Renard et al. 2015; Turner et al. 2014; Zhao et al. 2018), cultural services were first introduced to qualify the ecosystem services in the Chinese Loess Plateau. Previous studies ignored cultural services which helps to remind us of the importance and difficulties of capturing this entire category of ecosystem services (Wróblewski et al. 2018).

In Chapter 4, the combination of land use modelling and ecosystem service monetization tools offers scholars a new method to estimate the cost and benefit of land restoration actions. The majority of previous studies focused on the biophysical impacts of land restoration (Chen et al. 2013; Hu et al. 2017). The monetary value of ecosystem services was given little scientific attention in the Chinese Loess Plateau. This thesis may raise scientific awareness and understanding of the economic impacts from land cover change on local ecosystem services. In Chapter 5, stakeholder perception towards current and future land restoration policy was studied. In previous studies researching the societal impacts of land restoration, farmers were regarded as the main research object (Sjögersten et al. 2013; LI et al. 2017; Graves et al. 2017). This study found that along with farmers and government officers who directly participated in the land restoration program, other stakeholders who were passively influenced by the GGP were equally important. Understanding a more comprehensive stakeholder perception is helpful to avoid social conflicts, moreover, indigenous and local knowledge (ILK) provide valuable information for landscape restoration policy (Díaz et al. 2018). To summarize, this thesis stresses the importance of continuously monitoring the impacts of land restoration by examining the dynamics of ecosystem services, monetary value and social perceptions. This paper helps to visualize the trade-offs and synergies between different categories of ecosystem services and presents changes in economic values and sheds light on stakeholder perceptions on land restoration policy. Furthermore, limitations of this study and recommendations are described below.

6.4 Limitations and challenges

When looking back through the entire thesis, there are still limitations and challenges that could be improved upon and perhaps overcome in terms of research scale, ecosystem service categories and tracking of stakeholder perception. This study was mainly focused on one central area of the Chinese Loess Plateau. As the GGP was implemented nationally across 23 provinces in China, in order to assess the integrated impacts of the GGP, a larger research area should be used to comprehensively analyze the land restoration impacts across different geographical regions and climate zones. Additionally, the expansion of the research area could shed light on the downstream effects. In Chapter 2 we concluded that, according to the results of previous studies, land restoration induced streamflow reduction whereas in Chapter 3 and 5, the results illustrated that the streamflow actually increased from 2000 to 2020. The difference in scale may be one explanation for this: in Chapter 2 the research area covered the whole Loess Plateau while in Chapter 3 and 5, the research area was limited to Yan'an. As the water yield of the whole Loess Plateau was reduced, the increased water yield after GGP implementation in the Yan'an area may have led to a reduction in downstream water availability. When expanding the research area, the challenge will be how to obtain more complete datasets in order to quantify the ecosystem services and effectively reveal the perceptions of stakeholders. Additionally, the datasets will be more difficult to manage as the data quantity may increase dozens of times. Moreover, a larger scale of ecological modelling work and stakeholder investigation requires a huge amount of funding and the involvement of many more researchers.

In our study, the main methods for quantifying ecosystem services were analyzing trends from statistical yearbooks and applying InVEST models. Statistical yearbooks provide a data source for the four provisioning services, from which crop, fruit, livestock and timber production numbers were obtained for each county. Applying models, such as the Grain Production model from InVEST, to estimate the provisioning services can help to discover the density and geographical distribution of these services. A more complete mapping of the distribution of ecosystem services provides more precise information of ecosystem status, while the statistical data can be used to validate and calibrate the model.

Another limitation is the selection of a subset of ecosystem services, although it is impossible to qualify all services from one ecosystem (Bagstad et al. 2013). In Chapter 3, 11 ecosystem services were selected as indicators to monitor the impacts from land restoration, while in Chapter 4 and 5, 10 and 13 ecosystem services were considered, respectively. This means that several ecosystem services are not included in this thesis. It would be meaningful to estimate the land restoration impacts and perceptions by local stakeholders of these additional ecosystem services, for instance, air quality and tourism. An issue of increasing concern for many Chinese citizens is air quality, as air pollution causes environmental problems and can drastically affect human health (S. Wang & Hao, 2012). Considering air quality might be helpful to enhance stakeholders' awareness of how regulating services contribute to human well-being. Moreover, the link between restoration and air quality could then be established. A previous restoration project had improved air quality in terms of decreased PM_{10} and NO_2 concentration (Jang et al. 2010). Tourism is another ecosystem service interesting to stakeholders, especially for tourism operators. However, tourism data is only available at the city level from the year 2000 onwards and more precise data at the county level was only recorded starting in 2015. Lack of accurate data on tourist numbers makes it hard to assess the spatial distribution of this ecosystem service.

In the cost-benefit analysis of the land restoration, more land cover scenarios are needed in order to simulate possible consequences from land restoration in the future. For instance, a land cover scenario that simulates a more extreme land restoration with dramatic increases in forest and grass land cover could reveal how the monetary value of ecosystem services would change in the future, as well as how beneficial this extreme scenario is as compared to the current land cover. Combined with ecosystem service quantification models, this could also uncover potential side effects, for example, possible water scarcity in the future or deficiencies in other ecosystem services. Keeping track of stakeholder perceptions in the future will be helpful to avoid conflicts between stakeholder groups and provide suggestions for land restoration policy makers.

Additionally, in the investigation of stakeholders' perceptions in Chapter 5, stakeholders were investigated twice, in 2018 and 2021. However, the GGP was initiated in 1999, and information on stakeholders' perception towards land restoration before the start of the project and during the implementation of land restoration activities was missing. Understanding stakeholder perceptions during different implementation stages of land restoration may be valuable for policy makers, help the government to increase the acceptance of land restoration by stakeholders and avoid potential conflicts among stakeholder groups.

6.5 Expansion

In this thesis, I developed a framework to assess the integrated landscape restoration impacts based on the approaches and methodologies applied in the previous chapters (see Figure 6.1). Generally, as visualized in the dotted box, the integrated landscape restoration appraisal (ILRA) framework consists of three disciplinary angles including biophysical, economic and societal assessments. In the biophysical and economic assessments, quantification of ecosystem service changes and valuation of monetary changes are the main approaches to understand land restoration impacts, while investigating stakeholder perceptions is the main approach to assess societal changes. Methods for quantifying ecosystem services are introduced as ecological models such as the InVEST model, as well as statistical yearbook and land use area transfer. Monetary valuations are based on market price, benefit transfer and avoided costs using the quantification results of ecosystem services as input data. Stakeholder surveys follow a sequential process of stakeholder identification, questionnaire design and workshops & individual meetings. Results of the assessments include the assessment of ES trade-offs and synergies, cost-benefit analysis, and stakeholder support. In the end, results from the different disciplinary angles were integrated to make recommendations for policy making in order to influence the land restoration process.

This framework is useful for the assessment of landscape restoration impacts at both ex-ante and ex-post stages. In the ex-ante stage of landscape restoration, when landscape restoration is planned, the expected land cover changes will first be estimated by land cover scenarios. These scenarios should represent different land restoration policy alternatives that would alter the land cover and change the ecosystem functions and biodiversity in varying ways, and lead to different provisioning outcomes of ecosystem services. The integrated landscape restoration appraisal framework will estimate the restoration impacts based on the planned scenarios, offering insight ES trade-offs and synergies, costs and benefits as well as the degree of stakeholder support that can be expected based on the planned scenarios. In the ex-post stage of land restoration, the difference is that land cover scenarios are replaced by land covers from before and after restoration, the ILRA framework will be applied the same. The proposed framework is recommended for supporting land restoration policy making at both ex-ante and ex-post stages.

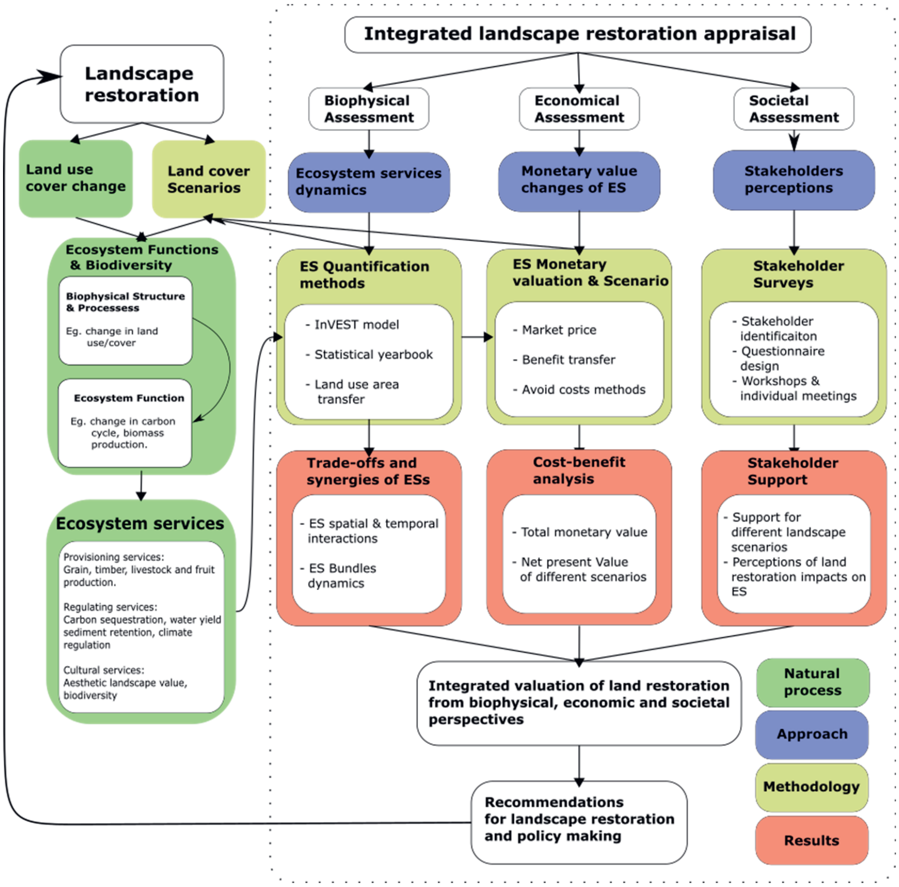


Figure 6.2 Integrated landscape restoration appraisal (ILRA) framework.

This framework aligns with the 4 Returns Framework for landscape restoration designed by the Commonland Foundation (Dudley et al., 2021). The 4 Returns (Appendix 6.1) offers a science-based, long-term implementation framework for restoring a degraded landscape by splitting the restoration area into natural zone, combined zone and economic zone, within a minimum 20-year timeframe to successfully implement large-scale integrated landscape management activities with all stakeholders. The 4 Returns approach aims at creating inspiration, social, natural and financial returns. Results of this thesis verified the feasibility of the 4 Returns approach from the Grain for Green project in the Chinese Loess Plateau. Improvements in ecosystem services, monetary value of the ecosystem and stakeholder satisfaction in the ecosystem during the GGP implementation from 1999 to 2020 complied with the theory from the 4 Returns approach in terms of realizing 4 returns in a 20-year plan. As the 4 Returns approach supported the structure of the land restoration impact assessment framework, I recommend the 4 Returns theory as an approach for landscape restoration design and initiation, and the ILRA framework for landscape restoration impact assessments.

6.6 Implications for restoration practice and policy

First of all, this thesis provides an integrated approach for assessing the impact of land restoration, which has implications for environmental management. From our approach, the impacts of land restoration were split into different branches: 1) natural impacts; 2) economic impacts and 3) social impacts. This approach can assist in comprehensively capturing and monitoring human-induced environmental impacts from different disciplinary angles. Monitoring temporal and spatial dynamics of ecosystem services provides essential information for environmental management. It reflects the ecological status of the ecosystem, avoiding misjudgment of whether the ecosystem is degraded or healthy. Therefore, the quantification tools and the suggested ILRA framework provide feasible methods to achieve sustainable environment management by monitoring the ecosystem services and assessing land restoration influences. The monetizing tools for cost-benefit analysis can be used to capture the monetary value of ecosystem services and calculate the potential return on investment for land restoration projects, providing managers with a valuation tool for feasibility analysis of land restoration projects (Baveye et al. 2013). The approach developed in this thesis offers the environmental manager a tool for the spatially explicit assessment of land restoration impacts in different locations and towards different stakeholder groups. Societal investigation towards stakeholders is also important for environmental management, as the monitoring of ecosystem services using different models may not be able to reflect all anticipated problems (Dorrough et al. 2016). For instance, in this thesis, the subsidy constraints and biodiversity issues arising from stakeholder meetings discussed in Chapter 5 were not determined by the models from Chapter 3 and 4. Thus, involving stakeholders during land restoration implementation is essential to improving environmental management as stakeholders hold indigenous and local knowledge and empirical experiences.

Along with the implications for environmental management, this thesis also has implications for land restoration policy. Findings in this thesis provide evidence that the introduction of land restoration enhanced ecosystem services – especially for the majority of regulating services and cultural services, improved the total monetary value of the local ecosystem, and was supported by more than half of the stakeholders. However, as Chapter 2, 3 and 5 revealed, land restoration had environmental side-effects that should not be ignored. In the policy making process, the potential drawbacks are supposed to be considered, for instance in this thesis, the land restoration implementation in the Loess Plateau has brought about water scarcity risks based on results from Chapter 2 and 3. Risk assessment is an important procedure to carry out during the policy making process, offering a clear understanding of the level of risk posed to the community, as well as appropriate targets for change (Latessa & Lovins, 2010). Furthermore, approaches used in Chapter 4 – scenario planning, monetization of ecosystem services and cost-benefit analysis – can be applied as a method to quantify the environmental impacts from land restoration. This leverage allows policy makers to build different future land restoration plans and support the final decision-making process by achieving comparably higher total monetary value for ecosystem services.

Additionally, this thesis has implications for society. Quantification and monetization of ecosystem services make the benefits people enjoy from ecosystem restoration more tangible for the stakeholders; this can potentially help increase public awareness of how ecosystem services contribute to human well-being. In Chapter 5, stakeholders were fully aware of the changes in ecosystem services, and the majority of the stakeholders self-declared that their environmental protection awareness was increased during the implementation of land restoration, as well as their forest fire prevention awareness. Meanwhile, the stakeholder perception investigation revealed that while a top-down land restoration policy might be helpful for increasing the implementation efficiency, stakeholders should also participate in the decision-making procedure to avoid potential conflicts.

Combining the findings from Chapter 2, 3, 4 and 5, this thesis made recommendations for future land restoration policy. First, the side-effects of land restoration should be considered. In Chapter 2 and 3, a reduction of water quantity was observed in the Chinese Loess Plateau while land restoration proved to be one of the major causes. Moreover, the decrease in grain and timber production was found to be a trade-off of regulating services. Policy makers need to consider the effects of reduced ecosystem services after land restoration, for instance, to maintain a basic agricultural area to support food security or develop a forestry industry to increase timber production. In order to maintain local water supply, it is recommended that further landscape restoration plans balance the revegetation area of forest and grassland. In Chapter 4, the future case of 2030 illustrates that the continuation of the GGP in the future may bring less economic return. Local authorities need to consider social-environmental factors to support future decision making. During our social investigation in Chapter 5, stakeholders - especially the majority of farmers who participated in the GGP – were elders living in the rural area far from a city and their voices were not often heard by the public. Policy makers should enable the involvement of the local population to acquire a joint understanding of the current situation through integrating the different points of view of all stakeholders. For instance, local GGP offices are encouraged to organize workshops to understand the needs of farmers during the later stages of restoration. Furthermore, there should be more diversity in tree and grass species used during revegetation efforts in order to improve the biodiversity of the restored forest, helping to strengthen the stability of the restored ecosystem.

6.7 Conclusions

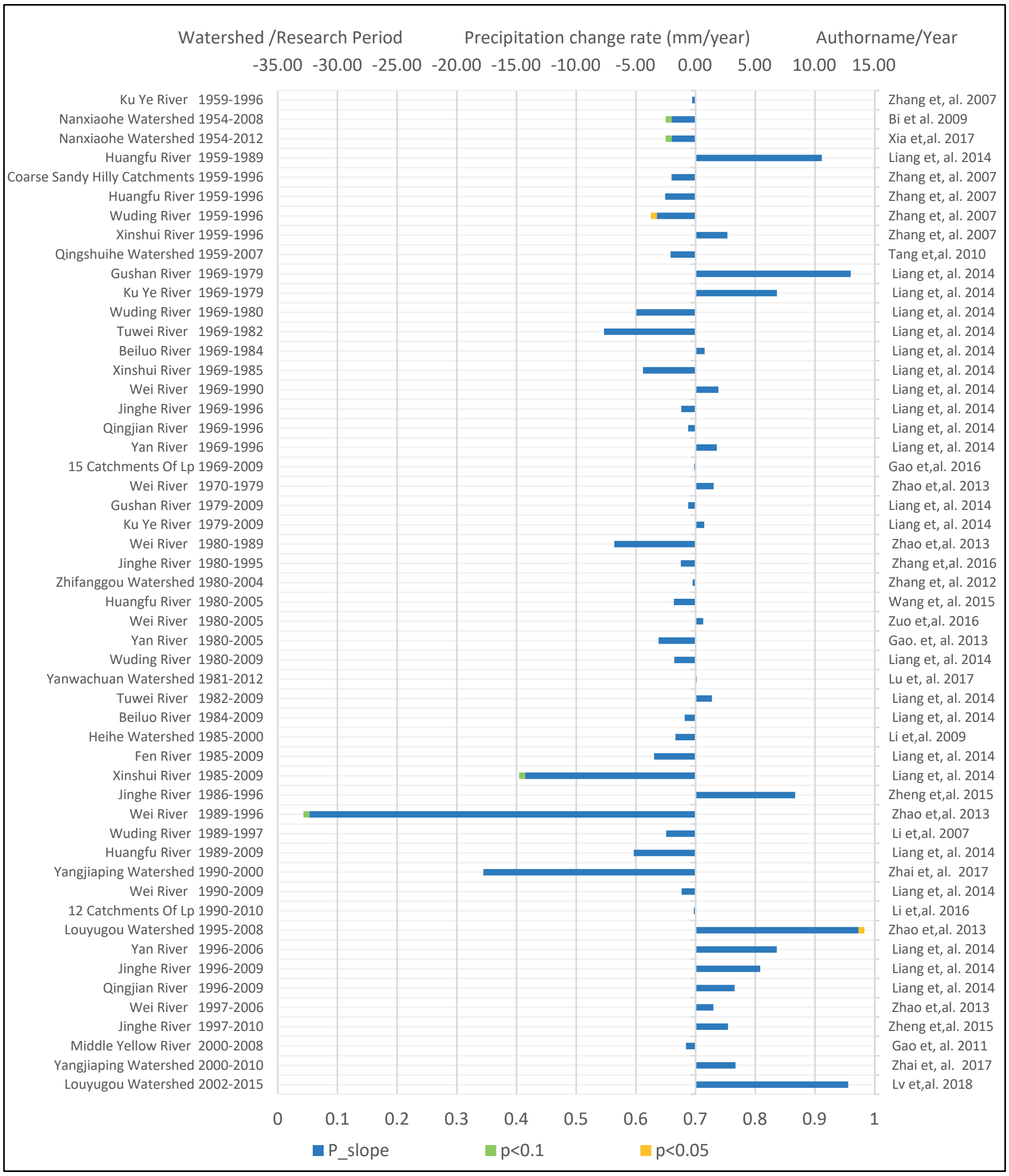
This thesis investigated the integrated impacts of a land restoration program in the Chinese Loess Plateau referring to a DPSIR framework, in terms of impacts on surface hydrology, ecosystem services, total monetary value and stakeholder perception. To conclude, land restoration has been a major driver of streamflow reduction in recent decades, another cause is climate change. Synergies were found between the majority of the regulating services and cultural services whereas trade-offs were discovered in provisioning services and water yield. The introduction of the Grain for Green project was more beneficial for the monetary value of ecosystem services as compared to not implementing the GGP. Most stakeholders support current land restoration while fewer people support its future extension, and stakeholders perceived that the GGP has stimulated local regulating and cultural services. In the end, this thesis offers a framework for integrated landscape restoration appraisal and makes recommendations for future land restoration policy making.

Appendix

Appendix 2.1 List of selected articles.

Author	Publication year	Watershed name	Drainage area (km2)	Name of publication
Lijuan Li et,al.	2007	Wuding river basin	30261	Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China
Xiaoping Zhang et, al.	2007	10 catchments from Coarse Sandy hilly catchment	113000	Responses of streamflow to changes in climate and land use/cover in the Loess Plateau, China
Zhi Li et,al.	2009	Heihe watershed	1506	Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China
Huaxing Bi *et al*.	2009	Nanxiaohe watershed	36.3	Effects of precipitation and landuse on runoff during the past 50 years in a typical watershed in Loess Plateau, China
Lixia Tang et,al.	2010	Qingshuihe watershed	436	Streamflow response to climate and landuse changes in Qingshui River watershed in the loess hilly-gully region of Western Shanxi Province, China
P Gao et, al.	2011	middle reaches of yellow river basin	344000	Changes in streamflow and sediment discharge and the response to human activities in the middle reaches of the Yellow River
Lulu Zhang et, al.	2012	Zhifanggou watershed	19.2	Separating the effects of changes in land management and climatic conditions on long-term streamflow trends analysed for a small catchment in the Loess Plateau region, NW China
Peng Gao. et, al.	2013	Wei riverbasin	134800	Impact of climate change and anthropogenic activities on stream flow and sediment discharge in the Wei River basin, China
Guangju Zhao et,al.	2013	Wei riverbasin	134800	Climate changes and their impacts on water resources in semiarid regions: a case study of the Wei River basin, China
Yang Zhao et,al.	2013	Luoyugou watershed	72.79	Effects of climate variation and land use change on runoff-sediment yield in typical watershed of loess hilly-gully region.
Wei Liang et, al.	2014	14 catchments of whole LP	197421	Quantifying the impacts of climate change and ecological restoration on streamflow changes based on a Budyko hydrological model in China's Loess Plateau
Fei. Wang et, al.	2015	Yan river basin	7687	Distinguishing the impacts of human activities and climate variability on runoff and sediment load change based on paired periods with similar weather conditions: A case in the Yan River, China
Peilong Zheng et,al.	2015	Jinghe river basin	45421	effects of climate change and land use change on the runoff of jinghe basin of the LP
Depeng Zuo et,al.	2016	Huangfuchuan river basin	3246	Assessing the effects of changes in land use and climate on runoff and sediment yields from a watershed in the Loess Plateau of China
Guangyao. Gao et,al.	2016	15 watersehds of whole LP	197421	Determining the hydrological responses to climate variability and land use/cover change in the Loess Plateau with the Budyko framework
Yanzhong Li et,al.	2016	12 catchments of LP	197421	Reduced Runoff Due to Anthropogenic Intervention in the Loess Plateau, China
Hongbo Zhang et,al.	2016	Jinghe river basin	45421	Influence of land use and land cover changes on runoff regime in Jinghe Basin
Ran Zhai et, al.	2017	Yangjiaping watershed	14124	Contributions of climate change and human activities to runoff change in seven typical catchments across China
Xia Lu et, al.	2017	Yanwachuan watershed	366.95	Impacts of precipitation variation and soil and water conservation measures on runoff and sediment yield i n the Loess Plateau Gully Region, China
Lu Xia et,al.	2017	Nanxiaohegou Watershed	36.3	Impacts of land use change and climate variation on green water in the Loess Plateau Gully Region——A case study of Nanxiaohegou basin
Xizhi Lv et,al.	2018	Luoyugou watershed	72.79	Effects of Climate Change and Human Activity on Runoff in a Typical Loess Gullied-Hilly Region Watershed

Appendix 2.2 Precipitation change of 52 watershed case studies. Note: colours on top of the column indicate the significant level.

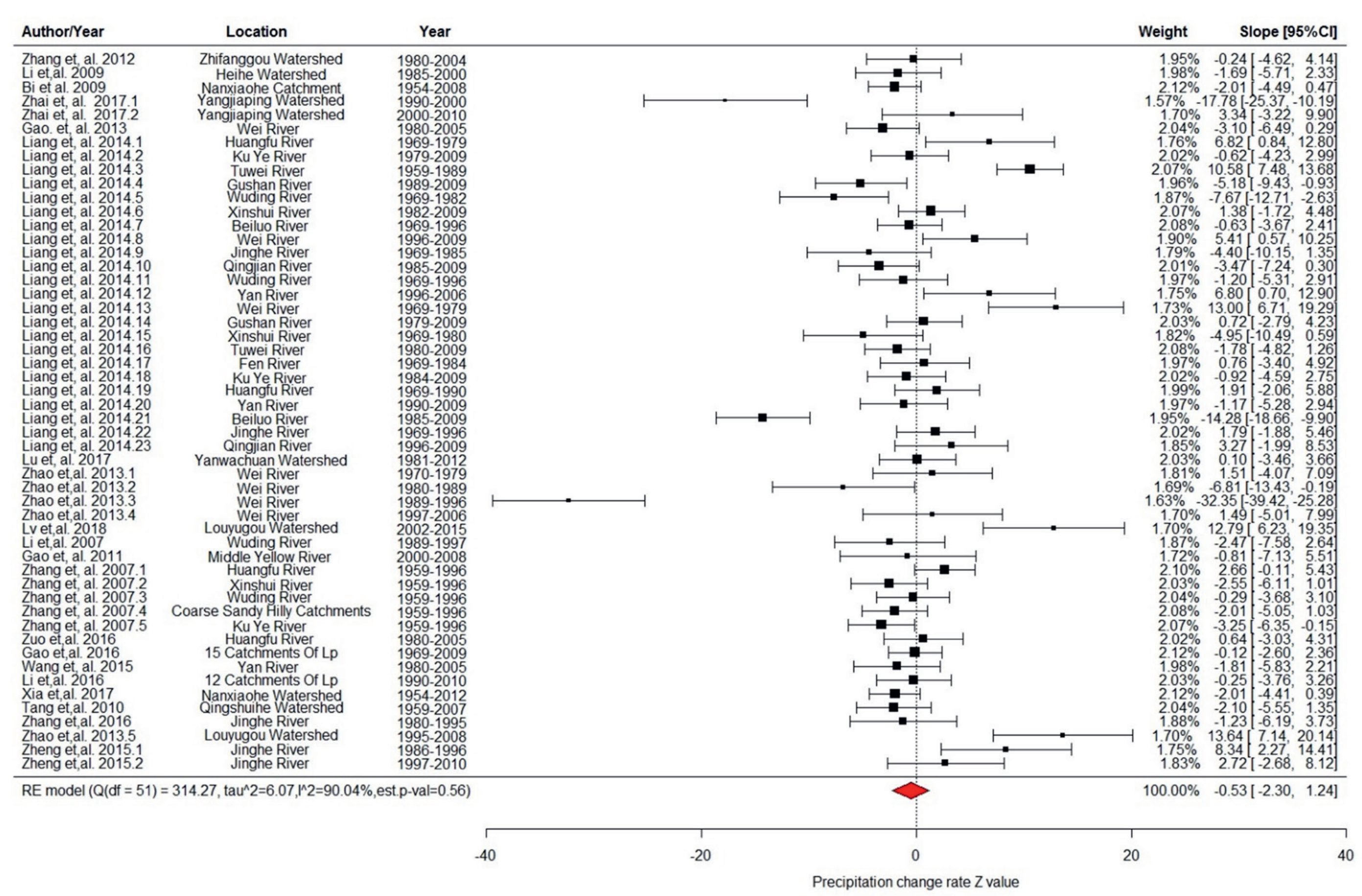


Appendix 2.3 Pettit's test result of streamflow(Q), precipitation(P) and runoff coefficient (Rc).

Author.name/Year	**Research Year**	**Watershed**	**Q-Point**	**Q p-value**	**P-Point**	**P-p value**	**Rc-Point**	**Rc-p value**
Wei Liang et, al. 2014	1959-1989	Huangfu River	1967		1963		1986	
Xiaoping Zhang et, al. 2007	1959-1996	Huangfu River	1969		1967		1993	*
Guangju Zhao et,al. 2013	1970-1979	Wei River	1972		1973		1970	**
Wei Liang et, al. 2014	1969-1979	Ku Ye River	1973		1974		1999	
Xiaoping Zhang et, al. 2007	1959-1996	Xinshui River	1974	**	1983		2010	
Xiaoping Zhang et, al. 2007	1969-1982	Tuwei River	1975		1979		1990	**
Wei Liang et, al. 2014	1959-1996	Wuding River	1975	**	1974		1974	
Wei Liang et, al. 2014	1969-1979	Gushan River	1976		1977		1999	**
Wei Liang et, al. 2014	1969-1985	Wuding River	1976		1971		1964	
Wei Liang et, al. 2014	1969-1980	Xinshui River	1976		1975		1999	*
Xiaoping Zhang et, al. 2007	1959-1996	Coarse Sandy Hilly Catchments	1978	**	1976		1975	
Lixia Tang et,al. 2010	1969-1984	Beiluo River	1979		1976		2000	**
Wei Liang et, al. 2014	1959-2007	Qingshuihe Watershed	1979	**	1971		1993	
Wei Liang et, al. 2014	1969-1990	Wei River	1982		1973		2007	
Huaxing Bi et al. 2009	1954-2008	Nanxiaohe Catchment	1984	**	1992		1981	
Wei Liang et, al. 2014	1969-1996	Jinghe River	1984		1973		1997	
Wei Liang et, al. 2014	1980-2004	Zhifanggou Watershed	1986		2000		1995	
Lulu Zhang et, al. 2012	1969-1996	Qingjian River	1986		1986		2000	
Wei Liang et, al. 2014	1980-2009	Wuding River	1986		1985		1975	
Wei Liang et, al. 2014	1969-1996	Yan River	1988		1992		1999	**
Guangju Zhao et,al. 2013	1980-1989	Wei River	1988		1986		1978	
Peilong Zheng et,al. 2015	1986-1996	Jinghe River	1988		1988		1987	
Xiaoping Zhang et, al. 2007	1959-1996	Ku Ye River	1992	**	1997		1973	
Depeng Zuo et,al. 2016	1981-2012	Yanwachuan Watershed	1993		1986		2001	
Xia Lu et, al. 2017	1989-1996	Wei River	1993		1992		1982	
Guangju Zhao et,al. 2013	1980-2005	Huangfu River	1993	*	1997		196	
Peng Gao. et, al. 2013	1985-2000	Heihe Watershed	1994		1991		2003	
Zhi Li et,al. 2009	1980-2005	Wei River	1994	**	1991		1991	
Lijuan Li et,al. 2007	1989-1997	Wuding River	1994		1997		2002	
Lu Xia et,al. 2017	1990-2009	Wei River	1996		1994		1996	
Wei Liang et, al. 2014	1954-2012	Nanxiaohe Watershed	1996	**	2004		1972	
Guangyao. Gao et,al. 2016	1990-2000	Yangjiaping Watershed	1997		1997		1982	
Wei Liang et, al. 2014	1979-2009	Gushan River	1997	**	2007		1990	
Fei. Wang et, al. 2015	1985-2009	Xinshui River	1997		2003		2004	
Wei Liang et, al. 2014	1969-2009	15 Catchments Of Lp	1997	**	1979		2006	
Ran Zhai et, al. 2017	1980-2005	Yan River	1997	*	1992		1990	
Wei Liang et, al. 2014	1982-2009	Tuwei River	1998	**	2001		2006	
Wei Liang et, al. 2014	1985-2009	Fen River	1998	*	1997	*	1964	
Wei Liang et, al. 2014	1989-2009	Ku Ye River	1999	*	1997		1979	*
Wei Liang et, al. 2014	1979-2009	Huangfu River	1999	**	1987		1986	**
Yanzhong Li et,al. 2016	1990-2010	12 Catchments Of Lp	1999	*	1997		1976	
Yang Zhao et,al. 2013	1995-2008	Louyugou Watershed	1999		1999		1978	**
Wei Liang et, al. 2014	1996-2006	Yan River	2000		1997		1993	*
Wei Liang et, al. 2014	1984-2009	Beiluo River	2001	**	2003		1982	**
Peilong Zheng et,al. 2015	1997-2010	Jinghe River	2001		2001		1997	
Wei Liang et, al. 2014	1996-2009	Jinghe River	2002	*	2000		2000	**
Hongbo Zhang et,al. 2016	1980-1995	Jinghe River	2003	*	1991		2002	**
Guangju Zhao et,al. 2013	1997-2006	Wei River	2004		2004		1999	**
P Gao et, al. 2011	2002-2015	Louyugou Watershed	2006		2008		2003	*
Xizhi Lv et,al. 2018	2000-2008	Middle Yellow River	2006		2007		2001	
Wei Liang et, al. 2014	1996-2009	Qingjian River	2007		2002		1988	
Ran Zhai et, al. 2017	2000-2010	Yangjiaping Watershed	2009		2009		2001	

Note: total number = 52, * were used to describe the significant level, * indicates $p < 0.05$, ** indicates $p < 0.01$.

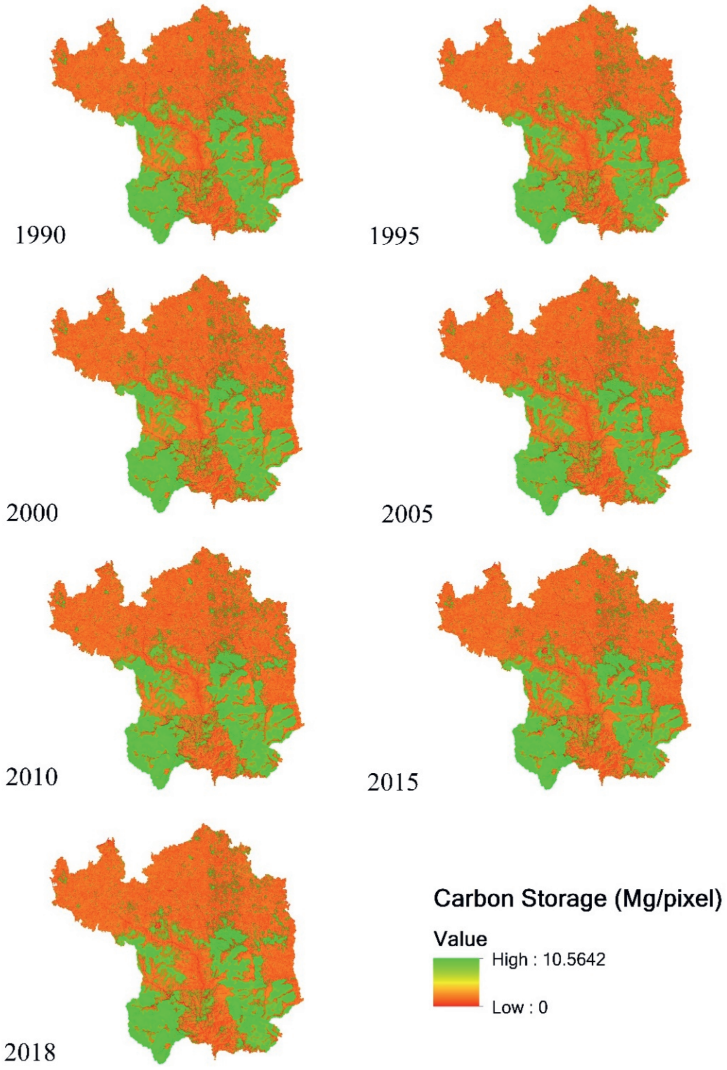
Appendix 2.4 Meta-analysis result of precipitation change rate.



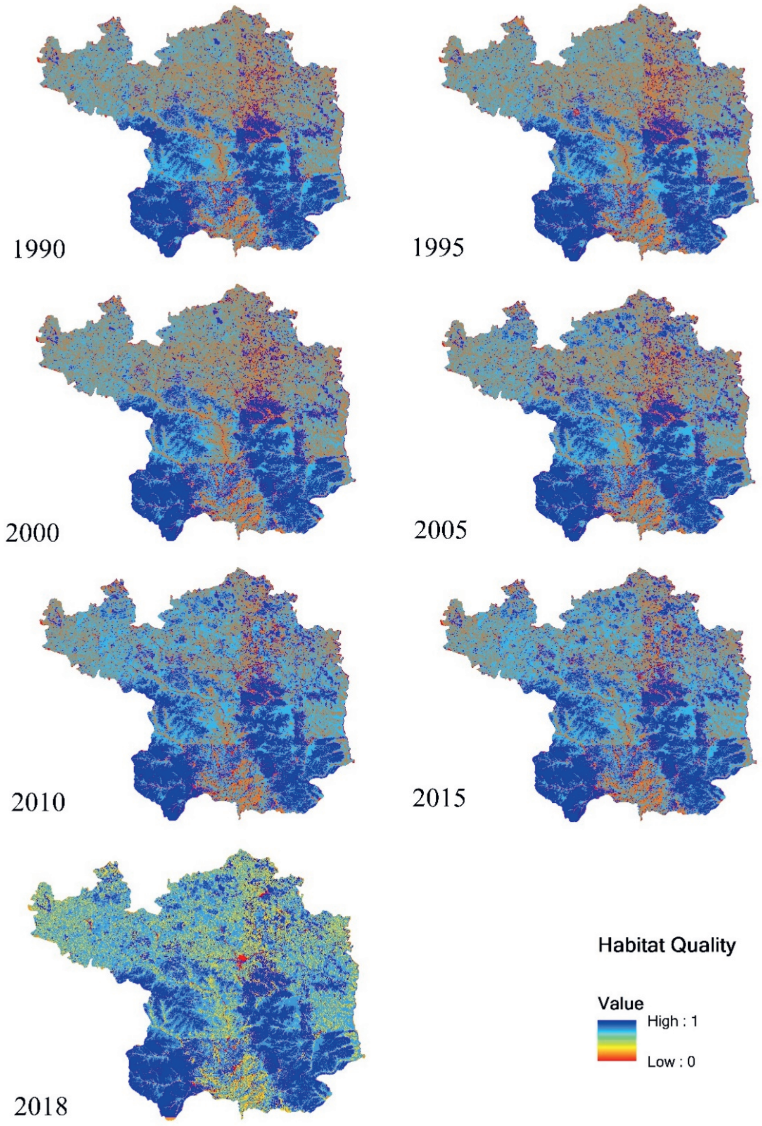
Appendix 2.5 Land use change and climate change impacts collected from articles.

No.	Author name/Year	Research Year	Location	Landuse change impacts on Q %	Climate change impacts on Q %
1	Wei Liang et, al. 2014	1959-1989	Huangfu River	98.00%	2.00%
2	Xiaoping Zhang et, al. 2007	1959-1996	Huangfu River	21.00%	79.00%
3	Guangju Zhao et,al. 2013	1970-1979	Wei River	54.47%	45.53%
4	Wei Liang et, al. 2014	1969-1979	Ku Ye River	74.00%	26.00%
5	Xiaoping Zhang et, al. 2007	1959-1996	Xinshui River	55.00%	45.00%
6	Xiaoping Zhang et, al. 2007	1969-1982	Tuwei River	72.00%	28.00%
7	Wei Liang et, al. 2014	1959-1996	Wuding River	43.00%	57.00%
8	Wei Liang et, al. 2014	1979-1982	Jialu River	86.00%	14.00%
9	Xiaoping Zhang et, al. 2007	1982-2009	Jialu River	82.00%	18.00%
10	Xiaoping Zhang et, al. 2007	1969-1979	Gushan River	78.00%	22.00%
11	Xiaoping Zhang et, al. 2007	1969-1980	Wuding River	67.00%	33.00%
12	Xiaoping Zhang et, al. 2007	1969-1985	Xinshui River	81.00%	19.00%
13	Xiaoping Zhang et, al. 2007	1959-1996	Coarse Sandy Hilly Catchments	46.00%	54.00%
14	Wei Liang et, al. 2014	1969-1984	Beiluo River	13.00%	87.00%
15	Wei Liang et, al. 2014	1969-1971	Dali River	63.00%	37.00%
16	Wei Liang et, al. 2014	1971-2009	Dali River	58.00%	42.00%
17	Xiaoping Zhang et, al. 2007	1959-2007	Qingshuihe Watershed	53.21%	46.79%
18	Lixia Tang et,al. 2010	1969-1990	Wei River	66.00%	34.00%
19	Wei Liang et, al. 2014	1954-2008	Nanxiaohe Catchment	50.00%	50.00%
20	Wei Liang et, al. 2014	1969-1996	Jinghe River	34.00%	66.00%
21	Huaxing Bi et al. 2009	1980-2004	Zhifanggou Watershed	74.00%	26.00%
22	Wei Liang et, al. 2014	1969-1996	Qingjian River	40.00%	60.00%
23	Wei Liang et, al. 2014	1980-2009	Wuding River	64.00%	36.00%
24	Lulu Zhang et, al. 2012	1969-1996	Yan River	49.00%	51.00%
25	Wei Liang et, al. 2014	1980-1989	Wei River	79.53%	20.47%
26	Wei Liang et, al. 2014	1986-1996	Jinghe River	73.40%	26.60%
27	Guangju Zhao et,al. 2013	1959-1996	Ku Ye River	22.00%	78.00%
28	Wei Liang et, al. 2014	1981-2012	Yanwachuan Watershed	62.10%	37.90%
29	Wei Liang et, al. 2014	1989-1996	Wei River	67.63%	32.37%
30	Peilong Zheng et,al. 2015	1980-2005	Huangfu River	46.30%	53.70%
31	Xiaoping Zhang et, al. 2007	1985-2000	Heihe Watershed	9.60%	90.40%
32	Depeng Zuo et,al. 2016	1980-2005	Wei River	83.00%	17.00%
33	Xia Lu et, al. 2017	1989-1997	Wuding River	87.00%	13.00%
34	Guangju Zhao et,al. 2013	1990-2009	Wei River	62.00%	38.00%
35	Peng Gao. et, al. 2013	1954-2012	Nanxiaohe Watershed	16.01%	83.99%
36	Zhi Li et,al. 2009	1990-2000	Yangjiaping Watershed	37.00%	63.00%
37	Lijuan Li et,al. 2007	1979-2009	Gushan River	71.00%	29.00%
38	Lu Xia et,al. 2017	1985-2009	Xinshui River	78.00%	22.00%
39	Wei Liang et, al. 2014	1969-2009	15 Catchments Of Lp	64.75%	35.25%
40	Wei Liang et, al. 2014	1980-2005	Yan River	48.00%	52.00%
41	Guangyao. Gao et,al. 2016	1982-2009	Tuwei River	70.00%	30.00%
42	Wei Liang et, al. 2014	1985-2009	Fen River	62.00%	38.00%
43	Fei. Wang et, al. 2015	1979-2009	Ku Ye River	76.00%	24.00%
44	Wei Liang et, al. 2014	1989-2009	Huangfu River	97.00%	3.00%
45	Ran Zhai et, al. 2017	1990-2010	12 Catchments Of Lp	68.53%	31.47%
46	Wei Liang et, al. 2014	1995-2008	Louyugou Watershed	66.90%	33.10%
47	Wei Liang et, al. 2014	1959-1996	Jialu River	39.00%	61.00%
48	Wei Liang et, al. 2014	1959-1996	Weifen River	57.00%	43.00%
49	Wei Liang et, al. 2014	1959-1996	Shiwang River	57.00%	43.00%
50	Yanzhong Li et,al. 2016	1959-1996	Zhujia River	45.00%	55.00%
51	Yang Zhao et,al. 2013	1959-1996	Sanchuan River	30.00%	70.00%
52	Wei Liang et, al. 2014	1996-2006	Yan River	48.00%	52.00%
53	Wei Liang et, al. 2014	1984-2009	Beiluo River	14.00%	86.00%
54	Peilong Zheng et,al. 2015	1997-2010	Jinghe River	92.40%	7.60%
55	Wei Liang et, al. 2014	1996-2009	Jinghe River	35.00%	65.00%
56	Hongbo Zhang et,al. 2016	1980-1995	Jinghe River	67.10%	32.90%
57	Guangju Zhao et,al. 2013	1997-2006	Wei River	62.75%	37.25%
58	P Gao et, al. 2011	2002-2015	Louyugou Watershed	66.90%	33.10%
59	Xizhi Lv et,al. 2018	2000-2008	Middle Yellow River	81.10%	18.90%
60	Wei Liang et, al. 2014	1996-2009	Qingjian River	41.00%	59.00%
61	Ran Zhai et, al. 2017	2000-2010	Yangjiaping Watershed	66.36%	33.64%

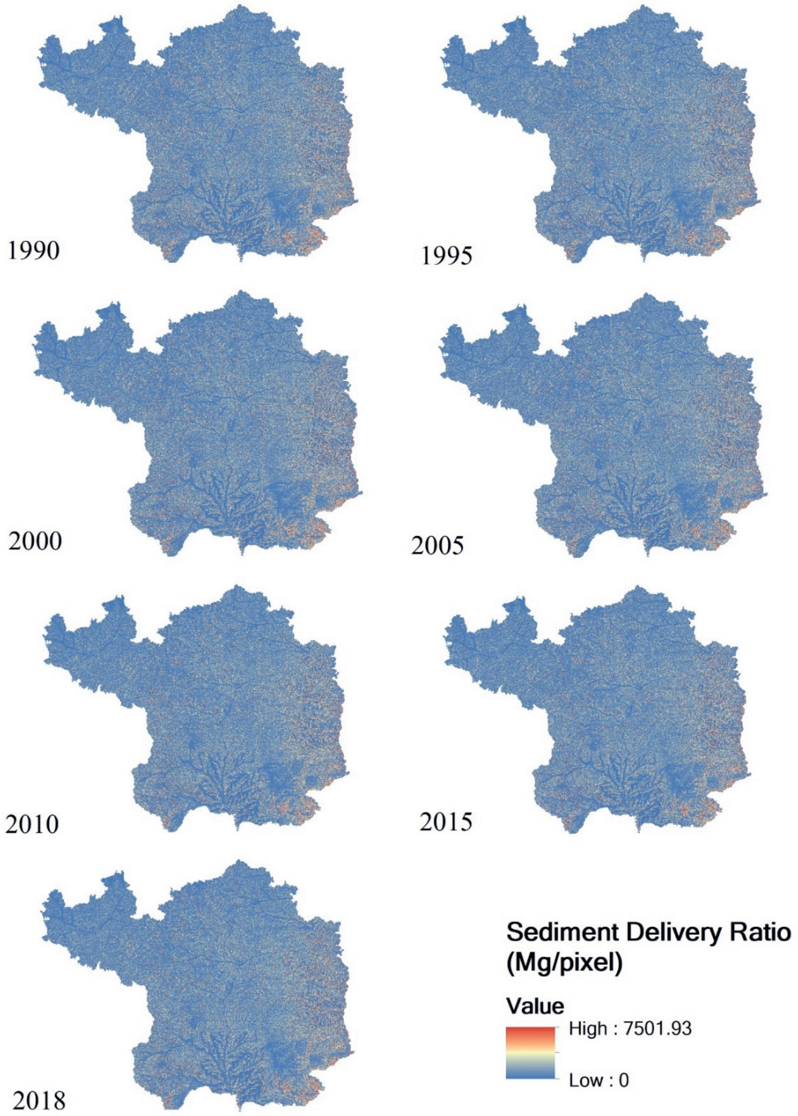
Appendix 3.1 Carbon storage map (Note: resolution of each pixel = 30m * 30m =900 m^2, same as following).



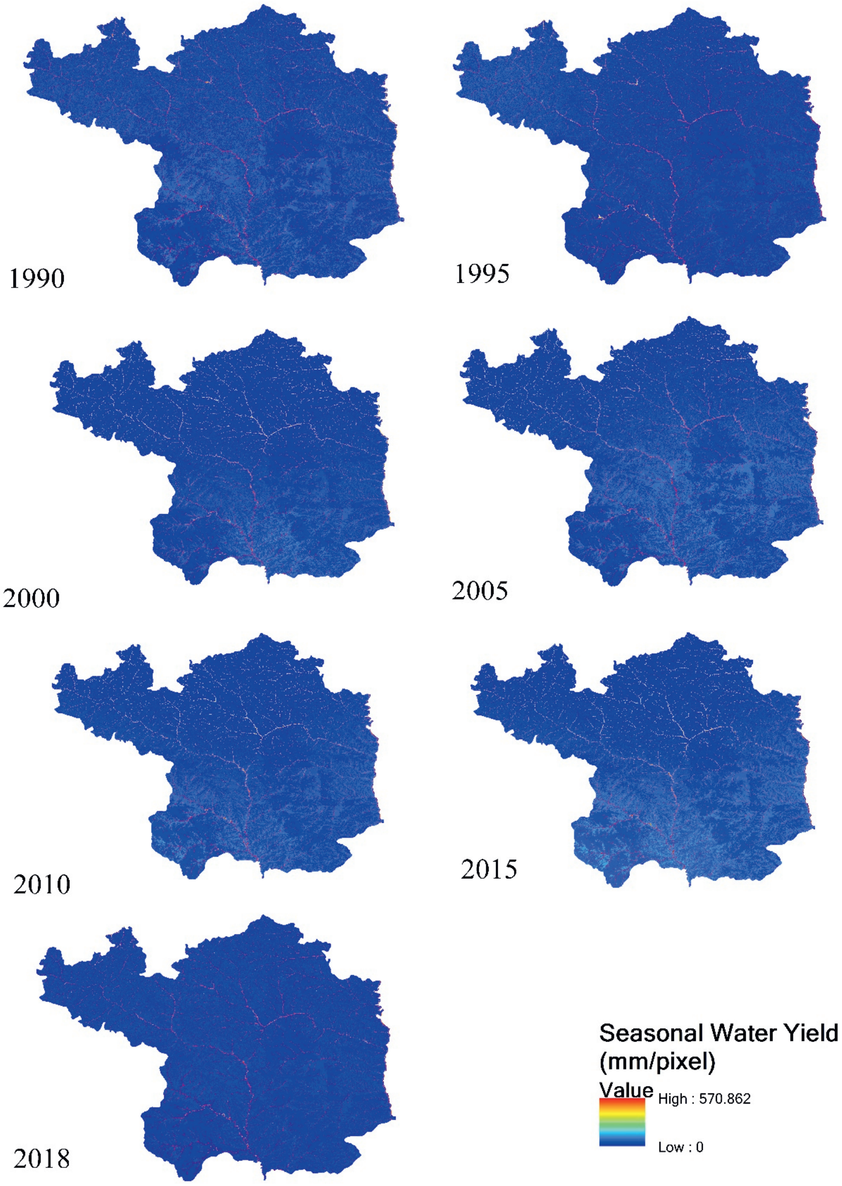
Appendix 3.2 Habitat quality map.



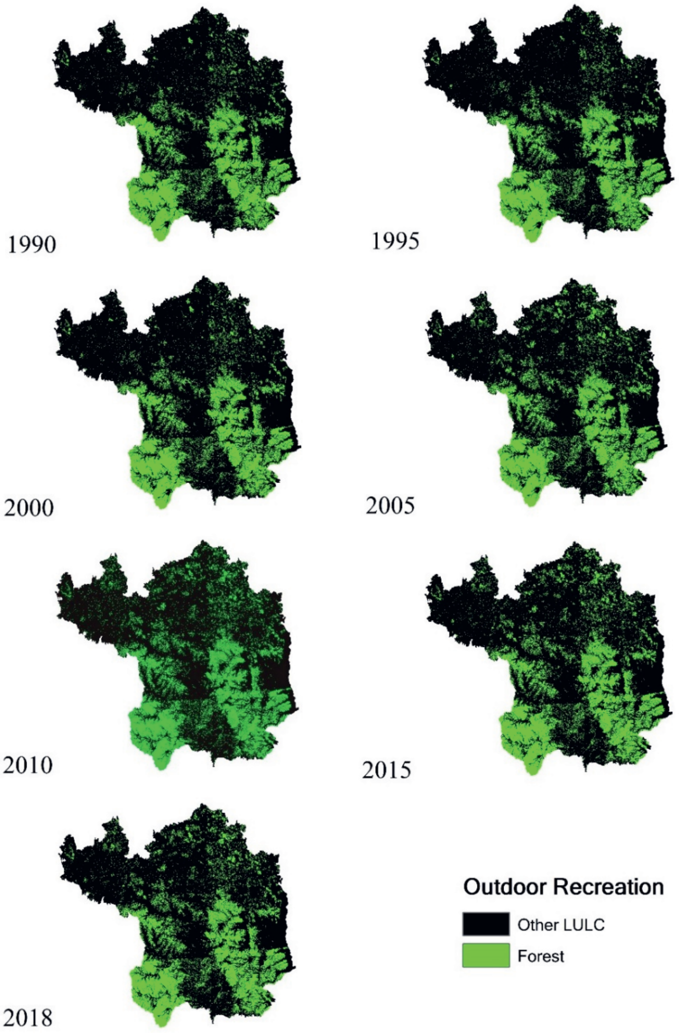
Appendix 3.3 Sediment delivery ratio map.



Appendix 3.4 Seasonal water yield map.



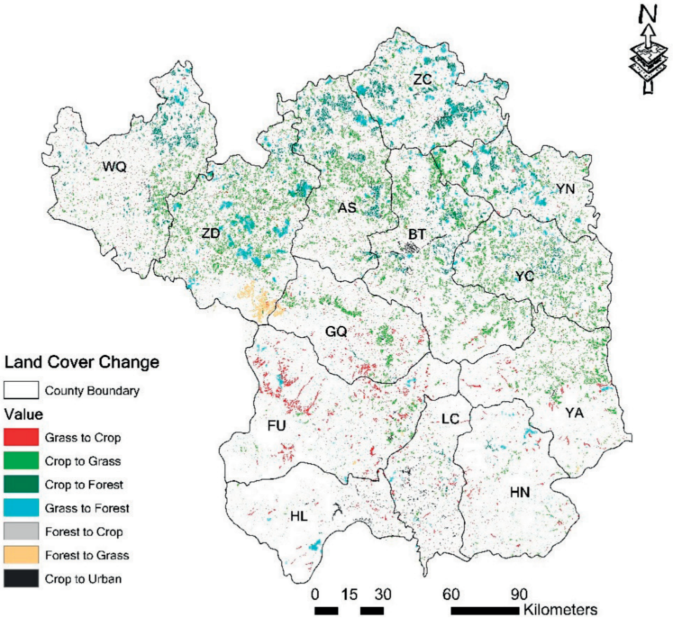
Appendix 3.5 Outdoor recreation map.



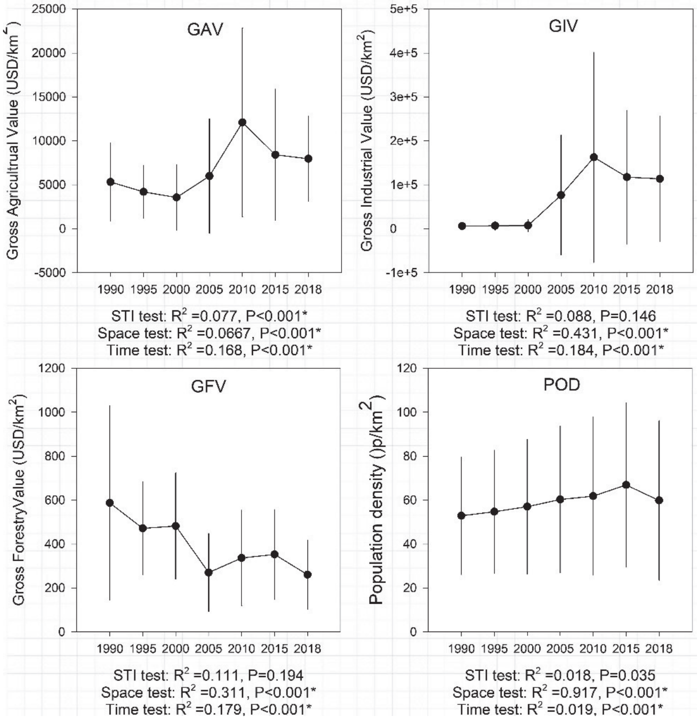
Appendix 3.6 Area of six land use types in Yan’an area for different years.

Year km^2	1990	1995	2000	2005	2010	2015	2018
Cropland	11488.21	11761.71	11771.17	10935.54	9502.78	9498.11	9356.89
Forest	9054.24	8659.35	9057.86	9790.82	9903.52	9899.23	9918.40
Grassland	16227.41	16304.86	15925.34	16013.34	17290.54	17291.81	17301.05
Waterbody	147.20	154.94	145.43	141.78	135.80	137.08	150.09
Urban	117.30	153.21	134.57	152.88	202.14	206.26	281.52
Bareland	2.64	2.93	2.64	2.63	2.22	4.52	31.29

Appendix 3.7 Land use change in the Yan'an area from 1990 to 2018.



Appendix 3.8 Change of economic factors and population density in Yan'an area.



Appendix 4.1 Calculation of TMV and NPV from 2000 to 2030.

Year	Project year	Discounted TMV	NPV (CBA)	Discount rate	IRR	B/C
2000						
2001	1	1,044,188,638	-520,408,823		N/A	0.77
2002	2	2,056,980,722	-1,025,170,047		N/A	0.77
2003	3	3,039,320,279	-1,514,754,164		N/A	0.77
2004	4	3,992,122,954	-1,989,617,518		N/A	0.77
2005	5	**4,916,276,857**	-2,450,202,729		N/A	0.77
2006	6	8,675,713,474	-33,869,037		-0.45%	1.00
2007	7	12,322,111,743	2,309,810,586		19.61%	1.16
2008	8	15,858,870,492	4,583,020,696		28.51%	1.27
2009	9	19,289,286,349	6,787,880,162		33.23%	1.36
2010	10	**22,616,556,821**	8,926,444,145		35.94%	1.43
2011	11	23,969,840,803	9,126,763,540		36.11%	1.41
2012	12	25,282,434,383	9,321,059,752		36.23%	1.40
2013	13	26,555,561,038	9,509,513,886		36.32%	1.39
2014	14	27,790,407,453	9,692,301,600		36.38%	1.38
2015	15	**28,988,124,636**	9,869,593,273		36.42%	1.37
2016	16	32,003,974,019	11,895,699,193		36.76%	1.43
2017	17	34,929,143,158	13,860,884,372		36.99%	1.49
2018	18	37,766,358,618	15,766,980,570		37.15%	1.54
2019	19	40,518,264,981	17,615,764,466		37.26%	1.58
2020	20	**43,187,427,311**	19,408,959,322		37.33%	1.62
2021	21	44,741,121,244			-0.45%	1.68
2022	22	46,248,098,871				1.73
2023	23	47,709,764,852				1.79
2024	24	49,127,481,613				1.85
2025	25	50,502,570,615				1.91
2026	26	51,836,313,585				1.88
2027	27	53,129,953,712				1.84
2028	28	54,384,696,802				1.59
2029	29	55,601,712,409				1.58
2030	30	**56,782,134,918**		3.10%		1.58

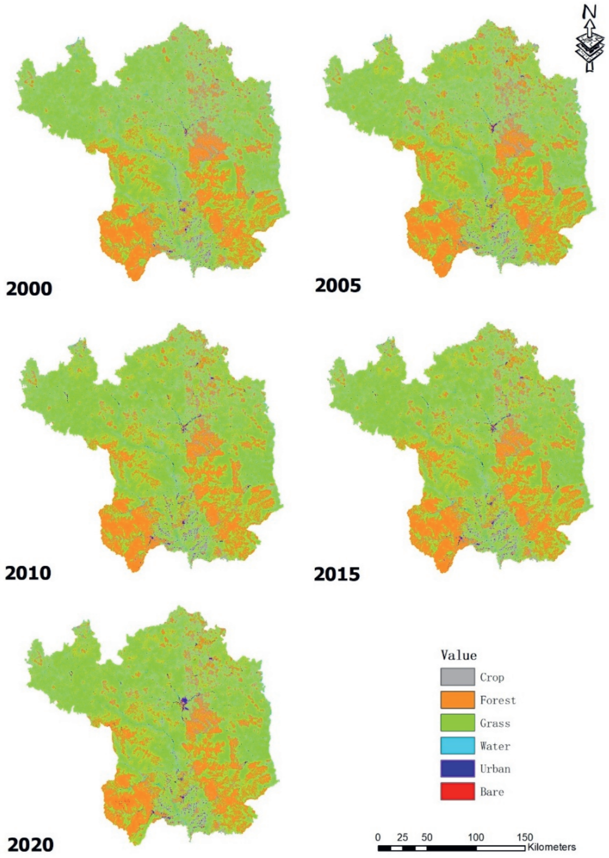
Appendix 4.2 Calculation of NPV of the 2020 NoGGP scenario.

	Project year	TMV	Benefit (RMB)	Cost	Discount rate	NPV
2000		**40,980,821,708**				
2001	1	42,593,921,691	1,613,099,982	-		1,564,597,461
2002	2	44,207,021,673	1,613,099,982	-		3,082,150,769
2003	3	45,820,121,655	1,613,099,982	-		4,554,074,444
2004	4	47,433,221,637	1,613,099,982	-		5,981,740,472
2005	5	49,046,321,620	1,613,099,982	-		7,366,479,587
2006	6	50,659,421,602	1,613,099,982	-		8,709,582,511
2007	7	52,272,521,584	1,613,099,982	-		10,012,301,157
2008	8	53,885,621,566	1,613,099,982	-		11,275,849,796
2009	9	55,498,721,549	1,613,099,982	-		12,501,406,186
2010	10	57,111,821,531	1,613,099,982	-		13,690,112,676
2011	11	58,724,921,513	1,613,099,982	-		14,843,077,263
2012	12	60,338,021,495	1,613,099,982	-		15,961,374,632
2013	13	61,951,121,478	1,613,099,982	-		17,046,047,152
2014	14	63,564,221,460	1,613,099,982	-		18,098,105,853
2015	15	65,177,321,442	1,613,099,982	-		19,118,531,363
2016	16	66,790,421,424	1,613,099,982	-		20,108,274,826
2017	17	68,403,521,407	1,613,099,982	-		21,068,258,786
2018	18	70,016,621,389	1,613,099,982	-		21,999,378,048
2019	19	71,629,721,371	1,613,099,982	-		22,902,500,515
2020	20	**73,242,821,353**	1,613,099,982	-	3.10%	**23,778,467,989**

Appendix 4.3 Land use area of different research years.

Unit: km^2	Crop	Forest	Grass	Water	Urban	Bare	Restored area
2000	11766.15	9025.65	15911.64	135.81	129.87	49.95	0.00
2005	10939.99	9794.80	16019.85	141.84	152.94	2.62	877.3677
2010	9506.64	9907.54	17297.56	135.85	202.22	2.21	2267.8227
2015	9501.94	9903.23	17298.80	137.13	206.34	4.51	2264.742
2020	9307.4607	9788.7789	17506.0656	161.271	238.32	35.3214	2357.5545
2020 NoGGP	15498.72	9130.05	11710.44	256.23	322.02	54.27	- 4096.8
2030	7639.83	10650.69	18105.21	151.29	376.38	50.58	3686.13

Appendix 4.4 Land use maps of research years.



Appendix 5.1 Change rate of different ecosystem services in 13 counties of Yan'an area from 2000 to 2020 (Source: Chen et al. 2020).

Location	GAP	FUP	LVP	TBP	CAS	SDR	SWY	HBQ	OR
Baota	-22.98%	2115.75%	-14.44%	-95.84%	7.47%	4.99%	-29.01%	6.30%	7.95%
Yanchang	29.47%	1790.58%	121.90%	-14.85%	13.60%	4.94%	-26.59%	10.09%	17.51%
Yanchuan	-63.13%	13524.73%	-15.08%	-75.37%	23.66%	6.21%	-11.57%	9.24%	47.87%
Zichang	-63.65%	8361.85%	-42.03%	-94.54%	43.93%	6.92%	-15.84%	10.92%	115.26%
Ansai	-35.55%	188.32%	20.12%	-94.73%	30.88%	7.67%	-43.52%	12.14%	91.80%
Zhidan	27.48%	1783.06%	12.07%	353.69%	12.03%	7.73%	-46.60%	8.27%	17.24%
Wuqi	15.96%	1793.83%	-0.14%	-99.56%	18.30%	7.72%	-26.76%	5.34%	83.94%
Ganquan	35.91%	213.99%	104.21%	-67.45%	0.49%	0.11%	-61.31%	1.69%	-0.75%
Fu	-29.68%	4962.46%	-47.75%	94.87%	-0.30%	-0.07%	-52.00%	-1.32%	0.43%
Luochuan	26.81%	825.05%	206.58%	-90.62%	1.07%	5.23%	-14.34%	-0.53%	2.39%
Yichuan	-40.70%	3680.59%	7.47%	-76.18%	1.01%	0.23%	-22.70%	3.14%	0.05%
Huanglong	44.81%	2166.23%	-34.47%	-98.37%	0.35%	0.00%	-30.95%	-0.16%	0.59%
Huangling	61.82%	1942.09%	5.62%	-95.28%	-0.37%	0.17%	-11.02%	-1.76%	-0.05%

Appendix 6.1 The 4 Returns framework (Dudley et al., 2021).

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English Summary

To address land degradation and ecological deterioration, a number of large-scale land restoration projects have been implemented worldwide. The Chinese Loess Plateau, as a (semi-) arid area experiencing severe soil erosion and land degradation, has been given a lot of attention in terms of land restoration policies by the national government. The implemented land restoration significantly altered land cover, transformed the delivery of ecosystem services and affected the livelihoods of local communities. The main objective of this thesis is to comprehensively understand the hydrological, bio-physical, economic and societal impacts of land restoration in the Chinese Loess Plateau. The thesis consists of six chapters.

In Chapter 1, first of all, the main research problems are identified, along with a summary of land restoration history in the Chinese Loess Plateau. This is followed by a DPSIR conceptual framework explaining the process of conducting an integrated landscape restoration impact assessment. After presenting the framework, the main research objectives and research questions are introduced; each research question corresponds to a specific theory and approach applied in the following chapters. In this thesis, a total of four sub-research questions are raised in terms of studying hydrological, bio-physical, economic and societal impacts of land restoration, which are answered in Chapter 2, 3, 4 and 5 respectively. At the end, the outline of this thesis book is presented.

In Chapter 2, impacts of land restoration and climate variability on streamflow are studied through a meta-analysis. The streamflow depth of the watershed case studies in the Loess Plateau shows a significant decreasing trend of -0.46mm/year over an assessment period ranging from 1959 until 2015, while no significant change was found in the precipitation data. Land restoration is recognized as having contributed 64% of the surface flow reduction whereas climate accounted for 36% of the impact. According to meta-regression, an increasing soil and water conservation area was negatively correlated to streamflow reduction. We conclude that in the Chinese Loess Plateau, streamflow shows a decreasing trend and land restoration is the major cause of this reduction, and impacts of soil and water conservation measures on streamflow change were following the order: total restoration area > terrace building > afforestation > grass planting > dam building.

In Chapter 3, land restoration impacts on the spatial and temporal dynamics of ecosystem services are determined by applying ecological models. Synergies were found between regulating and cultural services while both trade-offs and

synergies were determined among provisioning and regulating services. The process of ecosystem services components change by land restoration is discovered to start with the increase of regulating services at expense of provisioning services, followed by cultural services exceeding regulating services and occupying the main proportion of the total ecosystem service bundles. The most obvious change was observed in 2000, coinciding with the start of large-scale restoration activities. GGP implementation improved the majority of regulating and cultural services whereas it constrained timber production and local water yields.

In Chapter 4, a cost-benefit analysis of land restoration within the GGP is conducted based on the monetary value of ecosystem services through land use scenarios. We use the CLUE-S model to simulate land cover of Yan’an area in the Chinese Loess Plateau over the period 2000-2020 for a non-GGP scenario, and the monetary value of ecosystem services by using market prices, replacement cost and benefit transfer. From 2000 to 2020, the total monetary value of ecosystem services constantly increased from 45 billion RMB to 112 billion RMB, while the TMV of a hypothetical non-GGP is estimated to be 19.41 billion RMB lower in 2020 than that of the GGP scenario. Net present value of ecosystem services results illustrate that the introduction of the land restoration project enhanced local ecosystem services and augmented monetary benefits, although a lower monetary value return is estimated if land restoration continues to expand until 2030. The cost-benefit analysis results demonstrate that conducting a land restoration project is more beneficial compared to the non-restoration scenario.

In Chapter 5, stakeholders’ perception towards land restoration and its impacts on ecosystem services is investigated through a questionnaire survey. Using questionnaires administered in 2021, we investigated the perspectives of 150 stakeholders representing five stakeholder groups including farmers, governmental officers, citizens, tourism operators and forestry practitioners in the Yan’an area of the Chinese Loess Plateau. A reduction of grain production, livestock production and water yield were determined by the stakeholders, while most of the stakeholders observed an increase of regulating and cultural services as a result land restoration. The majority of the stakeholders had a positive attitude towards land restoration policy, although its negative impacts on farmers’ income was stated as a potential reason for some farmers to recultivate the restored forest. We recommend policy makers to adjust the compensation standards and durations for farmers and increase the diversity of restoration tree species. Engagement of stakeholders through a participatory process is suggested for future land restoration policy making.

Chapter 6 reviews the findings from Chapter 2 to 5 and discusses the scientific significance of this study by contrasting findings to previous publications in terms of methodological innovations and expansion of the research scope in the Loess Plateau. Additionally, constraints in the methods and limitations of this study are discussed. This is followed by a proposed integrated landscape restoration appraisal framework for both ex-ante and ex-post restoration impact assessments. In the end, the implications of this thesis for environmental management, land restoration policy and society are provided.

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Hao Chen
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About the Author

Hao Chen was born on October 26, 1992, in Xi'an, China. He spent his childhood and teenager age in this ancient city for 18 years. From 2010, he studied Soil and Water Conservation & Desertification Combating during his Bachelor in Southeast Forestry University in Kunming, China. His Netherlands journey started in 2014 as a Master student in International Land and Water Management (MIL) in Wageningen University. In 2017, he joined the Soil Physics and Land Management group (SLM) of Wageningen University as a PhD candidate. His PhD project was undertaken in collaboration with the Commonland Foundation in the Netherlands and the Institute of Soil and Water Conservation (ISWC) in China. During his PhD, he studied the impacts of land restoration on the Chinese Loess Plateau.

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List of Publications

Chen, H., Fleskens, L., Schild, J., Moolenaar, S., Wang, F., & Ritsema, C. (2021). Cost-benefit analysis of largescale land restoration in the Chinese Loess Plateau: evaluating the monetary value of ecosystem services. *Ecological Economics.* Under review.

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Chen, H., Fleskens, L., Schild, J., Moolenaar, S., Wang, F., & Ritsema, C. (2021). Impacts of large-scale landscape restoration on spatio-temporal dynamics of ecosystem services in the Chinese Loess Plateau. *Landscape Ecology*. https://doi.org/10.1007/s10980-021-01346-z

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- Conflicting demands in European Forests, PE&RC (2018)
- Geo statistics, PERC and WIMEK (2019)
- Integrated land use systems, Freiburg University (2019)
- Career perspectives, Wageningen Graduate Schools (2021)

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- Teaching assistant in the BSc course 'Climate change and adaptation' (2020)
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- Guest lecturer in the MSc course 'Introduction to land degradation and remediation' (2020)

Oral Presentations

- *Analysis of synergistic land restoration impacts on the Chinese Loess Plateau.* Ecosystem Services Partnership, 11-15 December 2017, Shenzhen, China
- *Using ecosystem service bundles to evaluate spatial and temporal impacts of largescale landscape restoration on ecosystem services on the Chinese Loess Plateau.* Europe Geoscience Union, 19-30 April 2021, Online

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