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Research

National environmental programs and local social-ecological system change in dryland China: implications for environmental governance

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ABSTRACT. Interdependence of ecological and social systems is widely acknowledged, but consideration of how local communities are influenced by processes at other sectors or scales is often omitted. This research addresses this gap by examining the implementation of China's national environmental programs (NEPs) to combat desertification. We investigate (a) the changes in local social-ecological systems and the role of the NEPs therein since the year 2000; (b) how the changes have affected local livelihoods and behaviors and attitudes toward the NEPs and the land; and (c) the role of other drivers in the changes and their implications. Interviews and surveys were conducted with scientists, grassroots implementers, and local farmers and herders. Secondary socioeconomic data were used to understand broader changes and drivers. Our results indicate that the NEPs generated both positive and negative biophysical and socioeconomic changes, and that they were both supported and disrupted by institutions at other sectors and scales. Although farmers and herders appreciated an improved environment and living standards, they suffered from other changes, such as reduced arable land area, rising costs of living and production, precarious markets, and extreme weather events. Absence of social security and limited social capital made farmers and herders unable to engage in long-term practices that support land conservation and their well-being. The findings highlight the need to foster systemic resilience in local communities through the provision of social security and social capital building to navigate the changing world.

Key Words: *institutional interplay; land stewardship; social capital; social-ecological-technological-regimes (SETRs); social security; systemic resilience*

INTRODUCTION

Anthropogenic changes to land, water, air, and other components of our life-support system have triggered environmental crises and demonstrated a failure to govern social and economic activities sustainably (Steffen et al. 2015). There have been increasing inquiries about how institutional arrangements could effectively govern both human affairs and the environment (e.g., Mitchell 2005, Montgomery 2013, Söderström and Kern 2017, Johnson 2019), particularly given challenges associated with the complexity of social-ecological systems (SESs). Like the boundaries between individual ecosystems, those separating specific institutions are difficult to precisely identify due to interdependencies and overlaps in their spatial domains of functioning (Young 2003). This means that identifying changes that can be attributed to specific institutional arrangements is methodologically challenging (Young 2002). Environmental policies are also rarely formulated to manage complexity and commonly give little consideration to governance arrangements of other sectors (e.g., Oberthür and Gehring 2011, Ren and Shou 2013, Durant et al. 2017). Moreover, analyses of environmental policies have tended to focus on biophysical and socioeconomic criteria of specific scales, often neglecting the influences of institutional arrangements emanating from other sectors or scales (Brondizio et al. 2009).

The rising density of institutions increases the likelihood of their interaction or interplay. Institutions interact when there are functional interdependencies stemming from inherent connections, or strategic links formed through political design and management (Young 2003). For example, before the European Union's Water Framework Directive (WFD) established the river basin management in 2000 to address institutional interplay between water management and land-use policy and planning, Moss (2004) noted that water managers had long warned of the substantial impact of urban development and intensive agricultural production over which they had very limited control. Fifteen years after its adoption, Voulvoulis et al. (2017) highlighted delays in delivering the WFD objectives due to interaction of the WFD with pre-existing institutions. The systemic thinking the WFD called for did not materialize because member states continued water management practices that regulated individual pollutants and neglected complexity (Voulvoulis et al. 2017)

Institutions interact horizontally and vertically, and this interplay can be more or less symmetric (Elsässer et al. 2022). The resultant consequences can be synergistic or disruptive. For example, Finland and Sweden adopted different national strategies for adaptation to climate change, which also affected their competence, capacity, and compatibility to incorporate and implement climate goals set at the EU level (Glaas and Juhola 2013). In the global south, international and national regulations can significantly affect local institutions. Failing to respect local institutional legacies, including informal institutions, can adversely affect the implementation of new policies or even cause them to fail (Lukat et al. 2022). From a historical perspective, North (1990) suggests that in contrast to formal institutions that often resist changes, informal institutions such as behaviors, habits, and social norms, can be more easily influenced and harnessed to drive the transformation of formal institutions.

Different actors influence ecosystems differently. In the seafood industry, over a dozen transnational seafood corporations that Österblom et al. (2015) refer to as "keystone actors" could trigger

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cascading effects within the entire seafood industry, fostering a critical transition toward enhanced management of marine living resources and ecosystems, despite their small numbers. Galaz et al. (2018) similarly found "keystone actors" among international financial actors, whose activities in globally significant forest biomes could either bolster or undermine the stability of Earth's climate system. Unlike the keystone actors, "dominant actors," analogous to dominant species in ecosystems, often wield significant influence in shaping ecosystems due to their abundance. In land management, the "dominant actors" are smallholder farmers whose lives depend on land. Their absolute number is so large that even simple interventions they adopt can have regional impacts on land degradation (Cherlet et al. 2018). However, their behaviors and outcomes of their actions are nested in both horizontal and vertical institutional arrangements: they need to navigate multiple levels of governance, alongside internal and external drivers of change (Berkes 2006).

Our world is a product of choices and actions of individuals and collectives of all levels, characterized by a complex web of interconnected drivers, dynamic structures, emergent phenomena, and unintended consequences (Bai et al. 2016). Global environmental changes raise the question of how humanity can sustain a liveable biosphere and take care of those already vulnerable in the near-term, as well as preventing further unintended consequences, such as worsening inequality and exacerbated damage to natural resources (Folke et al. 2021). Dramatic changes to the planet have exposed humans and ecosystems to increasing uncertainties and complexities and put human security and resilience in the spotlight (O'Brien and Barnett 2013). Folke (2016) cautions that if sustainability is to be taken seriously, resilience of SESs and its biosphere connections should be a priority.

Despite growing recognition of the need to build resilience in communities to reduce uncertainties and surprises while navigating the complex and dynamic environment (Olsson et al. 2014), efforts have focused on overcoming sudden events and on agency building (Berkes and Ross 2013, Koliou et al. 2018). However, changes such as those arising from floods and droughts, or fluctuations in commodity and energy markets, are beyond individual agency, and addressing the underlying reasons demands long-term efforts. Social security "as an effective automatic stabilizer in times of crisis, contributes to mitigating the economic and social impacts of economic downturns, to enhancing resilience against future shocks and achieving faster recovery towards inclusive growth and development" (International Labour Organization, accessed September 2023). This brand of resilience is an attribute fostered at the individual level but in a systemic way, so that it manifests across local, regional, and national levels. Interest in the role of social protection for local communities in adapting to the impacts of or mitigating climate change has dramatically increased (e.g., Johnson and Krishnamurthy 2010, Davies et al. 2013, O'Brien and Barnett 2013, Weldegebriel and Prowse 2013, Carter and Janzen 2018, Tenzing 2020). However, systemic resilience in tackling land degradation has so far received limited attention.

Dryland degradation has profoundly affected the livelihoods of over a billion people, predominantly in developing countries, where most livelihoods directly depend on the land (Cherlet et al. 2018). Communities in these areas also face other biophysical and socioeconomic challenges such as malnutrition and extended droughts, making it both urgent and challenging to build resilience (United Nations Convention to Combat Desertification [UNCCD] 2022). Addressing land degradation is pivotal for ecosystem restoration, climate change adaptation, biodiversity conservation, and achieving food security (Montanarella et al. 2018). Desertification and land degradation extend beyond natural resource management to human well-being, environmental management, and socioeconomic development, putting related institutional arrangements in a very testing position.

China is significantly affected by desertification and land degradation challenges, but also one of the most proactive nations in addressing them (Kong et al. 2021). The implementation of the National Environmental Programs (NEPs) began in the northwestern drylands in China over 20 yrs ago. Administered by several national departments with the central government's financial support, NEP implementation was at first supported at all levels and achieved environmental improvement (Chinese Academy of Sciences [CAS]-National Forestry and Grassland Administration [NFGA] 2018, NFGA 2020). However, difficulties in restoration of local ecosystems have increasingly been reported (Yuan et al. 2015, Ma et al. 2022); communities have been impoverished in some NEP locations (Wang et al. 2023); and farmers and herders have returned to cultivate land that was restored under the NEPs (Wei et al. 2020). These challenges question the sustainability of environmental governance under the NEPs, and how to safeguard both land and people under changing circumstances.

Although China has kept adjusting its environmental policies based on feedback and assessments, the mechanisms NEPs employed remain widely endorsed by policy makers and scientists (Lu et al. 2020; https://www.nfga.cn, accessed July 2023). Our case study of China in this paper offers a bottom-up perspective on how local biophysical and socioeconomic subsystems interact in the presence of the NEPs and other institutional arrangements, and what are the consequences for people and land on the ground. Specifically, we seek to answer the following questions:

1. What kind of changes have happened in local SESs and what is the role of the NEPs therein?
2. How have these changes affected local livelihoods and behaviors and attitudes toward the NEPs and the land?
3. What role have other drivers played in the changes and what are their implications?

An inductive approach is taken to identify patterns and themes in local SESs (Thomas 2006). We first examine the changes in local ecological and social systems in light of the views of scientists, grassroots implementers, as well as farmers and herders. Next, we explore farmers' and herders' attitudes toward land, and their concerns and needs. We then analyze secondary data from the National Statistical Yearbooks to understand the root cause (s) and driver(s) of their needs and concerns. We conclude by demonstrating through the analytical framework of social-ecological-technological-regimes (SETRs), how essential institutional arrangements can contribute to systemic resilience building and enable people to adeptly navigate changes and safeguard land in a changing and complex world.

Table 1. Control area and total investment of major national environmental programs to combat desertification and land degradation during 2000–2010 (adapted from Kong et al. 2021).

National program	Department (s) in charge	Control measures	Control area (km²)	Total investment (CNY: billion)
Three-North Shelterbelt Project (TNSP)	National Forestry and Grassland Administration (NFGA)	Afforestation/reforestation Enclosing hills/sand lands for afforestation/ reforestation Arial seeding for afforestation	68,700	23.677
Grain for Green Project (GGP)	NFGA	Enclosing hills/sand lands for afforestation/ reforestation Reforestation/afforestation on returned farmland Grass reseeding on returned farmland Reforestation/afforestation on barren and wasteland	244,672	207.904
Beijing-Tianjin Sandstorm Source Control Project (BTSSCP)	NFGA	Enclosing hills/sand lands for afforestation/ reforestation Enclosing grassland for natural restoration Small watershed management measures, mainly including afforestation and grass reseeding	165,480.96	31.403
Natural Forest Protection Project (NFPP)	NFGA	Enclosing hills/sand lands for afforestation/ reforestation Reforestation/ afforestation on barren and wasteland	295,186	88.676
Pastureland for Grassland Project (PGP)	Ministry of Agriculture and Rural Affairs (MOA)	Enclosing grassland for natural restoration	517,350	18.52
Three-Rivers Source Protection Project (TRSPP)	NFGA, Ministry of Water Resources (MWR)	Rangeland enclosure and grazing prohibition/ break/ rotation, wetland conservation, reforestation, growing grass	356,600	7.507
Total (km²)			1,647,988.96	377.687

TNSP is now in Phase 6 spanning from 2021–2030 and expected to end in 2050. The scope of GGP stopped expanding after the second phase until 2019. Present mechanisms focus on consolidation and conservation of existing achievements. BTSSCP terminated in 2022 after two phases and 20 yrs of implementation. There were two phases of NFPP from 2000–2010 and 2011–2020, respectively. PGP began to be administered in 2003 and closed in 2020. TRSPP was initiated in 2005 and its second phase ended in 2020. Specific measures and mechanisms of all the NEPs from the second phase were adjusted based on experience and feedback from the first phases (https://www.gov.cn/zhengce/, accessed Sept 2023).

METHODOLOGY

National environmental programs (NEPs) for combating desertification in China

Since the start of 21st century, China's government has taken a leading role in research, investment, administration, and implementation of the NEPs (Table 1) (Kong et al. 2021). In contrast to earlier approaches, the design and implementation of the NEPs was undertaken against the backdrop of prosperous economic development (Lu et al. 2020). The ability of the central government to provide generous compensation to local communities and governments for retired sloping and pasture land, and to subsidize tree planting and grass reseeding, initially garnered widespread support (Xu et al. 2006). Several assessments found that these programmes have reversed land degradation and improved dryland environmental quality, albeit with increased pressure on local water resources (Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences [IGSNRR-CAS] 2014, Lyu et al. 2020, Li et al. 2021). The compensation mechanisms later were formally institutionalized as part of environmental regulations and rules in 2020 (National Development and Reform Commission [NDRC] 2020).

The scale of the NEPs is enormous. By 2015, approximately 500 million people had directly engaged in these programs, and over 40 million households or 150 million farmers and herders were involved by 2019 in the "Grain for Green" project (GGP) alone (Lu et al. 2020). The NEPs and their implementation have brought various actors together to collaborate on reversing and rehabilitating the degraded land. They provide a unique interface to observe people's interactions and responses, and to investigate the underlying reasons behind them. It is also a good interface for examining how communities respond to external changes and drivers.

The social-ecological-technological-regimes (SETRs) framework

Social-ecological-technological-regimes are complex adaptive systems in which people and nature are inextricably linked (Berkes et al. 2000). Based on the concept, frameworks have been developed for the study of the intertwined human and natural systems, among which those of Berkes et al. (2000), Anderies et al. (2004), and Ostrom (2007, 2009) are very representative (Colding and Barthel 2019).

Berkes and colleagues' (2000) SESs framework stresses a systems approach in which resources cannot be treated as discrete entities and isolated from the rest of the ecosystem and social system. It has a people-oriented approach that focuses on institutions and property rights, emphasizing people in social, political, and economic organizations, with institutions as the mediating factor governing the relationship between a social group and its life-support ecosystems (Berkes et al. 2000). The framework has four sets of elements (ecosystem, people and technology, local knowledge, and property rights institutions) and focuses on key interactions, practices, and social mechanisms that result in sustainable outcomes. Although descriptive, it defines the social system as consisting of people and technology, noting that the type of technology available to potential users for exploiting resources can have significant impacts on resources and ecosystems in different ways (Berkes et al. 2000).

In the SESs framework developed by Anderies et al. (2004), institutional configurations are put in the center to observe how they affect interactions among resources, resource users, public infrastructure providers, and public infrastructure. The framework acknowledges that most components of SESs, such as ecological systems and social networks, are self-organizing, only rules of interaction are designed, and that uncertainty is high as experimentation is difficult or impossible. The framework proposes the concept of robustness to better understand how SESs deal with disruptions. Two types of external disturbances are introduced into the framework, one is the biophysical disruptions such as climate change, the other includes socioeconomic changes such as economic and political changes, to examine how institutional arrangements affect the robustness of SESs (Anderies et al. 2004).

Ostrom (2007) suggested a multilevel, nested framework for analyzing outcomes arising from SESs, emphasizing relationships of complex SESs at different spatial and temporal scales. Her framework considers that all resources are embedded in complex SESs, composed of multiple subsystems at multiple levels. The first-level core subsystems are resource systems, resource units, governance systems, and users. Each core subsystem is made up of multiple second-level variables, which are further composed of deeper-level variables; they are relatively separable but interact to produce outcomes at the SES level, which in turn feedback to affect these subsystems and their components, as well other larger or smaller SESs (Ostrom 2009). This framework takes into consideration the complexities and increasing connectivity and functional interdependence of the components of SESs at different levels and across them.

The social-ecological-technological systems (SETSs) framework was developed for application in urban areas (McPhearson et al. 2022). Interactions between humans and nature in cities are intense and complicated, making technological factors stand out as a dimension that enhances the complexities when addressing issues such as multi-functionality, systemic valuation, scale mismatch of ecosystem services, and inequity and injustice in cities (McPhearson et al. 2015, Keeler et al. 2019, Matsler et al. 2021). The SETSs framework acknowledges the interactions and interdependencies among social-cultural-economic-governance systems (social), climate-biophysical-ecological systems (ecological), and technological-engineered-infrastructural systems (McPhearson et al. 2022). With ties to different sectors of urban planning and overall governance, the SETSs framework provides opportunities for further mainstreaming nature-based solutions in urban development.

These SESs frameworks recognize the interlinkages between ecological and socioeconomic subsystems and the complexities therein, providing the theoretical and analytical foundation when environmental issues are to be addressed. But their foci differ. Besides, they were developed under different contexts, and the data and understanding these resource-use related frameworks built on have already evolved. For example, traditional ecological concepts such as regime and resilience have been increasingly applied in the framework of SESs (e.g., Folke 2016, Biggs et al. 2018). With the growing recognition of adaptive governance, new concerns such as human security (O'Brian and Barnett 2013) and planetary boundaries (Folke et al. 2021) have entered studies of global environmental change. Although they acknowledge cross-scale interactions, no scale(s) were explicitly defined in these frameworks.

Building on this scholarship, we develop a SETRs framework to guide analysis and discussion in this study (Fig. 1). The framework acknowledges the multiple levels and embeddedness of SESs (Ostrom 2007), how exogenous drivers (such as climate change) and endogenous changes (such as institutions) would affect the SESs (Anderies et al. 2004), and recognizes that technology can not only influence the way people use land but also how they safeguard it (Berkes et al. 2000, McPhearson et al. 2022). It focuses on local SESs as land use and efforts to address land degradation are embedded in local SESs (Cherlet et al. 2018). The SETRs framework is composed of biophysical, socioeconomic, and technological regimes, with the latter two nesting within the boundaries of the biophysical regime (Folke et al. 2021), and the technological regime (the outer colored circle around the socioeconomic regime) being an indispensable part of sustainable land management (SLM) (World Overview of Conservation Approaches and Technologies [WOCAT] 2016), controlling development in the socioeconomic regime. Institutions of various scales and levels are organizing activities and operating in the socioeconomic regime. For local farmers and herders, they are affected not only by land they depend on, the NEPs implemented on the land, and institutional arrangements from other sectors and scales, but also drivers from the technological and biophysical regimes. While focusing on the local level, the SETRs framework helps highlight interactions across scales.

Fig. 1. The framework of social-ecological-technological-regimes (SETRs) of this study.

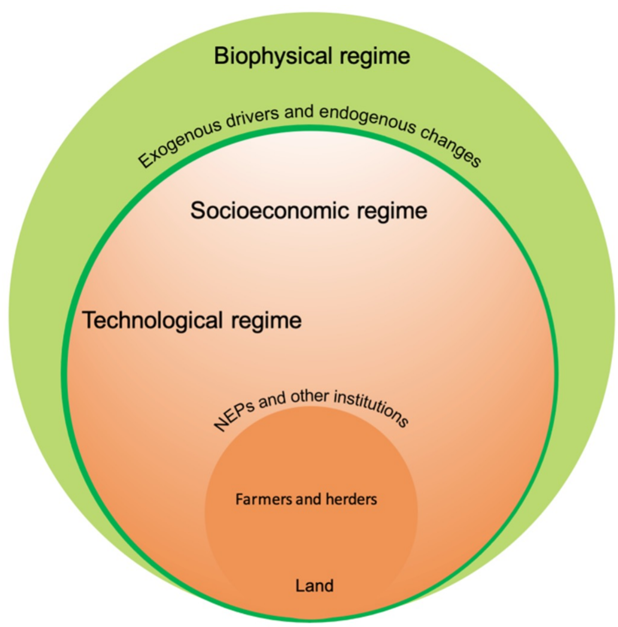


Table 2. Main biophysical and socioeconomic characteristics of the cases.

Cases	Climate zone	Annual average precipitation (mm)	Dominant ecosystem type	Dominant human activity	Specific land degradation issue	Main reasons behind land degradation	Main measures under the NEPs
DK	Arid, Temperate	142	Desert	Irrigated agriculture	Desertification	Intensive agriculture activities, overexploitation of ground water	Building farmland shelterbelts, wasteland reforestation, compensations to affected households
OR	Semi-arid, Temperate	360	Grassland	Irrigated agriculture, grazing	Desertification	Expansion of arable land, overexploitation of ground water, overgrazing, mining	Wasteland reforestation, seasonal grazing, compensations to affected households
AS	Semi-arid, Warm temperate	505	Forest-grassland	Rain-fed agriculture	Soil and water loss	Deforestation, sloping land cultivation, extreme rainfalls, fragile soil structure, climate change	Retiring sloping lands, wasteland reforestation, grazing prohibited, compensations to affected households

Moreover, the concept of regime is adopted instead of subsystem, emphasizing a spectrum of conditions across which a system may fluctuate while retaining a similar structure and function (Biggs et al. 2012), aligning with the concept of resilience this study is dealing with. The concept of regime also facilitates regime shift analysis, enabling dynamic explorations of drivers, interactions, impacts, and changes (Biggs et al. 2018).

Study area

Based on information from the Chinese Desert and Grassland Ecosystem Research Station Alliance (http://dga.ib.cas.cn, accessed several times since March 2020), Dengkou Desert Ecosystem Research Station (DK), Ordos Grassland Ecosystem Research Station (OR), and Ansai Agroecosystem Research Station (AS) and their surrounding communities were selected as study cases. In this paper, they are referred to as DK, OR, and AS, respectively (Table 2). The stations are located in northwestern China and are responsible for monitoring and assessing local ecosystems to inform policy making on desertification and land degradation (Fig. 2).

Before NEP implementation, DK experienced severe desertification and, in the 1980s, was designated as a target for national desertification control and management (source: https://slzx.caf.ac.cn/, accessed several times since March 2020). In OR, arable land expansion, overuse of groundwater, overgrazing, and unregulated mining transformed pasture land into sandy land by the early 1990s (source: http://esd.cern.ac.cn/, accessed several times since March 2020). Ansai Agroecosystem Research Station lies in ecologically fragile loess terrain where the fine soil is extremely susceptible to erosion. Deforestation, slope cultivation, irregular precipitation, and climate change exacerbated soil and water losses (source: http://dga.ib.cas.cn/). The NEPs were developed to tackle desertification and land degradation and have been implemented in these three areas since the year 2000 (Kong et al. 2021).

Methods

Primary data collection

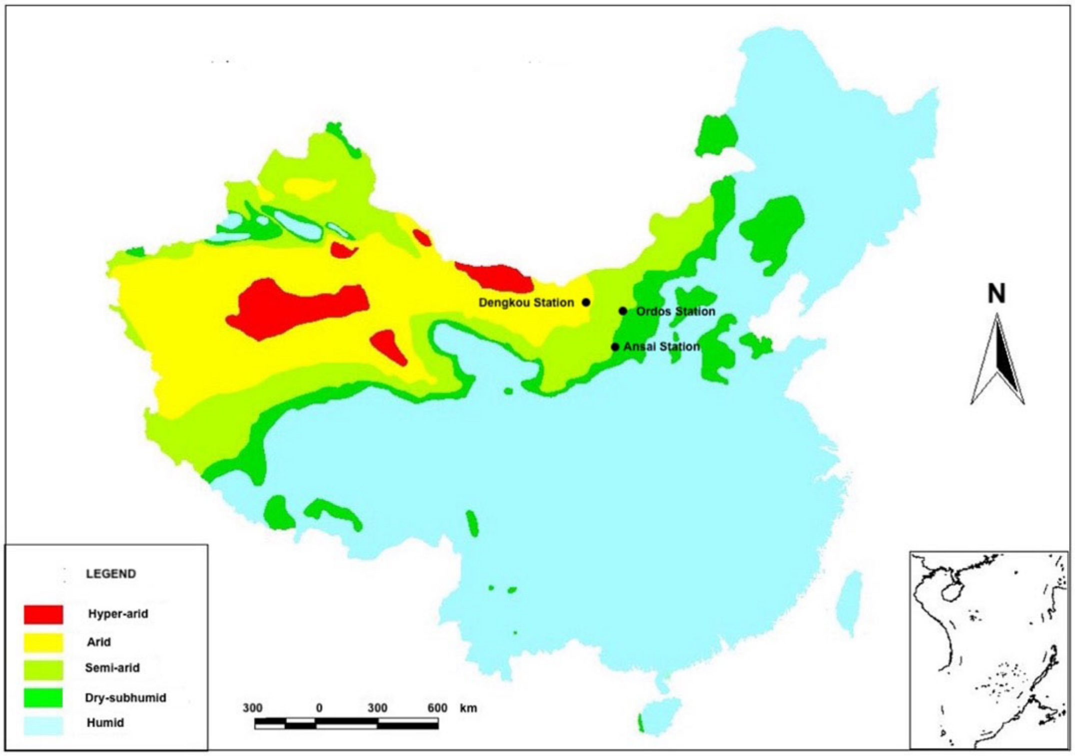
Fieldwork started in September 2021. Ethical approval was granted from the lead author's institution before fieldwork began. A questionnaire survey (Append. 1) was conducted with local farmers and herders who lived around the research stations and who had witnessed or were involved in NEP implementation. We adopted convenience sampling as September was part of the harvest season, and farmers were either at home or in their fields. To improve external validity, reduce possible bias due to the sampling strategy, and ensure diversity within our sample, we explained our sampling criteria to local contacts first, and made adjustments to participant recruitment when necessary, based on information they provided about the local communities. After participants' consent was obtained, surveys were conducted face-to-face in Chinese. Face-to-face engagement also facilitated open-ended conversations that often went beyond the survey questions. Analytical memos were made to record these conversations and other observations.

Like other rural areas in China, the villages had substantially reduced populations (Li 2015), with some only half or one-third occupied. Farmers living in towns and cities cannot change their status in China's Household Registration System: their records remain in the villages, so the local official population statistics often overstate the actual remaining population. In DK, six villages were visited, and 66 questionnaires were completed; in OR, 57 questionnaires from 11 villages; and in AS, 64 questionnaires from 15 villages, totalling 187 valid questionnaires (Append. 2).

Interviews were conducted with scientists at the research stations and with grassroots implementers of the NEPs. Consent was sought and obtained before the interviews. The face-to-face interviews were typically conducted in the interviewees' offices, and audio recordings were made with the explicit consent of the participants. If the participant felt uncomfortable at any point, note taking replaced recording. In total, 22 scientists and 14 grassroots implementers were interviewed (Append. 2). Three interviews were conducted using videoconferencing through WeChat (a Chinese version of WhatsApp), and four others were by email due to Covid-19 restrictions at the time of data collection.

An adapted snowball sampling approach was used for the interviews. We studied the research station webpages and discussed potential interview participants with local contacts. This kind of communication was maintained throughout the recruitment process, enabling us to recruit a diversity of scientists in terms of research field, age, and gender. Recruiting local grassroots implementers based on referrals by the stations turned out to be very fruitful. Rapport was built before interviews took place. The stations have been established for more than 30 yrs, and the interactions between the scientists, local authorities, and agencies were frequent. Their relationships are an important local

Fig. 2. Location of the research stations 1, 2 (adapted from Ci and Wu 1997).



social asset, and introductions allowed us to engage with the implementers as well as other members, such as agency heads. Permission from agency heads was essential for our interviews with their subordinates.

Secondary data

Secondary data over the period 2000–2021 (when the NEPs were implemented) were extracted from the China Annual Statistical Yearbooks 2001–2022. In light of the survey responses and conversations with the farmers and herders, five key products for agricultural production were identified: fertilizers, manual agricultural machinery, semi-automatic agricultural machinery, automatic agricultural machinery, and supportive agricultural production materials such as pesticides and mulch films. Data from the producer price index (PPI) for these products were extracted for the period 2002–2021. Corn was selected as a locally important crop, and data about its yields per hectare over the same period were extracted. Commodity retail price index (RPI) information was extracted for clothes, electricity, cooking oil, grains (for food, mainly flour, rice, and potatoes), construction materials and hardware for the period 2000–2021 (http://www.stats.gov.cn/sj/ndsj/, accessed several times since April 2023).

Coding and statistical analysis

Analysis began in parallel with primary data collection. Observations were noted as analytical memos each day (Saldaña 2016). For instance, the "policy" category emerged in conversations during surveys when participants often complained about policy changes or the influence of policy uncertainty on their agricultural activities. From the recurrence of "technical support" and "employment opportunities," the theme of "social capital" emerged. Other themes such as "institutions," "natural capital," and "change," manifested in similar ways.

Data from survey questionnaires were digitized and prepared for coding and descriptive statistical analysis. Recorded interviews were first transcribed using "Dictate" in Microsoft Word 365, followed by manual proofreading of all the transcripts.

NVivo 1.7.1 was used to code the original Chinese conversations and answers. Categories in English were created in the process. Next, key sentences and details related to specific questions were identified and translated into English. All answers to the same question were grouped and summarized to draw out patterns and categories. The last step was to zoom out and review, regrouping patterns and categories when necessary, or creating new ones under the overall interview topics. Holistic coding began simultaneously throughout the proofreading and coding processes, with recurring patterns and similar categories being highlighted. The thematic analysis was thus based on findings from these three coding approaches as well as referring to patterns and themes in the analytical memos.

The price index of each item in a specific year is recorded based on the assumption that the index in the preceding year is 100 (http://www.stats.gov.cn/sj/zbjs/202302/t20230202_1897106.html). The indices were normalized against a base of 100 for the year 2000. Descriptive statistical analysis was conducted using SPSS (version 28.0.1.1).

Table 3. Perspectives of scientists and grassroots implementers on local changes after NEP implementation.

	Positive changes	Negative changes
Biophysical changes	Increased vegetation coverage Reduced frequency and intensity of sandstorms Less mobile sand dunes Less soil and water loss Improved air quality More precipitation	Groundwater depletion due to expansion of irrigated farmland Maturing and dying trees, putting the monocultured forests and their ecological functions and services in danger Frequent occurrence of extreme weather events, such as droughts and heatwaves
Socioeconomic changes	Improved crop yields More fuelwood More labor released from the land More job opportunities More agreeable living environment People's environmental awareness improved Good progress in local economic development Improved infrastructure	The economic goal of NEPs for farmers and herders was not achieved Activities from oil and gas companies disturbed soil and polluted groundwater

RESULTS

Changes to local social-ecological systems after the implementation of national environmental programs

Of the 36 interviewed scientists and grassroots implementers, 32 considered that positive biophysical changes could be directly attributed to the NEPs (Table 3). Positive socioeconomic changes in local communities were most often mentioned, alongside increased crop yields, more fuelwood, and more labor released from land. Nearly three-quarters of the interviewees believed that these changes were due to NEP implementation. Some also considered that environmental awareness of locals had improved during the NEP implementation. However, several grassroots implementers indicated that trees in local newly established forests were maturing and dying after nearly 20 yrs. Given that forests are mostly monoculture, and complex and stable undergrowth communities were yet to form, some ecological functions and services the forests provided such as acting as a windbreak could decline or disappear if the trees died. Additionally, as the local environment improved, external actors also came in and some restored land was re-converted into arable use, expanding irrigated farmland and depleting groundwater.

Although national economic growth enabled investment in the NEPs, local development also supported their implementation. Several scientists had witnessed positive local economic developments during the NEP implementation, such as improved infrastructure and growing economic activity such as exploration and extraction of oil and gas resources. However, some grassroots implementers worried that oil and coal companies were damaging the environment. Also noticeably, almost all participating scientists highlighted more frequent extreme weather events, such as prolonged droughts and intense heatwaves, which exacerbated tensions over water supplies and stressed irrigated and rain-fed agricultural production systems. Implementation of the NEPs was affected too. Climate change adversely affected the survival, regeneration, and succession of newly planted trees, and (re) greening activities became less viable. These changes were corroborated by local farmers and herders, although they were also concerned about other changes (see below).

Changes from the perspective of farmers and herders

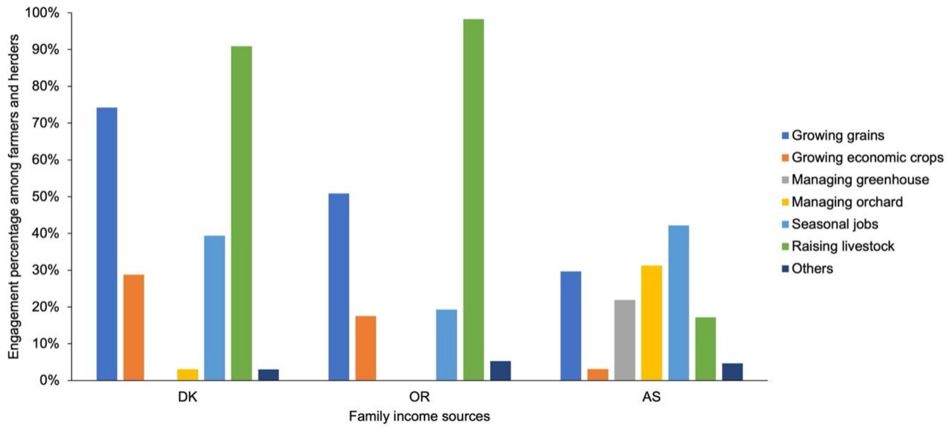
Changes from national environmental program implementation and the impacts on local livelihoods

Addressing the degradation of households' sloping land and degraded pastureland was an important part of the NEPs. As a result, the arable land area of most households was halved as it was converted to forest and grassland. Ansai Agroecosystem Research Station was characterized by hilly terrain. After NEP implementation, average arable land area per household was 13.05 mu (<1 ha; 1 ha = 15 mu) with the modal land area being only 10 mu (0.66 ha, the modal value of the data set) (Append. 3). Agriculture in AS was rain fed. Farmers felt that extreme weather occurred more frequently, as also noted by many scientists (e.g., Tang and Hailu 2020, Huang et al. 2024). In the absence of irrigation, arable harvests had become unpredictable. To make a living, farmers engaged in other livelihood activities (Fig. 3). Seasonal jobs were the most frequent option (40%), although most farmers were already in their 50s or 60s and found it more difficult to gain employment as they aged. Each farmer in AS had at least two income sources.

Agriculture in DK and OR was irrigated. After the NEP implementation, average arable land area per household was 35.67 mu (just over 2 ha) and the maximum area 200 mu (just over 13 ha) in DK (Append. 4). Ordos Grassland Ecosystem Research Station involved both farmers and herders, and the latter had more land than farmers. Average land area per household in OR was 1081.12 mu (approx. 72 ha), and the most common land area was 40 mu (<3 ha) (Append. 5).

Land-based livelihoods such as livestock rearing and grain cultivation dominated in DK and OR (Fig. 3). Many farmers and herders in OR had cars or trucks, and most spoke openly in the survey. In contrast, many farmers in AS spoke reluctantly, and their assets were visibly fewer. In traditional agricultural communities in China, the area of arable land is essential for livelihoods and profoundly affects living standards. Implementation of the NEPs dramatically reduced farmers' arable and pastureland, and compensation and supportive policies were considered inadequate. Consequently, farmers and herders were left in a more precarious situation, reliant on seasonal employment and produce markets that are beyond farmers' control.

Fig. 3. Family income sources across the three cases.



Changes in soil quality and the drivers

Although more than 70% of surveyed farmers and herders were positive about the NEPs, only 34% agreed that the quality of their soil had improved, whereas 31% felt the soil quality had declined. Almost 70% believed that SLM practices such as terracing land, organic fertilization, seasonal grazing, and crop rotation were responsible for the positive changes. Another 21% attributed positive changes to an improved environment, whereas 11% felt that increased precipitation had helped. Adverse soil quality changes were attributed to droughts and frosts by over half of the respondents. Important factors for the decline in soil quality also included overfertilization, groundwater pollution, and soil salinization caused by groundwater mismanagement (Table 4).

Soil quality changes were triangulated with farmer and herder views, which echoed those of the scientists and grassroots implementers. Overuse of fertilizer, for example, happened because farmers and herders hoped to improve harvests by applying more fertilizer, but they lacked technical support on what kind of and how much fertilizer they should use.

Changes promoted by technology

The majority of the households in the survey were using machinery for either ploughing the land, planting, irrigation, or harvesting, especially for those from DK and OR where local terrains were relatively flat. But most participants also mentioned they had used oxen and donkeys before that. The machinery made farming less labor demanding and pumping groundwater much easier, especially in the case of DK and OR. In our investigation, the application of machinery helped the farmers and herders who were already in their 50s and 60s, and the women who used to be housekeepers, became the main laborers in the fields when young people or men left the villages and found jobs in towns and cities. As one of the national agriculture-related policies, both the manufacturing and purchasing of agricultural machinery have been subsidized by the central government since 2004 (https://www.gov.cn). Although the mechanization of agriculture policy aims to provide strength to farmers and herders, improving production efficiency and their incomes, many in the survey expressed that the machines were still heavy for them to handle and worried for the future, as they were aging.

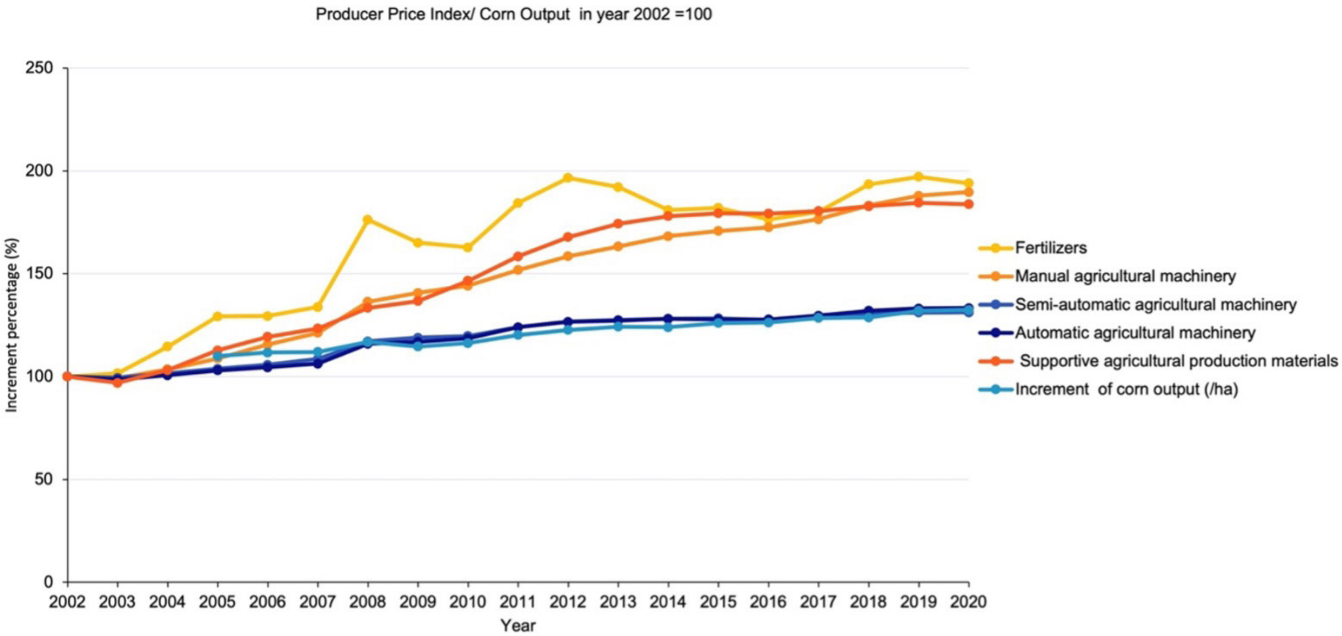
Table 4. Farmers' and herders' perspectives about reasons behind soil quality changes (n = 187).[†]

Reasons for positive change	Percentage of participants (%)	Reasons for negative change	Percentage of participants (%)
Terraced land	28	Droughts	45
Use of organic fertilizer	26	Overuse of fertilizer	21
Improved environment	21	Groundwater pollution and depletion	13
Increased precipitation	11	Soil salinization	11
Seasonal grazing	11	Frosts	8
Crop rotation/ rotational grazing	3	Lack of management	1
		Overgrazing	1

[†] Based on open questions. Answers were not predefined and thus were often multiple.

Another noticeable change was the way people received information and communicated with each other or outside. Television was in every home the survey took us to. However, only some senior farmers in their 60s or 70s relied on TV or face-to-face conversation to receive information. Over 90% of the participants had mobile phones (MPs). Facilitated by easy access to Wi-Fi, people could carry out daily communications with family members and friends whenever and wherever they wanted. About 60% of the participants were using social media to organize groups of common interests and exchange information among them, such as sharing market demands and price information of crops, exchanging experience or asking for help in a group of farmers who were raising livestock. They were also encouraged to install local government apps through which the governments issued notices or organized activities. During the NEP implementation, notices were sent before every meeting to village heads and farmers and herders who otherwise would be very difficult to coordinate and organize as they lived in rather scattered villages. Despite the development in communications, we found that local governments would disclose information mostly when they needed the farmers and herders to work with them rather than appealing to farmers and herders' concerns and needs, and few scientists and grassroots implementers were in the networks of the farmers and herders.

Fig. 4. Increment of main agricultural production investments vs. corn yield increment during 2002–2020. Data source: China Statistical Yearbooks (2002–2021).



Changes in costs of agricultural production and living during year 2000–2020

Secondary data analysis indicated the PPI of semi-automatic and automatic agricultural machinery increased by over 30% between 2002–2020. The PPI of annual agricultural expenditure on fertilizers, manual agricultural machinery, and pesticides and mulch films almost doubled from 2002 to 2020. At the same time, use of fertilizers, pesticides, and mulch films increased by more than 30%. Unit output of corn increased by 32% over the same period (Fig. 4). But, given the lower market price of corn and that 40% of households had less than 1 ha of arable land, income increases from corn were negligible, even in normal years when the costs of inputs were accounted for. For most, a good corn harvest ensured that farmers at least could maintain self-sufficiency of food in case of emergency. But this became less attainable as extreme weather events reduced yields. Similarly, prices of goods to meet basic needs rose palpably (Fig. 5), which explains why people were so concerned about extreme weather and seasonal jobs.

The commodity RPI indicates that grain prices increased by almost 150%, cooking oils by close to 83%, and construction materials and hardware about 50% between 2000 and 2020. Electricity prices increased 120%, whereas its use increased over threefold. Only prices of clothes rose just slightly. People also highlighted the costs of education and medical care, but official price statistics for these services do not exist. During the survey, we encountered three participants whose family members had undergone surgery. None had recovered fully. Two already worked in the fields, and the third was unable to move. Their treatment had drained savings and forced families to borrow from friends and relatives, leaving them in debt. The Rural Medical Insurance Scheme barely provided sufficient cover for expensive medical services. One scientist in AS who had relatives in the villages spoke of the reluctance of senior farmers to obtain medical care when they fell ill: “They would endure the pain silently rather than risk getting their family into debt [for receiving medical services]. Most often, when they were finally sent to hospital, the illness had become incurable [as it was too late].”

Concerns and needs: understanding livelihoods of local communities

Table 5 indicates that farmers and herders were more concerned about social capital (84%) and natural capital (80%) than financial (51%) or human capital (10%). The most common concern was the applicability of measures and policies, technical support, and seasonal job opportunities. Extreme weather events, arable land area, and groundwater depletion and pollution were the most frequent natural capital concerns. Markets, costs of agricultural production and family income were the main financial capital concerns.

Applicability of measures and policies, extreme weather events, arable land area, technical support, and seasonal job opportunities were the five most often mentioned concerns (Table 6). Applicability of measures and policies concerns centered on policy appropriateness when changing circumstances made policies untenable, as well as on policy predictability. People were also concerned about the lack of technical support, many participants saying that they “do not know” about specific practices or from whom to obtain advice. The lack of social capital among farmers and herders became apparent in terms of policies, knowledge availability to practice SLM and/or sell produce at the market, and support for additional employment opportunities. Extreme weather events such as droughts, heatwaves, and frosts

Fig. 5. Increment of commodity RPI of five basic living items during 2000–2020. Data source: China Statistical Yearbooks (2000–2021).

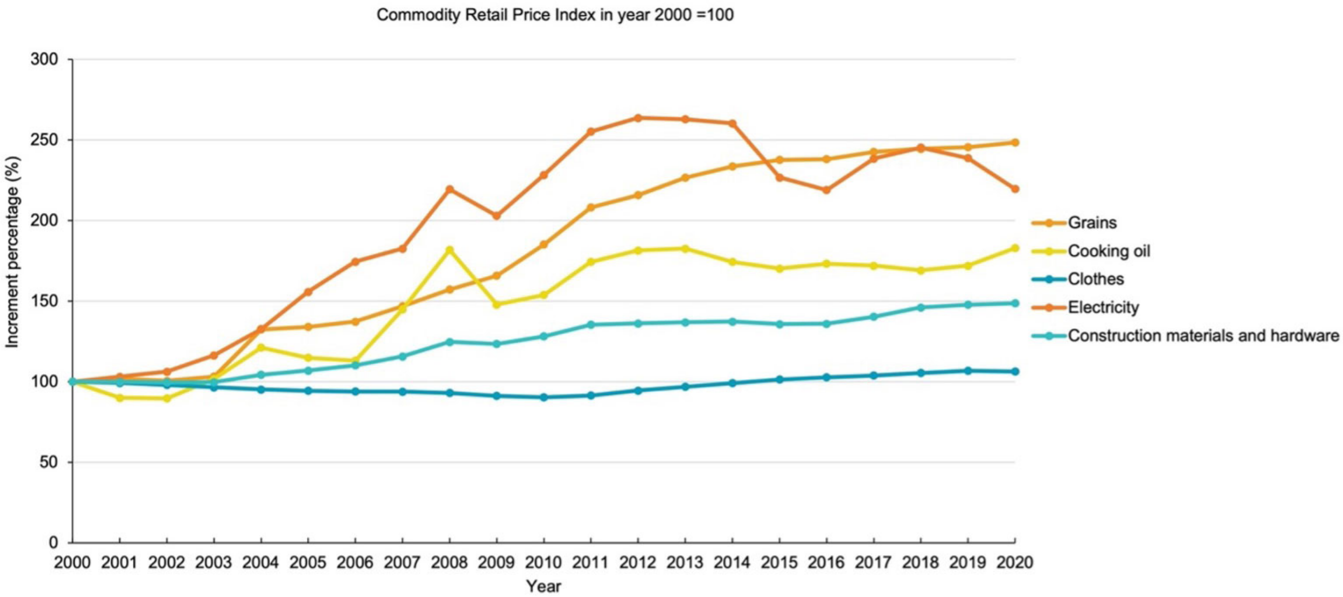


Table 5. Farmers' and herders' concerns and or needs.

Name	Number of participants
Concerns for now or future	187
Financial capital	95
Compensation	15
Costs of living	5
Family income	22
Harvests	5
Markets	24
Costs of agricultural production	24
Human capital	19
Knowledge or skills	2
Ability to work	17
Natural capital	150
Soil quality	10
Extreme weather events	54
Feed for sheep and cattle	2
Arable land area	38
Groundwater depletion and pollution	23
Water scarcity	23
Social capital	158
Applicability of measures and policies	65
Seasonal job opportunities	33
Affordable medical services	4
Social care for senior villagers	19
Nepotism and corruption of village head	2
Technical support	35

were threats to pastureland restoration, crops, and orchard management. Respondents expected it to become more challenging to implement conservation measures when livelihoods depend on a small arable land holding and if social support for coping with the changes is lacking.

None of the participants considered food security an issue, but high costs of living and expensive medical care and education forced them to adopt multiple livelihood activities. The small area of arable land provided a lifeline, but yields were often threatened by extreme weather and precarious markets. Lack of social capital and social protection pushed them to put more pressure on the land that they could still use.

DISCUSSION

Changes and the role of national environmental programs

Lambin et al. (2001) noted that, in developing countries, land changes are influenced more by institutions and markets than population growth or poverty. The NEPs have brought about positive environmental changes, such as increased vegetation cover, reduced frequency of sandstorms and improved local air quality, resonating with earlier findings (Zhang et al. 2016, Bryan et al. 2018, Chen et al. 2019, Cai et al. 2020, Wang et al. 2020). Under the NEPs, detrimental activities such as deforestation, land overexploitation, overgrazing, and farming on sloping land were prohibited, and restoration measures such as afforestation, wasteland revegetation, retirement of sloping land, and pastureland rehabilitation were introduced (NFGA 2020). Lyu et al (2020) found that other environmental strategies and policies such as eco-industrialization and forestry policies also contributed to the reversal of desertification. Others draw attention to the substantial government investment in the NEPs, which was indispensable for their implementation (Feng et al. 2019, Cai et al. 2020, Wang et al. 2023).

The impacts of the NEPs are more far-reaching than originally designed. Cao et al. (2010) suggested that large-scale afforestation in arid and semi-arid northwestern China had exacerbated pressure on local water resources, and that only small-scale, short-

Table 6. The five most frequently mentioned concerns among farmers and herders.

Category	Pattern		Illustrative quotes (examples)
	Capital	Type of concern	
Applicability of measures and policies	Social	Inappropriateness of policies Unpredictability of policies Unavailability of policies	“...compensation becomes irrelevant as living costs grow so high” (Male farmer, 50s, DK). “...the market is overwhelmed with the products that local governments have encouraged us to grow“(Male farmer, 60s, DK). “...trees in the shelterbelt are growing quickly and they begin to compete for water and nutrients with crop; but no measures are in place to solve the conflict” (Male farmer, 60s, DK). “...trees are maturing and dying, and we don’t know what the next steps are” (Male farmer, 40s, OR).
Extreme weather events	Natural	Extended droughts Intensified heatwave Frequent frosts	“...we haven’t seen any effective precipitation on the pastureland since March” (Male herder, 40s, OR). “...the sudden frost in May killed almost all the corn in my fields” (Female farmer, 50s, AS). “...it was too hot to work in the fields in the middle of the day” (Female farmer, 50s, AS).
Arable land area	Natural	Wasteland cultivation banned Sloping land retired Limited arable land area per household	“...several of our villagers were put in prison because they cultivated the wastelands without authorization. The cultivation had been encouraged by governments before” (Male farmer, 50s, DK). “...here and over there, the stands covered with black locusts were all my family’s slope lands. Only this patch of vineyard is left for us now” (Female farmer, 50s, AS). “...food is not an issue. But it is impossible to pay family bills with such a small area of land” (Male farmer, 50s, AS).
Technical support	Social	Lack of knowledge about soil Lack of knowledge about fertilization and seeding Lack of knowledge for forest and woodland management Lack of information about market	“...don’t know where to buy the right corn seeds to grow” (Female farmer, 40s, DK). “...don’t know the status of the soil, what kinds of and how much fertilizers should be applied” (Male farmer, 50s, DK). “...don’t know whom to consult with about the management of the greenhouses” (Male farmer, 40s, AS). “...don’t know which products can be marketable” (Male farmer, 50s, DK).
Seasonal job opportunities	Social	Few opportunities No supportive mechanisms	“...It is becoming difficult to find seasonal jobs in recent years. The bosses are not willing to take on senior people despite we can prove we are still capable” (Male farmer, 50s, AS). “...supportive policies? No one is organizing us” (Male farmer, 50s, DK).

term success had been achieved. Li et al. (2021) also argued that restoration measures were increasing aridity, echoing the worries of scientists and grassroots implementers in our study. Additionally, Feng et al. (2016) highlighted an over-emphasis on revegetation in semi-arid areas, suggesting that reduction of onsite water and soil loss put local water supplies at risk as plants retained water and reduced runoff to rivers. Given frequent droughts and heatwaves, our participants worried about the potential increase of desertification, in line with observations in other studies (e.g., Huang and Zhai 2023). These concerns indicate a need to reform the NEPs by the inclusion of SLM practices, which farmers favor due to their positive impact on soil quality.

Economic prosperity expected as the result of NEP implementation was not fully realized despite some positive socioeconomic impacts. The consequences of the reduced arable land area after the NEP implementation became more conspicuous as compensation declined. Cao et al. (2009) and Feng et al. (2015) warned that, although there was widespread support in local communities for restoration, many poorer residents would return to cultivate forest land and pastureland as there were no alternatives for making a living after NEPs prohibited tree felling, grazing, and groundwater extraction. The evidence indicates that the NEPs caused a decrease in the incomes of farmers and herders, and that local economic needs far exceed the provided compensation, contributing to local impoverishment (Wang et al. 2023).

Institutional interplay and the implications for local livelihoods

Brondizio et al. (2009) demonstrated that increasing environmental and social connectivity of the resource-use systems renders the management success at one level dependent on another. They suggested that the multilevel nature of such problems needs institutions that facilitate cross-level environmental governance for the long-term protection of ecosystems and the well-being of people. Our farmers and herders benefited from an improved environment due to the NEPs, alongside economic development in terms of improved living standards. They were food secure and had transportation and communication facilities. But they also faced impacts from other sectors and scales, such as an increasing cost of living and agricultural production. Medical services and housing became increasingly unaffordable.

Healthcare costs could pull families into poverty as the financial protection health insurance offered was insufficient (Li et al. 2012). In a booming economy, farmers and herders therefore had to cover rising costs by turning to their only available resource: the land. However, as Wang et al. (2020) noted, farmers could no longer support their basic needs if they relied only on croplands.

In China, rural people have been left behind in the national development agenda. In 2000, there was a widely reported letter from a grassroots official to then Prime Minister Zhu, which began: "farmers are suffering; the villages are so poor; and agriculture is in danger," followed by a stark description of the plight of local communities, such as aging and the loss of laborers (as young farmers moved to towns and cities for better employment opportunities), taxes even on items irrelevant for agricultural production (such as taxes on family membership, homestead, and family plot, etc.), unenforced supportive rural polices etc (https://zhuanlan.zhihu.com/p/38519460, accessed in January 2024). Three rural issues: agricultural production, rural development, and farmers' well-being, have ever since entered on the agenda of central government (https://www.gov.cn, accessed in January 2024).

Agricultural production tax has been canceled since 2006. Farmers are free to sell their products at markets, but market prices of grains are regulated by the government. In the dual-tier social security system, urban people are protected by comprehensive welfare measures, whereas most farmers had no medical insurance until 2009. The Rural Revitalization Strategy was initiated by the central government in 2017. However, the system, including pensions in rural areas, remained incomplete until 2021 (Chen et al. 2022). At the same time, costs of living have increased dramatically. The average cost of raising a child in China until the age of 18 is more than 6.3 times the GDP per capita, compared with 4.11 times in the USA or 4.26 times in Japan, making China one of the most expensive places in this regard (Liang et al. 2024). Many studies have noted aging farmers, empty villages, and increasing income gaps and inequalities between rural and urban people (e.g., Guo et al. 2019, 2020, Kong et al. 2023).

Impacts of the changes on local communities and the role of social security

Farmers and herders had concerns for climate change, which adversely affects their ability to predict harvests and creates additional costs. Amid global environmental change and in particular climate change, there is increasing collective perception of insecurity and uncertainty worldwide (Morrissey 2023). Vulnerability to environmental change has profound social dimensions. Factors contributing to vulnerability often stem from political, economic, social, and cultural processes (Smit and Wandel 2006), which result in disparities not only in people's exposure to environmental changes but also in their capacity to respond to them (O'Brien 2006). Although exposures, sensitivities, and adaptive capacities are evident at the local level, they reflect broader forces, drivers, and determinants that shape and influence local-level vulnerabilities. Examples of these include infrastructure, institutional environment, kinship, social networks, and political support (O'Brien 2006). Both human security (the capacity of individuals and communities to address threats to their basic needs and fundamental rights, allowing them to lead dignified lives) and social and ecological resilience (the ability of ecosystems, individuals, and groups adapt to environmental change) have been increasingly examined in the literature on environmental change, human development, and disaster relief (e.g., Adger 2000, O'Brien and Barnett 2013, Folke 2016).

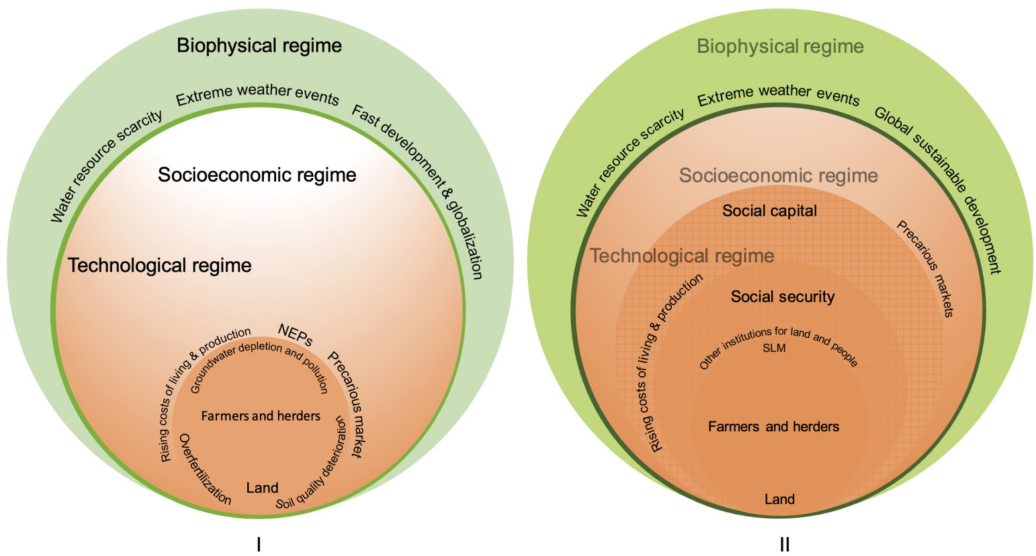
Social security is the legal "protection that a society provides to individuals and households to ensure access to healthcare and to guarantee income security, particularly in cases of old age, unemployment, sickness, invalidity, work injury, maternity or loss of a breadwinner" (International Labour Organisation, https://www.ilo.org). Although social security influences individuals' and communities' attitudes and capabilities, spending on social security in developing countries is low (Chukwunonso 2014, Seekings 2019, Tasci and Tatli 2019, World Bank Group 2022). Social protection can improve agricultural production and livelihoods by enhancing households' abilities to cope with risks and non-farm investment, and build human capital (Tirivayi et al. 2016). Kosec and Mo (2017) noted that government relief in Pakistan enabled flood-hit people to restore livelihoods, replace damaged assets, and retain their aspirations for the future. Levels of social security impact people's spending and investment plans and decisions in the short and long term (Carter and Janzen 2018, Patrick and Simpson 2020). Liang et al. (2014) discovered that farmers were happy to be relocated from an ecologically degraded area to let it regenerate, but inadequate support for employment made over half of them consider returning. Although China's Administrative Measures for Farmland Transfer have been in force since 2005 to consolidate fragmented plots for improved production efficiency, land management and economic benefits, the sought-after results were not delivered (Huang and Wang 2008). Contracted farmers tried to maximize short-term gains from the land within the term and were unwilling to invest to maintain its functions, for example, by using organic fertilizers due to lack of social security (Ke et al. 2022).

The insufficiency of social security in rural communities in China poses a risk of social instability as rural communities remain under a different social security system than urban people (Guo 2014, Shen and Zhang 2018). Although farmers and herders are motivated to protect the environment their livelihoods depend on, they need to put their survival first. In the absence of social protection and confined to degraded land, they have to navigate the challenges by largely relying on their own knowledge and experience (Guo 2013).

Social capital of local communities in environmental governance

When analyzing rural livelihoods in Latin America, Bebbington (1999) found that their sustainability and implications for poverty largely depended on the networks and links with state, market, or civil society actors who could help them access, defend, and capitalize on their capital assets. Such assets include produced, natural, human, and social capitals, which can enhance rural people's capacity to be their own agents of change. He also noted that government could build synergistic relationships with local organizations that increase the quality and coverage of the provision of services, and thereby enhance family assets (Bebbington 1999). With institutions linking multiple levels, government is an important enabler of social capital and essential for the long-term protection of ecosystems (Brondizio et al. 2009).

Fig. 6. Changes and the roles of social capital and social security for farmers and herders and land in the social-ecological-technological regimes framework.



Putnam (1993) argued that the networks or links of a society were influential in affecting government effectiveness and economic performance. He noted that where social structures were more "vertical" and based on authority relations, citizens' capacity for collective action is more limited, and access to and influence over state and market are weaker. In more efficient, effective and inclusive governments and economies, relationships were more "horizontal" (based on trust and shared values), with higher levels of participation in social organizations and networks that cut across the boundaries between different institutions (Putnam 1993).

In our cases, the farmers and herders took advantage of the technological advancement and used various social media to exchange information and knowledge, but only within circles they could reach and often, away from public attention. Studies show 80% of social media users in China are those under 30 who use social media to maintain contacts but mainly through following or sharing entertainment activities; about 20% of users were in their 40s or above who care for a broader scope of topics, but seldom reached by environmental and social issues (Sina Technology 2021). More than that, actors from official institutions, such as policy makers, scientists, and grassroots implementers, often appear in their working groups while refraining from making opinions in the public domain and or beyond their working agenda due to cultural and institutional concerns, such as low visibility, privacy exposure, or risk of information leaking (Niu 2019). Although governments, news agencies, and institutions are encouraged to post environmental and social topics appealing for public engagement or support, negative responses are often incurred due to lack of knowledge and transparency (Liu et al. 2023).Even though social media are used in knowledge exchange, traditional interpersonal social capital, such as *guanxi* (personal relationships), dominates the communication process in professional service firms (Davison et al. 2018).

Social capital plays a pivotal role in facilitating the sustainable management and governance of shared resources (Pretty 2003). As demonstrated by Bebbington (2008), actors with different backgrounds can bring in new ideas as well as networks of contacts, which help local communities gain access to non-local institutions and resources, to NGOs with technical expertise and financial resources, to sources of technology, donors, and alternative trading networks. In NEP implementation, local communities lacked contacts with outside actors, whether for land conservation, agricultural production, or for adaptation to climate change and markets, resonating with observations that networks between scientists, grassroots implementers, and policy makers were working efficiently around the design and/or implementation of the NEPs, but above the level of local communities and outside the scope of local livelihoods (Kong et al. 2023).

Linking sustainable land management and resilient community building in the social-ecological-technological regimes (SETRs) framework

As a local SES, the farmers and herders, and the land, are deeply embedded in the SETRs (Fig.6). Although we focus on the NEPs, interventions and changes from other sectors and scales also impact on local SESs, such as prices rising amidst fast national economic development, precarious markets brought by globalization, extreme weather events due to climate change, and so on. All these drivers are putting local SESs into a more vulnerable state, but solutions stay beyond the local scope and local coping capacities. Yet, policies have not kept pace with the changing situation. Thus, emerging local environmental problems such as overfertilization, groundwater depletion and pollution, overgrazing, and declining soil quality made the situation on the ground even more complicated ("I").

National environmental programs were designed to address local land degradation, but failed to accommodate the effects of other measures on local ecosystems and livelihoods. Although farmers and herders navigated the complex SETRs, their activities affected the land and in part undermined the outcomes the NEPs aimed to achieve. This demonstrates that not only short-term measures from the NEPs should be transitioned into long-term practices of SLM, but also shows the critical roles social security and social capital can play in contributing to resilience building among the uncertainties and changes, and how essential they are for local farmers and herders to safeguard land and develop their own well-being ("II"). Moreover, as part of our society and also important institutional arrangements in a society, social security and social capital embody collective assets/efforts that environmental governance aims for. Their significance thus in solving current global environmental challenges cannot be overestimated.

Sustainable land management relies on technological innovations (WOCAT 2016), but technological factors have also been reported as robust drivers of desertification. When technological innovations are applied with the intention to improve land and water management (e.g., through motor pumps and boreholes or through construction of hydrotechnical installations such as dams or collectors), these developments are often coupled with high water losses due to poor infrastructure maintenance, or they induce fundamental and often irreversible changes to the natural hydrological network (e.g., through tapping into groundwater reservoirs) (Geist and Lambin 2004). The use of agricultural machinery and irrigation systems in this study has improved land productivity. Although we cannot unravel direct relationships between the technological changes in farming and the decline of soil quality as other operations, such as those from oil and coal companies were raised as one of the concerns, caution needs to be maintained when technological applications are introduced. Nevertheless, effective knowledge sharing could be realized due to technological advancement in communications, which is essential for the implementation of technologies and approaches of SLM.

Although we find that greater focus on social capital and social security is needed, they are not always beneficial as Portes (1998), Lin (1999), Dwyer (2018), and Engelhardt et al. (2022) have suggested. For example, social capital can be used to limit opportunities for those outside of the networks, but providing social security is costly, and beneficiaries may become dependent on it rather than retaining their personal motivation. But for the rural communities in China, building social capital with outside actors would enable them to have the networks accessing knowledge and resources they need to safeguard land and improve their own well-being; and the provision of social security could shelter them from adversaries to livelihoods and facilitate them to do so even in the face of challenges. With social capital and social security, they could retain the resilience for the land and themselves when navigating the unprecedented uncertainties global environmental change has brought about.

CONCLUSIONS

We investigated changes in local SESs during the implementation of the NEPs. While focusing on the NEPs, other drivers of change were also identified and examined. Some biophysical and socioeconomic impacts can be directly attributed to the NEPs; others are driven by other institutions, markets, and climate change. Some changes have been positive, others negative, demonstrating how institutional interventions targeting one sector can produce unexpected effects across sectors and scales. Our results show that traditional environmental restoration approaches and institutions such as NEPs require supportive mechanisms from other socioeconomic sectors.

By examining the concerns and needs of local communities, drivers that could cause further challenges to NEP implementation and outcomes were also discussed. In the absence of social security, local communities are exposed to changes beyond their control, exacerbating the relationship between the land and the people. A lack of measures for building links between local communities and outside actors impedes collaboration, social learning, long-term environmental conservation, as well as social development. Without a systemic approach that incorporates social security and building of social capital to improve the general resilience of local communities in face of the changes, the goals of environmental governance in China will be difficult to achieve with effectiveness, efficiency, and equity.

The case study highlights the challenges China's environmental governance is facing. Although it reveals the need for new governance approaches and mechanisms such as social capital and social security when navigating the fast-changing and complex SETRs, discussion about specific pathways toward related institutional arrangements is still lacking at this stage, and thus requires further exploration.

Author Contributions:

Conceptualization, Z-HK, LS, and JP; methodology, Z-HK, LS, and JP; investigation, Z-HK ; resources, Z-HK, LS; writing—original draft preparation, Z-HK; writing—review and editing, JP, LS and Z-H K; visualization, Z-H K; supervision, JP and LS.

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Data Availability:

The data and code that support the findings of this study are available on request from the corresponding author, Z.-H. Kong. None of the data and code are publicly available because they contain information that could compromise the privacy of research participants. Ethical approval for this research study was granted by Environment and Geography Department, University of York, Ethical Review Committee on 4 June 2021.

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Appendix 1. Questionnaire of this study

Questionnaire survey

(Explain the surveyed project information sheet. Ask for their verbal consent. Each survey will take approximately 30-45 mins)

Section 1: General

1	Name of head of Household				
2	Gender of head of household	M		F	
3	Estimated age	18-30	31-50	50-65	65+
4	Number of people in household	1-2	3-5	6-8	9+

Section 2: Land and Land use

5	How long ago were you allocated land (years)?	<5	6-10	11-15	16-20	21-40	41+	DK
6	How much land was you allocated (ha/mu)?							
7a	How much land do you have now (ha/mu)? （							
7b	What types of land are they?	Slope land	Irrigation land	Grass land	Other			
7c	Did you have sufficient land to provide food for your family last year?	Y	N					
7d	When was the last time your harvest was lower than you hoped for?	(year)	Never	Prefer not to say	Other			
7e	Why do you think the yields were lower than you hoped?	Frost	Drought	Lack of manure/fertilizer	Disease	Not weeding	Other	
7f	How did you get food?	Go to buy	Ask government	Ask family for help	Ask neighbors	Prefer not to say	Other	

Section 3: Arable land

8a	Which crops did you grow last year?	Maize	Rice	Wheat	Millet	Other	None
8b	Which others?	Beans	Cabbages	Cucumbers	Cotton	Green-leaf vegetables	Other(s) Tomatoes
9a	Do you sell the crop (s)?	Y	N				
9b	If yes, what percentage did you sell last year?	1-29%	30-49%	50-69%	70-90%	Other	
9c	Where do you sell them?	Village	Town	County	Other		
10	Has your yield increased in the past 5 years?	Y	N	Varies	DK		
11	Has your yield increased in the past 10 years?	Y	N	Varies	DK		
12	Do you apply fertilisers?	Y	N	N/A			
13	Do you apply manure?	Y	N	N/A			
14	How do you plough your land?	Oxen	Tractor	Both	Other	N/A	
15a	Did you fallow your land? If so, how long for?	Y for ___ years	N				
15b	Why?	Restore soil fertility	Stop pests	DK	Tradition	Others	

Section 4: Fuel

16	What kind of fuels do	Coal	Gas	Electricity	Straw	Solar	Wind	Charcoal	Fuelwood	Other

	you use for daily life? (tick all that apply)									
17	Do you use wood grown on your land as fuel?	Y	N							
18	Has time spent collecting wood increased, decreased, or stayed the same over the last 5 years?	Inc	Dec	Same	DK	Other				
19	Has access to wood increased or decreased over the last 10 years?	Inc	Dec	Same	DK	Other				
20a	If access increased, why?	More trees	Changed policy	DK	Other					
20b	If access decreased, why?	No trees near	No new trees	Policy ban	DK	Other				

Section 5: Natural resources

21	Did you harvest any other natural resources last year?	Y	N (if no, go to section 6)						
22a	What did you harvest?	Grass	Fruits	Both	Raw herbal medicine	Other			
22b	During which months did you harvest grass?	Jul	Aug	Sept	Other				
22a	Which fruits do you harvest?	Apple	Pear	Peach	Strawberry	Date	grap e	Watermelon	Other
22b	When harvest raw herbal medicine	March-April	May-Jul	Aug -Oct	other				
22c	When harvests other?	March-May	Jun-Aug	Step-Oct	Nov-Feb				
23	Who was allocated the land you harvest the resource from?	Government	Collective	Own	Other				
24a	Do you sell the resource?	Y	N						
24b	If yes, where?	Village	Town	County	Along the road	Other			
24c	How do you get there?	Walk	Bus	Collected	other				
25	Do you sell the resources in their raw state?	Y	N						
26	Has access to wild resources increasing or decreased in the last 5 years?	Inc	Dec	Same	Varies	DK			
27	Has time spent harvesting wild resource increased or decreased in the last 10 years?	Inc	Dec	Same	Varies	DK			

Section 6: Livestock

28	Do you keep poultry?		Y		N	
29a	How many poultry?	＜10	10-20	21-30	31-40	41+
29b	Do you keep cattle?		Y		N	
29c	How many cattle?	1-2	3-5	6-10	11-20	21+
29d	Do you keep goats?		Y		N	
29e	How many goats?	＜10	10-20	21-30	31-40	41+
29f	Do you keep sheep?		Y		N	
29g	How many sheep?（有多少只？）	＜10	10-20	21-30	31-40	41+
29h	Do you keep any other animals?				Y	N
29i	How many?	1-2	3-5	6-10	11-20	21+
30	Have cattle/sheep/goat numbers changed over the last 5 years?			Inc	Dec	Same

31a	Why the increase?		Bought	Bred	Other
31b	Why the decrease?		Sold	Died	Other
32	Why do you keep animals?	Food	Bank	F&B	Tradition	Other

Section 7: Income

33	Main sources of cash income?	Arable sale	Job (if ticked, cont.' with the following questions)	Seasonal job (if ticked, cont.' with the following questions)	Other	None

34a	Where was the job/seasonal job found?	Town	County	Nearby cities	Big cities	Other

34b	What are the most likely sectors to find a job/seasonable jobs?	Construction sites	Factories	Restaurants	Delivery business	Other

34c	Is it easy to find a job/seasonal job?	Y	N

34d	What are main reasons that motivated you to find the job?	Support family	Easy money	Seasonal arable activity pause	Friend invitation	Other

35	Are you going to move your family to the place where you work?	Most likely	likely	DK	unlikely	Very unlikely

36a	What would make you decide to move?	Children's education	Medical services	More money	Decreasing harvest	Degrading environment	Other
36b	What would make you decide to stay?	Harvest well	Improved environment	Improved infrastructure	Can't find a job	Tradition	Other

Section 8: Environmental change

37	Is the grazing pasture quality/soil fertility good at the moment?	Y	N	DK

38a	Why is it good?	Few sheep/goats/cattle	Project improved it	DK	Enough land	Use rotational grazing/fallowing

38b	Why bad?	Little rain	Strong and constant wind	DK	Sheep/goats/cattle track	Slope	Lack of mgt	Other

39a	How do you recognize that it is good?	Fat cattle/ sheep/ goats	Fat cattle /goats /sheep and good grasses	Good harvest	Lots/ good grass	Less sandstorms	DK	Cattle/ sheep/ goats live longer

39b	How do you recognize that it is bad? （	Poor harvest	Short grass	Lots cattle/ sheep/ goats	Bare ground & gullies & rocks	Thin/dead cattle/ sheep/ goats	Cattle/ sheep/ goats walk away	Dry grass	DK

40a	Has the pasture quality/soil fertility changed in the last 5 years?	Worse	Better	Same	DK

40b	Has the pasture quality/soil fertility changed in the last 10 years?	Worse	Better	Same	DK

41a	Have the bush and grass species present on your land changed in the last 5 years?	Y	N

41b	Nature of change?	Planting	Air seeding	Less G	Short	DK	More	Longer

42a	Has the amount of bare ground on your land changed in the last 5 years?	Inc	Dec	Same
42b	Has the amount of bare ground on your land changed in the last 10 years?	Inc	Dec	Same

43	Have you ever seen the soil on your land washed away by rain?	Y	N

44	What do you think causes soil erosion?	Heavy rain	Cattle/ sheep/ goats	slopes	DK	Others

45	Is soil erosion a problem for you?	Y	N

46	How serious is the problem out of 5, with 1=no problem, 2=slight erosion, 3=moderate erosion, 4=severe erosion, 5=extreme erosion?	1	2	3	4	5

Section 9: About the NEPs

47a	Do you carry out any activities to conserve soil on your land?	Y	N

47b	If yes, what kind of activities?	Furrows	Grass strips	Terracing	Strips/plant trees/fill gullies	Others

47c	Why do you use this/these activities?	Tradition	Told	Cheap	Easy upkeep	DK/other

48	How successful are strips/furrows… out of 3, 1=very successful, 2=successful, 3=not successful	1	2	3

49	Have you heard of the concept of desertification?	Y	N

50	If yes, where from?	Grassroot implementers	Social media	NGO	TV broadcasting	Others

51	Have you heard of TNSP/GGP?	Y	N, go to 53

52a	Can you describe what are major measures with TNSP/GGP?	A. Cash subsidies for retiring slope lands
		B. Grain subsidies for retiring slope lands
		C. Planting trees on slope lands
		D. Planting grass on slope lands
		E. Confined cattle/sheep/goat raising
		F. Seasonal grazing
		G. Others, please specify

52b	Which measures do you prefer? (select one or more of the above choices)	

52c	Why?	Extra income	Extra grain	Good environment	More job opportunities	Other

53	Can you tell me if you think the following activities are very important, important or not important?			
Activity	VI	I	NI	DK

Making people aware of who to approach with problems relating to damaged land				
Educate people about environment problems they might face				
Encourage people to join in with the community activities to help the environment				
Encourage people with different resources to deal with desertification with different ways				
Enhance the role of scientists in policy making process				
Mend damaged land				
Help the government to make a set of rules about the use of trees				
Improve research and technology for farming and help reduce damage to the land				
Develop other fuels for people to use				
Improve the ways in which livestock are managed				
Develop plans to reduce the effects of drought and poverty				
Improve local infrastructures and community services (transport, school, hospitals)				
Help the government to create a land use plan				
Help the government to create a settlement and resettlement policy				
Control population growth				
Others				

Section 10 Knowledge communication

54a	Have you got any information about the NEP when it was to be implemented on your land?	If Yes, what kind?	N	Others

54b	If yes, where from?	Grassroot implementers	Social media	NGO	TV broadcasting	Others

54c	If yes, do you think it is helpful with the understanding of the implementation on the land?	Y	N	Other

54d	What kind of information you would like to know about the NEP on your land?	Effects the NEP will have	Actions to be taken on the land	Supportive measures (e.g., sapling supply, mechanic availability etc)	Compensations	Other

54e	From whom do you expect to have the information?	Local government	Grassroot implementers	Scientists	Village head	Other

54f	Why?	More accurate and reliable	Easy understanding	Amicable attitude	Often being available	Other

55a	Have you ever been involved in demonstration visits to the station?	Y	N

55b	If yes, how do you think of them?	Very helpful	Helpful	Not relevant	Not helpful	Other

56	What kind of information you would like	(Local) Environmental	(Local) Educational	(Local) Entertainment	(Local) Employment	Local policy	Other

	to have more? (						

57	How do you usually get the information?	Friends talks	Social media	NGO	TV broadcasting	Other

58	Have you considered sharing your knowledge with grassroot implementers and scientists?	Y	N	Others

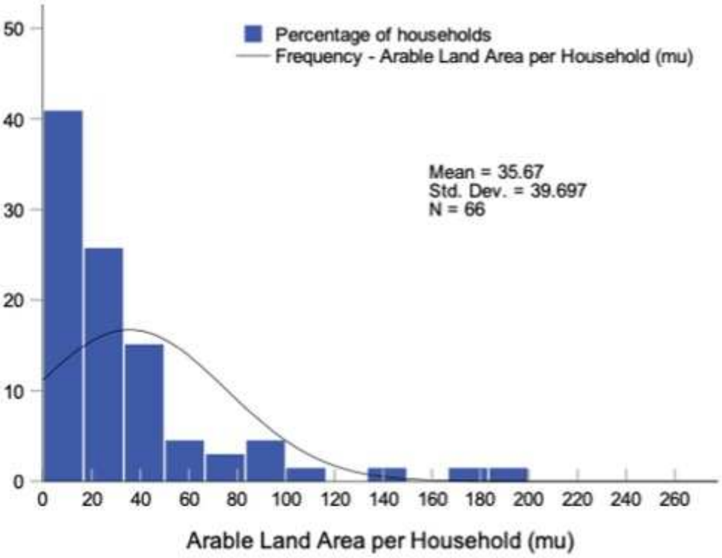
59	Why?	Cannot meet them	Have no opportunity to talk	Nothing to share	They know more	Other

60	What is your greatest fear for the future from a farming perspective?
61	Do you have any other comments to make about farming/soil/drought/land?

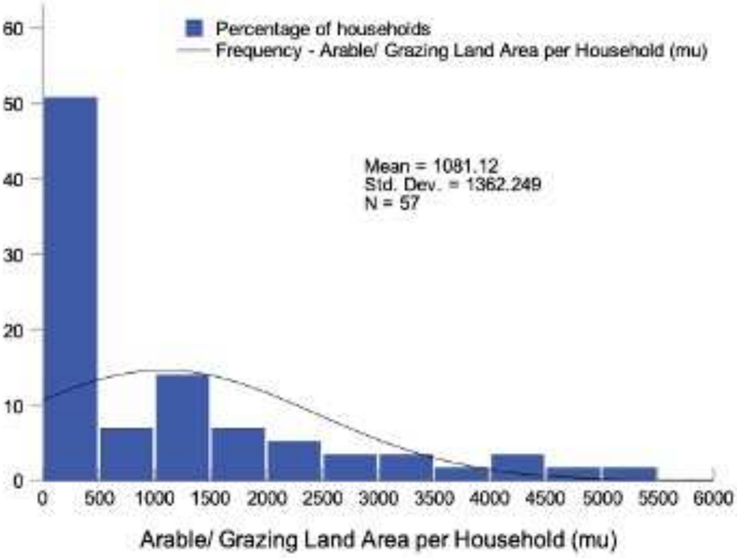
Appendix 2. Characteristics of the participants in the dataset

	Farmers/herders[1]		Grassroots implementers		Scientists	
	No. of valid questionnaires	**Type of participants**	**No. and type of interview**	**No. of years and experience with implementation of the NEPs**	**No. and type of interview**	**Academic background of participants**
DK	66	2 outside contracted farmers[2], 64 smallholder farmers, incl. 4 village heads	4 in person semi-structured interviews	1 with 7 years' experience, the other 3 for almost 20 years, incl. 1 head of local forestry agency	10 semi-structured interviews, of which 9 face to face, 1 through video by WeChat[3]	Drylands ecology, climate change, agroforest management, dryland germplasm resources investigation
OR	57	28 smallholder farmers, and 29 herders incl. 7 village heads	6 in person semi-structured interviews, 1 structured interview through email	3 with more than 10 years' experience, 3 for almost 20 years, and 1 with 3 years	2 semi-structured interviews through video by WeChat, 4 structured interviews through emails	Dryland ecology, pastureland ecology, plant physiology, climate change, desertification control and management
AS	64	All smallholder farmers, incl. 3 village heads	3 in person semi-structured interviews	All with more than 20 years' experience, incl. 1 head of local agency	6 in person semi-structured interviews	Soil and water conservation, sustainable agriculture, small watershed management, sustainability
In total	187		14		22	

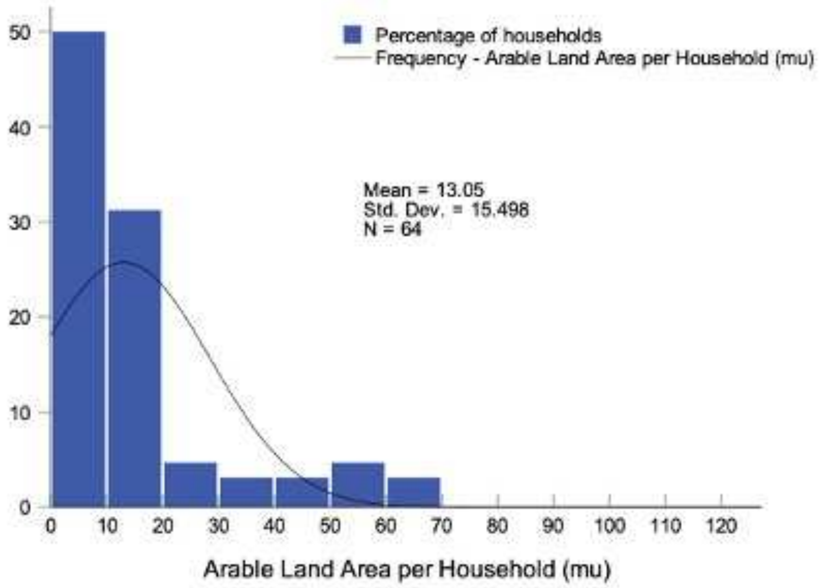
[1] Farmers were mostly of Han ethnicity- the biggest ethnic group in the country. Herders were of Mongolian ethnicity-the second biggest group of the 55 minor ethnic groups in China.
[2] These farmers came from outside with resources enabling them to cultivate relatively larger areas of land based on contracts with local villages, as many local farmers had stopped tilling the fields after migrating to towns and cities.
[3] One of the most popular social media Apps in China, having similar functions to WhatsApp.



Appendix 3. Arable land area per household in DK (mu)



Appendix 4. Arable land area per household in OR (mu)



Appendix 5. Arable land area per household in AS (mu)