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Regional development boundary of China's Loess Plateau: Water limit and land shortage

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A B S T R A C T

The planetary boundary concept aims to define the environmental limits within which humanity can safely operate in the global scale. Identification of the regional development boundary and solutions for problems therein is the basis of the local and global earth system sustainable operation. The Loess Plateau in China is an ideal area for studying the regional development boundary concept. After reviewing the main natural and anthropogenic changes on the Loess Plateau and their hydrological and social-economic effects during recent decades, we identified the water limit for large scale revegetation and the land shortage caused by the Grain for Green project as the most important determinants of the regional development boundary. Therefore, it is necessary to readjust the existing revegetation strategy according to the water capacity, including identifying the suitable priority zones and the corresponding species, density and management for keeping the planted ecosystem healthy. In addition, as an integrative mode of land management, gully reclamation can not only create cropland and conserve soil and water, but also strengthen the construction of agricultural infrastructure, foster large-scale agricultural operations and promote the development of rural economy.

1. Introduction

The planetary boundary (PB) concept, introduced by Rockstrom et al. (2009a, 2009b) in 2009, aimed to define the environmental limits within which humanity can safely operate in the global scale. This is a new paradigm that can successfully integrate the continued development of human societies and the maintenance of the biophysical earth system in a resilient and accommodating state. The PB concept is mainly based on the intrinsic biophysical processes that regulate the stability of the Earth system and defines the planetary boundary as a human-determined acceptable level of a key global variable (Steffen et al., 2015). For example, nine boundaries representing specific thresholds of climate change, ocean acidification, stratospheric ozone, global nitrogen and phosphorus cycles, atmospheric aerosol loading, freshwater use, land-use change, biodiversity loss, and chemical pollution have been proposed and quantified. This concept of PB and the idea that there is an identifiable set of boundaries beyond which anthropogenic change will put the natural earth system outside a safe operating space for humanity, has already attracted great interest in the scientific community and gained some support among environmental policy makers (Mace et al., 2014).

Planetary boundary processes inevitably operate across scales as do ecosystem processes, from sub-region scale to the level of the Earth system as a whole (Hughes et al., 2013; Steffen et al., 2015). Hence, Steffen et al. (2015) argued it is necessary to link global and regional scales because changes in control variables at the sub-global level can influence functioning at the whole global Earth system level. This interdependence indicates the need to define sub-global boundaries that are compatible with the global-level boundary definition. In addition, the control variables for many processes are spatially heterogeneous (Hughes et al., 2013). Therefore, we need to focus attention on some special and important regions to identify and quantify regional development boundaries.

The Loess Plateau in China, which covers an area of 640,000 km^2 and is home to more than 50 million people, is widely acknowledged as the region with the highest soil erodibility in the world

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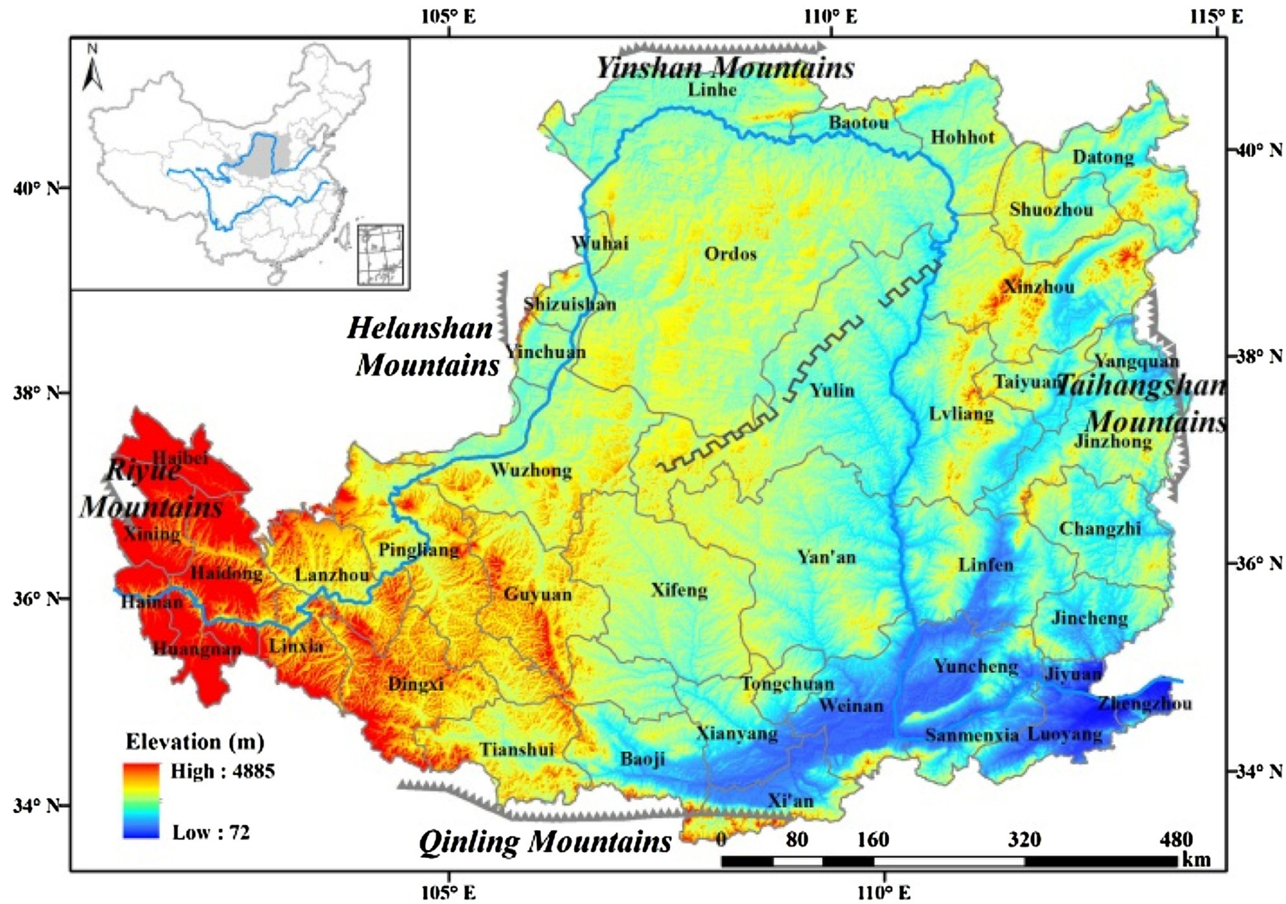

Fig. 1. Location of the Loess Plateau.

(Fig. 1). Nearly 90% of the sediment load of the Yellow River comes from the Loess Plateau. For a long time, this region was notorious for severe drought, erosion, sparse vegetation, high population pressure, low agricultural productivity and local farmer's poverty. Currently, the region is also of significance for China's entire ecological security and natural resources (e.g., coal, oil and gas, etc.) provision (Zhao et al., 2013). The Chinese government has recognized the serious situation in the Loess Plateau for many decades (Lü et al., 2012). Huge efforts and measures have been implemented to repair the deteriorated environments. Since the end of last century, many projects such as "Grain for Green" (GGP) and "Natural Forest Protection" were implemented (Feng et al., 2005, 2013). Large areas of sloping farmland were returned to forestlands and grasslands as a result of these projects (Wang et al., 2013). On the other hand, recent decades have also showed accelerated climate change trends in this region (Sun et al., 2015; Wang et al., 2012a,2012b).

Therefore, the Loess Plateau of China has experienced significant changes in earth surface processes and ecosystem structure and functions in these decades. The Loess Plateau has been the most effective zone for ecological restoration in China since 1999. Large-scale restoration measures and drought have led to a significant reduction of both runoff and sediment losses on the Loess Plateau, which have both advantages and disadvantages for the lower Yellow River (Huang and Zhang, 2004). Some local soil erosion has been successfully controlled, but the whole region remains very fragile ecologically. Thus, it is necessary to identify the regional development boundary of this ecologically vulnerable and climate change-sensitive area and propose some suitable solutions to the problems that exist within the boundary.

Some discussions exist on the synergy and trade-off relationships among the ecosystem services in the Loess Plateau. These discussions have been supported by quantitative assessment of ecological benefits of GGP and changes of major ecosystem services using a combination of remote sensing, model simulation and multivariate statistical analysis (Jia et al., 2014; Lu et al., 2014). Hu et al. (2014) developed a spatially explicit assessment and optimization tool for regional ecosystem services (SAORES), including a database, model base, scenario analysis module, tradeoff analysis module and integrated optimization module. Lü et al. (2012) revealed the spatial-temporal dynamic characteristics of ecosystem services, including water retention, soil retention, carbon sequestration and food production, in the Loess Plateau. However, few of these studies are related to the threshold of these ecosystem services for the socio-ecological system sustainable development in the Loess Plateau.

In this study, we applied the conceptual interpretation of a circular multistep knowledge development process for social-ecological systems research (Fig. 2), which includes system, target, and transformative knowledge (Partelow and Winkler, 2016). We reviewed the main natural and anthropogenic changes on the Loess Plateau during recent decades to identify the main development boundary of this region and propose some solutions for problems therein.

2. Materials and methods

Land cover data of the Loess Plateau were extracted from LANDSAT images with some additional images from the HJ 1A/B satellite (Fu et al., 2011; Zhang et al., 2014) to reveal the land cover changes from 1975 to 2010. In detail, land cover of 1975,

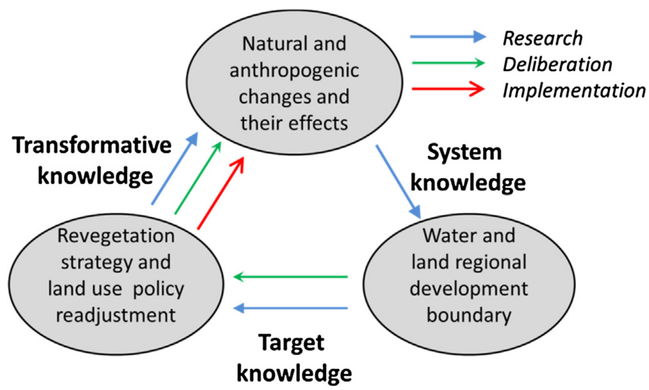

Fig. 2. Research framework of the study (Partelow and Winkler, 2016).

1990, 2000 and 2010 were produced and used for the analysis (Feng et al., 2013; Feng et al., 2012). Satellite-estimated net primary productivity (NPP) and actual evapotranspiration (ET) over the Loess Plateau for the period 2000–2010 was derived from a previous study (Feng et al., 2016). Annual runoff and sediment load data from the main gauging stations along the Yellow River and 12 tributaries on the Loess Plateau were obtained from the Bureau of Hydrology, Yellow River Conservancy Commission. Daily precipitation data were provided by the National Meteorological Administration of China. Records of soil and water conservation measures, including terraces, dams, and reservoirs, were provided by Yellow River Conservancy Commission, the Yellow River water conservancy yearbook, and the bulletin of the first national water resource census. Soil moisture was observed manually across the North–South Transect of the Loess Plateau based on the precipitation gradient and land use type. We also investigated changes in the industrial structure of Yanchang County of Shaanxi province and explored the key factors that play a pivotal role in people's satisfaction of their life.

3. Results

3.1. Land use and land cover change

Land cover of the Loess Plateau changed dramatically during recent decades, both in spatial pattern and area. The land cover change mainly appeared in the region's "Hilly and Gully" area, and was characterized by a decrease in farmland (by 14%) and water-body, and an expansion of non-agricultural vegetation cover (by 8%) and built-up area. Because farmland is the critical area for soil erosion, abandoning sloping farmlands for revegetation is a dominant measurement for revegetation effectiveness. After the 2000s, a large amount of sloped farmlands were transferred to grassland or forest. The shrinkage of farmland and expansion of non-agricultural vegetation and built-up area occurred at a greater rate during 2000–2010 than before. From 2000 to 2010, the area of farmlands decreased by 13%. On the contrary, farmland area was increasing during 1975–1990, and only slightly decreased during 1990–2000. Farmlands and barren area were the main contributor for increased grassland area. After 1990, peculiarly after the launch of Green for Grain project, grassland expansion gained the largest proportion of transferred farmlands. Furthermore, some of the grasslands became forest through succession and reforestation, and the proportion enlarged dramatically after 2000 as result of artificial revegetation (Fig. 3).

Table 1
The mean and trend of the water discharge during 1961–2009 in the main tributaries in the Loess Plateau.

Catchment	Mean (km^3 y^{-1})	Coefficient of Variation (%)	Trend (km^3 y^{-2})	p
Huangfu	0.12	79.66	0.00	0.00
Kuye	0.52	54.31	−0.01	0.00
Tuwei	0.32	28.43	−0.01	0.00
Jialu	0.06	64.37	0.00	0.00
Wuding	0.86	25.39	−0.01	0.00
Dali	0.14	33.61	0.00	0.00
Qingjian	0.14	39.94	0.00	0.10
Yan	0.20	37.49	0.00	0.00
Beiluo	0.61	41.17	−0.01	0.00
Jing	1.43	37.38	−0.01	0.05
Wei	1.97	55.49	−0.05	0.00
Fen	0.76	77.68	−0.03	0.00

Table 2
The overall rating of the farmers on the natural environment and living conditions (3 = Very satisfied; 0 = Very unsatisfied).

Conditions	3	2	1	0	Score
Land shortage	41.25	16.25	28.75	13.75	1.39
Public transport	37.31	25.37	11.94	25.37	1.75
Medical	34.07	20.88	17.58	27.47	1.62
Shopping	31.40	23.26	11.63	33.72	1.54
Security	65.22	21.01	11.59	2.17	2.51
Road	34.62	23.08	19.23	23.08	1.70
Housing	41.38	28.74	20.69	9.20	2.03

3.2. Hydrological effects

Newly introduced vegetation usually consumes more soil moisture than native plants and thus rapidly depletes local soil moisture resources and leads to the formation of a dry soil layer. Transect survey data indicated that bare soils usually have a higher soil moisture content than vegetated soils and that annual crops and grasses have a higher soil moisture content than forests (Fig. 4). The vegetation intercepts precipitation, improves the infiltration rate of water into the soil, slows or retains the runoff, and increases evapotranspiration, consequently delaying or even reducing runoff. For the 14 tributary stations, the hydrological variables including both water and sediment discharge displayed a significantly decreasing trend at most stations (Table 1). We also noted that since 1997, the observed river flow at Huayuankou Station tended to be lower than at Lanzhou Station, emphasizing that water consumption had already exceeded the water yield within the Loess Plateau (Fig. 5).

3.3. *Social-economic effects*

With the changing of land use, the social-economic system also changed. For example, the proportion of the primary industry in Yanchang County's GDP decreased and the proportion of secondary and tertiary industries increased rapidly. Previously, we used linear regression analysis to sort the income categories according to the degree to which they contributed and found the order to be: orchard income > migrant work income > livestock and poultry breeding income > other income > grain cultivation income > technical income > vegetable income self-employed income > subsidy for GGP (Zhen et al., 2014). The incomes generally balanced expenditures and the major items in expenditure were living expenses, investment in agriculture, and educational and medical expenses. Local people felt satisfied about the environment (air quality, water quality, soil conservation, and refuse disposal), traffic conditions and housing conditions. But most respondents thought that the cultivated land was insufficient to support a whole family and the price was high (Table 2).

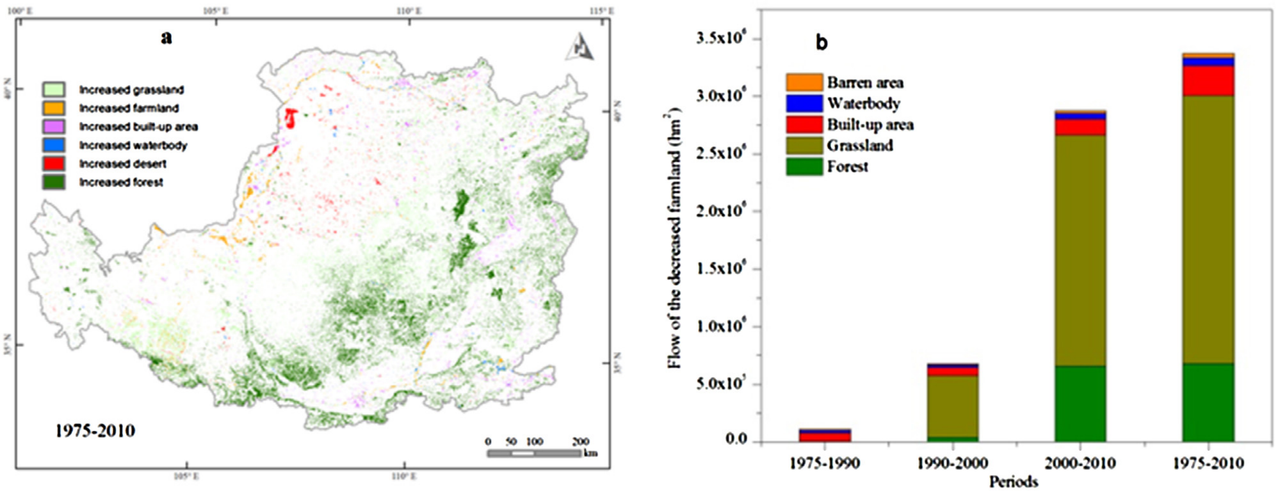

Fig. 3. Spatial pattern of land cover change during 1975–2010 on the Loess Plateau (a) and the changes in farmlands during the different periods (b).

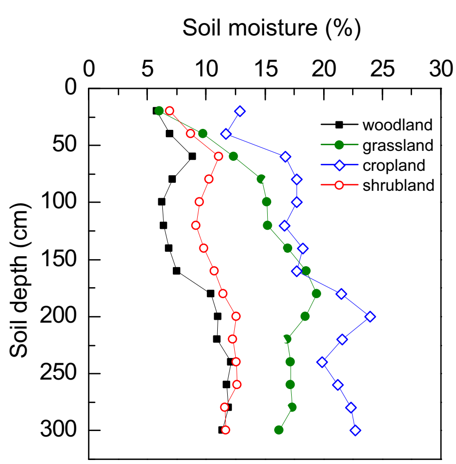

Fig. 4. Typical vertical profiles of soil moisture along the Loess Plateau transect.

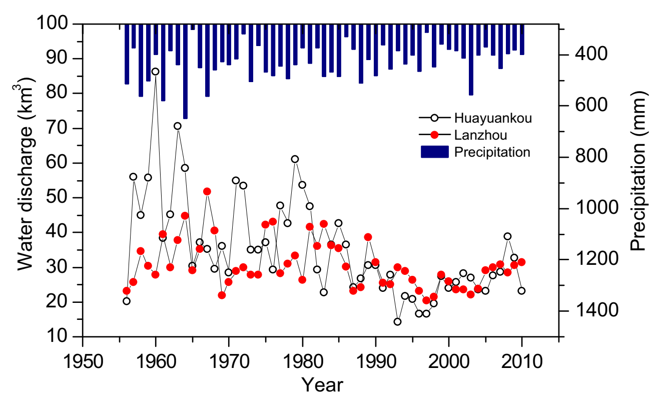

Fig. 5. Precipitation and river discharge at the Lanzhou station (the Yellow River inlet of the Loess Plateau) and Huayuankou station (outlet).

4. Discussion

4.1. Water limit for regional revegetation

Long-term human activities and climate change reshaped the complex land cover pattern of the Loess Plateau (Zhou et al., 2014). Among them, agricultural activities were the main factors responsible for vegetation coverage loss over a long period. After the Opening and Reform of China at the end of the 1970s, restoration and reconstruction of vegetation cover driven by economic benefit and incentive policy became critical forces that encouraged efforts to control the soil and water loss in the Loess Plateau (Lü et al., 2012).

Ecosystem conversion has already altered (i.e., increased) the annual NPP in the ecologically restored areas independent of whether climatic conditions remained sTable Significantly increased net ecosystem production was also found on the Loess Plateau, and an increase of 30% in MODIS-derived vegetation greenness has occurred in the Loess Plateau (Zhou et al., 2009). Accordingly, satellite-derived ET estimates increased by 4.3 ± 1.7 mm yr^{-1} over the last decade, and these are consistent with, although lower than, the independent trend of ET inferred from the water balance of the Loess Plateau area (Feng et al., 2016). Zhang et al. (2016) also indicated that the annual average water use efficiency decreased in the order of grasslands > woodlands > shrublands > croplands. Increased ET due to revegetation implies a decrease in runoff and soil water availability, because precipitation input has not significantly increased during the last decade (Wang et al., 2016b). However, water resources on the Loess Plateau are essential for supporting the 108 million people that inhabit in the Yellow River basin. Hence, balancing vegetation demand for water and water supply is critical to promoting sustainable management of the re-vegetation programs and safeguarding water demand of the social-economic system.

Current NPP in the Loess Plateau has already reached the threshold of the regional vegetation capacity, implying that the existing vegetation recovery strategy needs to be adjusted. The environmental gradient is obvious in the Loess Plateau, where the annual precipitation varies from 200 mm yr^{-1} in the northwest to 800 mm yr^{-1} in the southeast; thus, identifying the suitable revegetation priority zones according to the vegetation capacity and the corresponding species and density is necessary (Wang et al., 2016a). In addition, in the areas where annual precipitation is less than 500 mm, efforts should restore a more natural ecosystem, based on planting perennial shrubs and grasses instead of trees, and with the density of plantations being thinned regularly (Cao et al., 2009, 2011). Otherwise, terrain can also significantly affect the water redistribution processes and concentrate them in valleys; thus finding a suitable land position for revegetation is also important in the loess "Hilly and Gully" area (Jiao et al., 2016).

Fig. 6. A gully reclamation project under construction (left) and after the planting of crops (right) (photos by courtesy of Yurui Li, CAS).

4.2. Land shortages and solutions

Although the GGP has significantly improved environmental quality on the Loess Plateau, it has also led to a sharp decrease of cropland area. While the construction of check dams can indeed add cropland area and enhance cropland productivity, their primary function of sediment interception has gradually diminished due to the implementation of other soil and water conservation measures. As an integrative mode of land management, gully reclamation can not only create cropland and conserve soil and water, but also strengthen agricultural infrastructure construction, foster large-scale agricultural operations and promote the development of rural economy (Fig. 6). However, certain environmental risks must be avoided in the process of implementing gully reclamation.

Wang et al. (2011) summarized the advantages of check dams in terms of enhancing environmental services and food security on the Loess Plateau. The construction of check dams has indeed added cropland to the Loess Plateau region over the last decade, which has in turn increased food production (Xu et al., 2004). These changes, however, have not been without cost. One of the negative effects of check dams is the reduction of regional water yields and the resulting severe water resource stresses downstream (Miao et al., 2010; Xu et al., 2012). Furthermore, other soil and water conservation measures effectively decreased soil erosion in the Loess Plateau over the last decade, reducing sediment deposition in the check dams. The sediment load gauged by the Tongguan hydrologic station decreased substantially to 0.132 billion metric tons per year in 2011, representing only 12.57% of the sediment load of 1.05 billion metric tons per year occurring between 1950 and 2010 (The Ministry of Water Resources of the People's Republi of China, 2012). At present, the large scale of check dam construction has negated the primary functions of many check dams in terms of sediment interception and cropland creation (Jin et al., 2012). An urgent need exists for a completely new comprehensive land management approach.

Liu et al. (2013) introduced the advantages of filling gullies to create farmland on the Loess Plateau. The Ministry of Land and Resources launched the Gully Reclamation Project on the Loess Plateau in 2012. This project intends to reclaim 33.78 thousand ha of cropland between 2013 and 2017. The gully reclamation project is designed as an integrative form of gully management engineering, combining the cutting of adjoining slopes to fill the gullies, the construction of new check dams, the restoration of old check dams, treatment of saline-alkali lands, exploitation and utilization of idle lands, the digging of irrigation and drainage canals, the building of field roads, and ecological construction. In light of the dense distribution of gullies, the Loess Plateau is likely to have excellent potential in terms of successful gully reclamation, which will substantially contribute to increasing cropland area. For example, in Yan'an Municipality alone there are approximately 44,000 gullies with lengths longer than 500 m, and 20,900 of these are longer than 1000 m. By means of leveling land, enlarging parcel size, improving irrigation and drainage systems, repairing and constructing field roads, and implementing saline-alkali land treatment, comprehensive gully reclamation can also significantly improve the quality of croplands. The building and repair of check dams can also help enhance cropland productivity by improving the retention of nutrient rich soil that erodes from hillsides and by improving water availability. Food production on cropland treated by check dams is 2–3 times higher than that in terraced cropland, and 6–10 times higher than in untreated sloped cropland. The average crop yield is 45,000 kg ha^{-1}, with some yields reaching 105,000 kg ha^{-1} (Wang et al., 2011).

Based on land use evaluation and scenario analysis, Chen et al. (2003) regarded the following land use scenario as being the most acceptable. First, all land with deep soil and slopes less than 15° should be used for agricultural cropland, possibly combined with biological conservation measures such as mulching together with improved fallowing. Second, all land with slopes steeper than 15° should be used for purposes other than cropland (orchards and other cash trees, woodland, shrubland, and grassland). In accordance with this research, the Gully Reclamation Project Construction Management Interim Procedures stipulate that, "for every ha of cropland reclaimed in the gully, there must be 3 ha cropland returned to forest or grassland on terrace or slope." This thoughtful provision prevents vegetation loss in the process of cropland creation, effectively consolidating the achievements of the GGP.

While the gully reclamation project has the positive effects described above on environmental protection and food security, some associated environmental risks remain common concerns among scientists and policy makers. The Loess topography is highly susceptible to soil erosion, especially during continuous high intensity rainfall. For example, 1800 ha of the 8400 ha of cropland newly created by dam construction were damaged in Yan'an in July 2013 by the longest duration, strongest intensity rainstorm that occurred since meteorological data were first officially recorded in 1954. In addition to the continuous heavy rainfall, poor engineering standards were a major cause of this damage. Due to funding restrictions, 90% of the drainage canals were built of soil, and approximately 31 km of these were destroyed during the rainstorm. Also relevant in this regard is the fact that an obviously drier and warmer trend is anticipated in terms of future climate change for the Loess Plateau (Wang et al., 2012a,2012b). While the decreased precipitation will probably result in reduced topsoil erosion, the probability of head-cut gully erosion will increase because of extreme precipitation events. To reduce the risk of environmental damage, it is necessary to select suitable reclamation sites, improve engineering construction standards, and strengthen vegetation recovery (both on the slopes and in the dammed fields) through a combination of engineering and biological measures.

The integrated implementation of the GGP on terraces and slopes and land reclamation efforts in the gullies is now progressing steadily on the Loess Plateau. From the perspectives of social-economic-ecological functions, these projects have established an integrative platform for ecological security, cropland protection, and alleviation of poverty in the Hilly and Gully area of the Loess Plateau region. Advancing new rural construction, strengthening agricultural infrastructure construction, and fostering large-scale agricultural operations have been described as effective measures to narrow the gap between urban and rural areas (Liu et al., 2014). From this perspective, gully reclamation can also contribute to the achievement of this goal in this ecologically vulnerable and relatively impoverished area of Northwest China.

5. Conclusions

Planetary boundary is an important concept and useful for quantifying the sustainability of the social-ecological system. Identification of the regional development boundary and devising solutions for problems therein are the basis of the sustainable operation of local and global earth systems. The Loess Plateau in China is an ecologically fragile area that is sensitive to climate change and has recently experienced significant natural and anthropological influences. Thus, the Loess Plateau is an ideal area for a regional development boundary study.

Large scale land use and land cover change during recent decades effectively contributed to the vegetation restoration. However, these changes increased evapotranspiration and ultimately reduced the soil moisture and water discharge in the Loess Plateau. Recent revegetation on the Loess Plateau has already approached the regional water resources development boundary. It is necessary to readjust the existing revegetation strategy according to the water capacity, including identifying the suitable priority zones for revegetation and the corresponding species and density, and assuring the density of plantations is thinned regularly to keep the planted ecosystem healthy. In addition, large scale restoration programs have significantly improved environmental quality on the Loess Plateau, but also have caused a sharp decrease of cropland area. While the construction of check dams can indeed add cropland area and enhance cropland productivity, their primary function of sediment interception has gradually diminished due to the implementation of other soil and water conservation measures. As an integrative mode of land management, gully reclamation can not only create cropland and conserve soil and water, but also strengthen construction of agricultural infrastructure, foster large-scale agricultural operations and promote the development of rural economy. However, certain environmental risks must be avoided in the process of implementing gully reclamation.

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References

Cao, S., Chen, L., Yu, X., 2009. Impact of China's Grain for Green Project on the landscape of vulnerable arid and semi-arid agricultural regions: a case study in northern Shaanxi Province. J. Appl. Ecol. 46, 536–543.

Cao, S., Chen, L., Shankman, D., Wang, C., Wang, X., Zhang, H., 2011. Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. Earth Sci. Rev. 104, 240–245.

Chen, L.D., Ingmar, M., Zhang, S.R., Fu, B.J., Stig, L., 2003. Land use evaluation and scenario analysis towards sustainable planning on the Loess Plateau in China—case study in a small catchment. Catena 54, 303–316.

Feng, Z.M., Yang, Y.Z., Zhang, Y.Q., Zhang, P.T., Li, Y.Q., 2005. Grain-for-green policy and its impacts on grain supply in West China. Land Use Policy 22, 301–312.

Feng, X., Sun, G., Fu, B., Su, C., Liu, Y., Lamparski, H., 2012. Regional effects of vegetation restoration on water yield across the Loess Plateau, China. Hydrol. Earth Syst. Sci. 16, 2617–2628.

Feng, X., Fu, B., Lu, N., Zeng, Y., Wu, B., 2013. How ecological restoration alters ecosystem services: an analysis of carbon sequestration in China's Loess Plateau. Sci. Rep. 3.

Feng, X., Fu, B., Piao, S., Wang, S., Ciais, P., et al., 2016. Revegetation in China's Loess Plateau is approaching sustainable water resource limits. Nat. Clim. Change 6, 1019–1022.

Fu, B., Liu, Y., Lü, Y., He, C., Zeng, Y., Wu, B., 2011. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. Ecol. Complexity 8, 284–293.

Hu, H., Fu, B., Lü, Y., Zheng, Z., 2014. SAORES: a spatially explicit assessment and optimization tool for regional ecosystem services. Landscape Ecol. 30, 547–560.

Huang, M.B., Zhang, L., 2004. Hydrological responses to conservation practices in a catchment of the Loess Plateau China. Hydrol. Processes 18, 1885–1898.

Hughes, T.P., Carpenter, S., Rockstrom, J., Scheffer, M., Walker, B., 2013. Multiscale regime shifts and planetary boundaries. Trends Ecol. Evol. 28, 389–395.

Jia, X., Fu, B., Feng, X., Hou, G., Liu, Y., Wang, X., 2014. The tradeoff and synergy between ecosystem services in the Grain-for-Green areas in Northern Shaanxi. China. Ecol. Indic. 43, 103–113.

Jiao, L., Lu, N., Fu, B., Gao, G., Wang, S., Jin, T., Zhang, L., Liu, J., Zhang, D., 2016. Comparison of transpiration between different aged black locust (Robinia pseudoacacia) trees on the semi-arid Loess Plateau, China. J. Arid Land 8, 604–617.

Jin, Z., Cui, B.L., Song, Y., Shi, W.Y., Wang, K.B., Wang, Y., Liang, J., 2012. How many check dams do we need to build on the Loess Plateau? Environ. Sci. Techonol. 46, 8527–8528.

Lü, Y.H., Fu, B., Feng, X., Zeng, Y., Liu, Y., Chang, R., Sun, G., Wu, B., 2012. A policy-driven large scale ecological restoration: quantifying ecosystem service changes in the Loess Plateau of China. PLoS One 7, e31782.

Liu, Q., Wang, Y.Q., Zhang, J., Chen, Y.P., 2013. Filling gullies to create farmland on the Loess Plateau. Environ. Sci. Techonol. 47, 7589–7590.

Liu, Y., Yang, R., Long, H., Gao, J., Wang, J., 2014. Implications of land-use change in rural China: a case study of Yucheng, Shandong province. Land Use Policy 40, 111–118.

Lu, N., Fu, B., Jin, T., Chang, R., 2014. Trade-off analyses of multiple ecosystem services by plantations along a precipitation gradient across Loess Plateau landscapes. Landscape Ecol. 29, 1697–1708.

Mace, G.M., Reyers, B., Alkemade, R., Biggs, R., Chapin, F.S., Cornell, S.E., Díaz, S., Jennings, S., Leadley, P., Mumby, P.J., Purvis, A., Scholes, R.J., Seddon, A.W.R., Solan, M., Steffen, W., Woodward, G., 2014. Approaches to defining a planetary boundary for biodiversity. Glob. Environ. Change 28, 289–297.

Miao, C.Y., Ni, J.R., Borthwick, A.G.L., 2010. Recent changes of water discharge and sediment load in the Yellow River basin China. Prog. Phys. Geogr. 34, 541–561.

Partelow, S., Winkler, K.J., 2016. Interlinking ecosystem services and Ostrom's framework through orientation in sustainability research. Ecol. Soc. 21 (3), 27, http://dx.doi.org/10.5751/ES-08524-210327.

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., 2009a. A safe operating space for humanity. Nature 461, 472–475.

Rockstrom, J., Steffen, W., Noone, K.J., Persson, A., Stuart, F.M., Chapin, I.F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., 2009b. Planetary boundaries: exploring the safe operating space for humanity. Ecol. Soc. 14.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., 2015. Planetary boundaries: guiding human development on a changing planet. Science 347, 1259855.

Sun, Q.H., Miao, C.Y., Duan, Q.Y., Wang, Y.F., 2015. Temperature and precipitation changes over the Loess Plateau between 1961 and 2011, based on high-density gauge observations. Glob. Planet. Change 132, 1–10.

The Ministry of Water Resources of the People's Republi of China, 2012. Chinese River Sediment Bulletin (pp: 21.).

Wang, Y.F., Fu, B.J., Chen, L.D., Lu, Y.H., Gao, Y., 2011. Check dam in the Loess Plateau of China: engineering for environmental services and food security. Environ. Sci. Techonol. 45, 10298–10299.

Wang, Q.X., Fan, X.H., Qin, Z.D., Wang, M.B., 2012a. Change trends of temperature and precipitation in the Loess Plateau Region of China, 1961–2010. Glob. Planet. Change 92-93, 138–147.

Wang, Q.X., Fan, X.H., Qin, Z.D., Wang, M.B., 2012b. Change trends of temperature and precipitation in the Loess Plateau Region of China, 1961–2010. Glob. Planet. Change 92, 138–147.

Wang, J.Y., Liu, Y.S., Liu, Z.G., 2013. Spatio-temporal patterns of cropland conversion in response to the Grain for Green Project in China's Loess Hilly Region of Yanchuan County. Remote Sens. 5, 5642–5661.

Wang, S., Fu, B., Liang, W., 2016a. Developing policy for the Yellow River sediment sustainable control. Natl. Sci. Rev. 3, 162–165.

Wang, S., Fu, B., Piao, S., Lü, Y., Ciais, P., Feng, X., Wang, Y., 2016b. Reduced sediment transport in the Yellow River due to anthropogenic changes. Nat. Geosci., 38–41.

Xu, X.Z., Zhang, H.W., Zhang, O.Y., 2004. Development of check-dam systems in gullies on the Loess Plateau China. Environ. Sci. Policy 7, 79–86.

Xu, Y.D., Fu, B.J., He, C.S., 2012. Assessing the hydrological effect of the check dams in the Loess Plateau, China by model simulations. Hydrol. Earth Syst. Sci. Discuss. 9, 13491–13517.

Zhang, L., Li, X., Yuan, Q., Liu, Y., 2014. Object-based approach to national land cover mapping using HJ satellite imagery. J. Appl. Remote Sens. 8, 464–471.

Zhang, T., Peng, J., Liang, W., Yang, Y., Liu, Y., 2016. Spatial–temporal patterns of water use efficiency and climate controls in China's Loess Plateau during 2000–2010. Sci. Total Environ. 565, 105–122.

Zhao, G., Mu, X., Wen, Z., Wang, F., Gao, P., 2013. Soil erosion, conservation, and eco-environment changes in the loess plateau of China. Land Degrad. Dev. 24, 499–510.

Zhen, N., Fu, B., Lu, Y., Zheng, Z., 2014. Changes of livelihood due to land use shifts: a case study of Yanchang County in the Loess Plateau of China. Land Use Policy 40, 28–35.

Zhou, H.J., Van Rompaey, A., Wang, J.A., 2009. Detecting the impact of the Grain for Green program on the mean annual vegetation cover in the Shaanxi province China using SPOT-VGT NDVI data. Land Use Policy 26, 954–960.

Zhou, X., Li, X., Dodson, J., Yang, S., Long, H., Zhao, K., Sun, N., Yang, Q., Liu, H., Zhao, C., 2014. Zonal vegetation change in the Chinese Loess Plateau since MIS 3: Palaeogeogr. Palaeoclimatol. Palaeoecol. 404, 89–96.