China's Loess Plateau -- A Region of Heterogeneous Environmental Communities

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Abstract

The Loess Plateau is an area of extreme soil erosion and water scarcity. Restoration methods in the past have tried to solve environmental problems like these through large-scale land reformation such as terracing. Though this model has been successful where implemented, it cannot be used as a model for the Loess Plateau as a whole because this area is a very heterogeneous landscape in terms of environmental factors, such as slope, soil composition, climate, etc. Additionally, the social resources vary dramatically. This study investigated a region in the southern portion of Shanxi province where unsustainable water use appears to be an important issue. Water statistics analyses suggest that groundwater use is increasing and more water has been diverted from river systems into reservoirs. Local interviews confirmed these trends. The findings of this paper suggest that a one-size-fits-all restoration model cannot work for the Loess Plateau. Instead, local planning and implementation at the village level may be more appropriate.

Key words: Water resource management, Loess Plateau, Reforestation, Ground Water, Surface Water

Background on the Loess Plateau: Natural and Human-Caused Conditions

Natural Conditions. The Loess Plateau is a region of northwest-central China defined by its characteristic loess soils. Estimates for the area of the Loess Plateau range from several hundred thousand square kilometers. The loess deposits are up to 2.5 million years old and can be found at depths ranging from 50 to 200m, making China's Loess Plateau the largest loess deposit in the world both in terms of area and depth. Because of its immensity and unique composition, China's Loess Plateau is also the most investigated deposit (Liu 1999). The texture of the loess soil in the highland regions of the Loess Plateau is generally uniform: fine, pliable, and porous (Ho 1969, Mei and Dregne 2001, Liu 1999, Yang et al. 2010). High erosion rates, especially during moments of high water velocity on slopes, are also in the nature of fine soils with homogeneous texture (Xu 2004). As such, the plateau loses an average 3720 t/km^2 per year (Liu 1999). Though this high rate of erosion is largely due to anthropogenic factors, historically much of this can be attributed to natural erosion by wind and water.

The Yellow River winds through the region, creating a physical boundary between Shaanxi and Shanxi provinces. Much of the soil that gives the river its color originates on the Loess Plateau and enters the river due to erosion. More than 60% of the Yellow River basin precipitation occurs between June and September in flash downpours and sudden storms that bring higher rates of precipitation than the infiltration rate of loess can tolerate, causing much of the soil to be lost in a very small length of time. Gully slopes can carry as much as 505 kg/m^3 of sediment in heavy rains. Precipitation ranges between 200-750 cm: generally decreasing from southeast to northwest (Giordano *et al.* 2004, Mei and Dregne 2001).

Human-Caused Conditions. The Yellow River basin contains 8.7% of China's population and 17% of its agricultural land (YRCC 2002). The farmers in this region are among the poorest rural residents in China (Veeck *et al.* 1995) and increasing population trends force agricultural practices onto land surfaces that are naturally erosion-prone, further exacerbating natural erosion and decreasing soil quality (Cai 2002). Forty-five to 62% of land under cultivation in northern Shaanxi province is located on slope land that is already composed of the world's most erosive soil. Seventy to 80% of hilly and gully land is under cultivation and of this, 15-20% is on a slope of 25 degrees or greater (Liu 1999).

More than 200 plant species have become extinct since the 1950s and more than 61% of wildlife species have suffered severe losses of their habitats from poor land practices such as overgrazing or reforestation failures (Cao *et al.* 2009). The Yellow River has also seen huge changes – a significant huge flow decline since the 1950s. Water loss has been attributed to silt-retention dams and terracing, industrial development, irrigation expansions, and population growth (Mei and Dregne 2001).

In response to this environmental degradation, the government has instituted slope conversion and reforestation programs intended to reduce erosion and increase biodiversity and ecosystem stability. At present, the most pressing issues lie in forming a balance between high crop yield and sustainable farming practices. The past 50 years have seen large-scale cropland expansion and unsustainable use of water resources, grassland overgrazing, and deforestation – all with the long-term goal of increasing agricultural productivity (Wang and Shen 2009).

Economic progress has brought a new level of pollution into watersheds, impacting both ground and surface water, and depletes water levels (Mei and Dregne 2001). Sustainability is a term that has been used often in recent years in policy decisions, but there is a gap between discussion and implementation at the local level (Cao *et al.* 2009). When large policy decisions are made in a centralized government and then introduced to a range of ecologically divergent areas, the environment suffers. Solutions are not fine-tuned to specific areas. Invasive species may colonize, proliferate and threaten the balance of ecosystems (Shapiro 107, Cao *et al.* 2009).

The variation in surface water resources across the region and in Shanxi province alone has led to increased use of groundwater for both agriculture and industry in the area. Water resources have been exploited throughout China's long history of agriculture in the Loess Plateau and Yellow River basin, but as the population continues to increase at a rate of at least 1% per year (Liu and Diamond 2005), and the Chinese economy continues to boom, exploitation of resources is increasing and in particular need for water in this region is becoming more and more urgent. Groundwater pumping in the Yellow River basin alone has increased by 5.1 billion cubic meters in the past 30 years (MWR 2002). Declining supply and increasing demand have meant a 61% increase in groundwater pumping from 1980 to 2002. This rate is unsustainable for the entire nation as it holds 20% of the world's population but a mere 7% of its water resources (Xinhua). Groundwater mining results in dry wells, reduced rivers and lakes, deterioration of water quality, increased pumping costs of deepening wells, land subsidence, and the formation of sinkholes (Prud'homme 258). These and other consequences of groundwater overdraft can be witnessed across China, from seeing a number of China's major cities sinking into the holes made from depleted aquifers (ABC News) to the five billion cubic meters of sewage input that contributes to the Yellow River's annual flow (Basin Short Profile, IWMI).

Restoration Work and This Study

As mentioned above, various environmental restoration projects, such as the World Bank China Loess Plateau Watershed Rehabilitation Project, have been employed to try to combat water conservation and soil erosion. In 1994 and again in 1998, the World Bank model was implemented throughout the plateau with goals of improving water catchment, reducing erosion rates, and increasing agricultural yields to improve local communities. To determine the exact restoration method needed, developers looked at topography, soil, water, agricultural, and institutional conditions. Large-scale land transformation projects were then completed by creating some combination of sediment control dams, rainwater diversion and harvesting infrastructure, terracing sloped land, reforestation and groundwater irrigation infrastructure. Research and local capacity building was then employed to ensure the project's success. Follow-up monitoring studies have shown that this model has succeeded in meeting all of the initial goals to some degree (United Nations Environmental Programme, 2003).

This study aims to assess the environmental and social conditions of a specific region of the Loess Plateau and investigate restoration work that has been completed. In this project, four students received funding from the U.S. National Science Foundation and the University of Pittsburgh to explore the nuances of water use in villages across Shaanxi and Shanxi provinces, which are located on the Loess Plateau. Proficient in some areas and deficient in others, the management of natural resources in this region of China is a complex political phenomenon and one that merits further academic study. The findings of this paper will contribute to the understanding of the Loess Plateau social and environmental milieu as well as provide insight into preparation for environmental restoration work.

Materials and Methods

Statistical Data Collection. The majority of the data used in this paper is from Chinese Provincial Statistical Yearbooks and Chinese National Agricultural Yearbooks. Statistics include provincial groundwater use, groundwater and surface water resources, reservoir numbers, reservoir capacities, and surface area of land under erosion management. Data is presented temporally over a span of five to ten years. Scatter plots were used to determine what trends were present. Temporal evidence is limited to what is available on online databases and in the University of Pittsburgh's library system. The Chinese government's data collection process and resources also limit temporal data collection. For example, data for water resources were only available from 2000 in National Agricultural Yearbooks and provincial water usage data is only published every two years. Thus, the most recent statistics published in the 2011 provincial statistical yearbook are from 2009.

Anecdotal Evidence. Anecdotal evidence was acquired at meetings with local officials and interviews with villagers in both Shanxi and Shaanxi Provinces. In Shaanxi, field research was conducted in villages located in Yanchuan (延川县), a county of Yan'an City (延安); and Qingjian (清涧县), a county of Yulin City (榆林). Villagers were interviewed in a total of six villages: Liang Jia Ta (梁家塔), Liang Jia He (梁家河), Xiao Cheng Cun (小程村), Xia Qi Li Wan (下七里湾), Qian Tan Cun (前摊村), and Zhang Zhuang Cun (张庄村). In Shanxi province, two counties were visited in Yuncheng City (运城市): Pinglu County (平陆县) and Hejin County (河津县). In Hejin, four villages were visited: Longmen Cun (龙门村), Dong Guang De Cun (东光德村), Fan Cun (樊村), and Zhao Jia Zhuang Cun (赵家庄村). Village visits would begin with a meeting of village leaders and local officials who would lecture on village water, agricultural, and living conditions. After these meetings, local officials would accompany interviewers into the villages and introduce villagers selected to be interviewed. Interviews were generally conducted in homes and questions were asked in the presence of local officials, often with a camera crew. Interview questions were tailored according to each village's geographic characteristics. For villages that have terracing, questions were asked about what crops are grown on the terraces, government subsidies that support terracing, and perceptions of terraces. For better endowed villages, questions were asked about government-organized job training, how living standards have changed over the past ten years, and perceptions of air and water pollution. In almost every village, villagers were asked where they get their water for agricultural and household use, how much they pay, and if there has ever been a shortage. Questions were also asked about natural disasters such as soil erosion or flooding and what actions were taken to prevent these incidents. The responses from villagers varied from village to village and depending on the presence of village leaders and conditions under which people were interviewed. More candid responses were obtained when interviewers broke up into smaller groups and sought villagers out without the presence of a local official. These observations support empirical data.

Results:

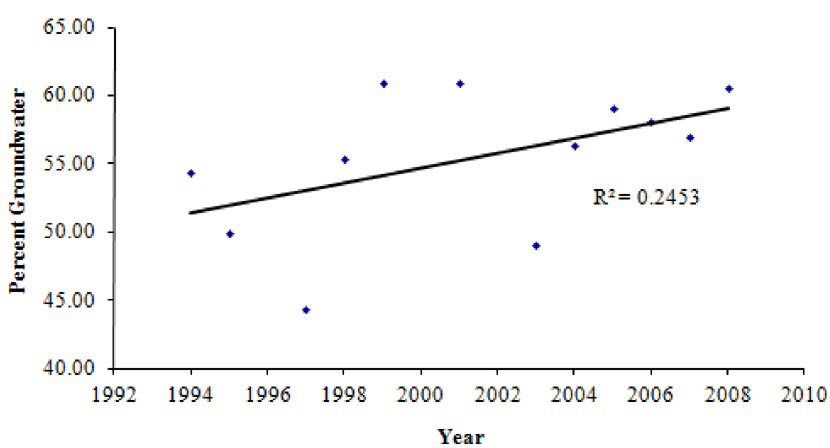

Figure 1: Percent groundwater use of total water use trend over time.

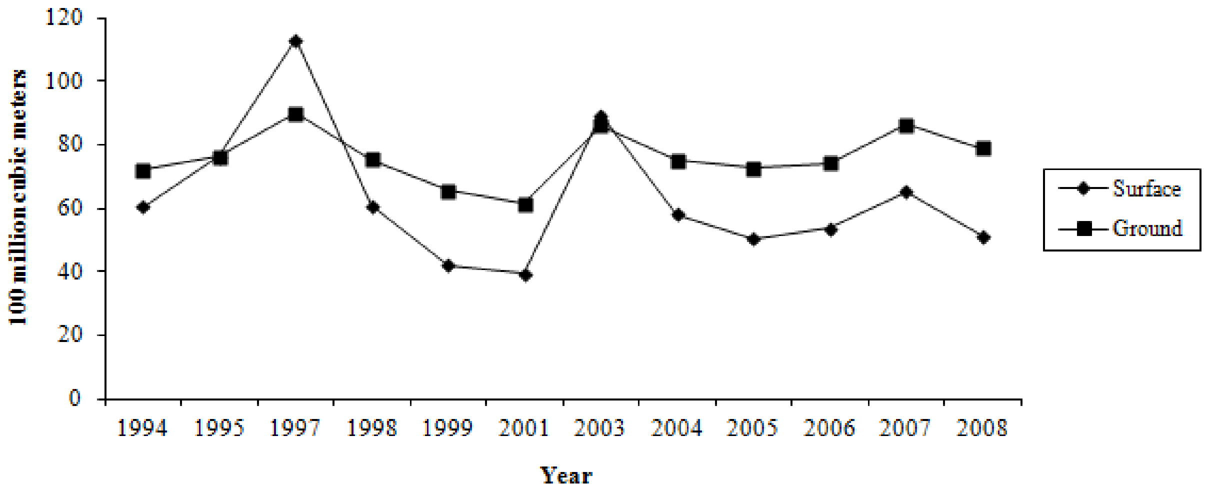

Figure 2: Amount of groundwater and surface water use plotted over time.

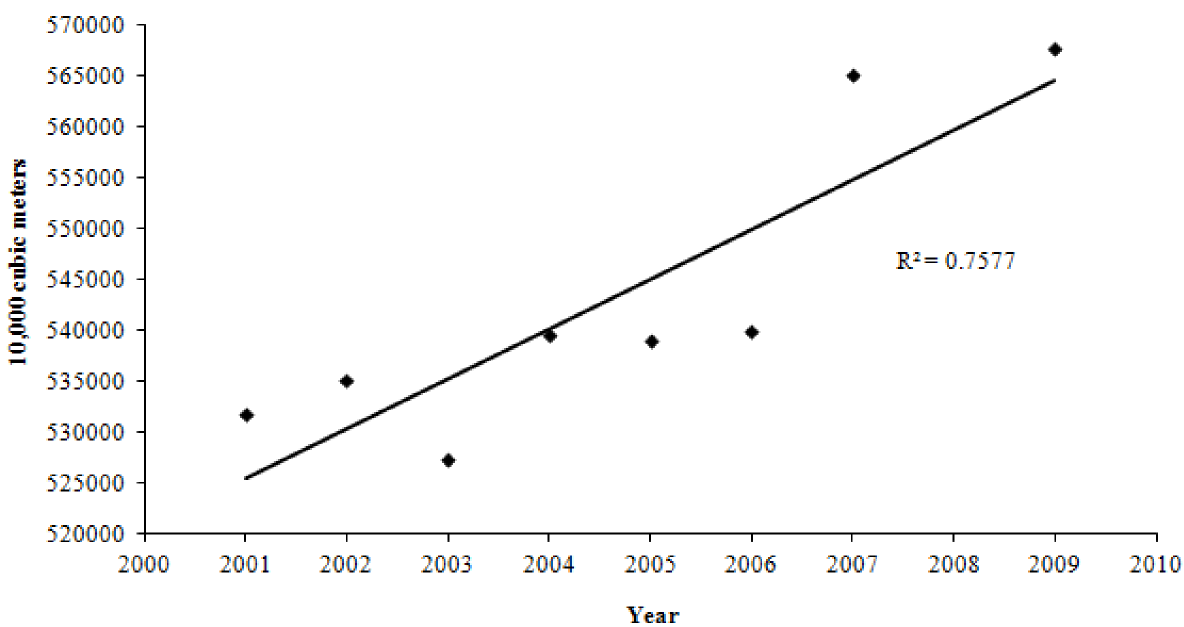

Figure 3: Volume of water stored in reservoirs plotted by year.

Table I: Summary of Interview Points Organized Categorically

	Liang Jia Ta Village, Shaanxi	Liang Jia He Cun Village, Shaanxi	Xiao Cheng Village, Shaanxi	Qing Jian County, Shaanxi
Water	Irrigation water comes from rainwater, Household water comes from a well; Water scarcity is a bigger problem than water pollution	Not mentioned	Terracing is believed to have increased water availability for crops such that irrigation is no longer necessary for the crops grown	Roughly an 8:1 ratio of groundwater use to rain water use
Land Reformation (Terracing)	Farmers typically cannot access highlands to terrace but slopes greater than 25 degrees are left untouched	Biggest environmental problem is soil erosion; No terracing because the land is too steep to terrace according to the Land Protection Program; The Land Protection Program does not allow agriculture on slopes greater than 25 degrees and terracing is seen as an agricultural practice	Terracing is prevalent both on agricultural lands and in naturally vegetated areas; Farmer bought a machine to upkeep terraces and is given government subsidies per mu of land that remains terraced; Believes that terracing improves soil and water	Currently there is some terracing on the higher elevation for corn, potatoes, and bean but most of the crops are grown in greenhouses and most of the sloped land is left as native vegetation; Terracing is viewed as an outdated agricultural practice that is too much effort and not very effective
Demographic Changes	Agriculture is mainly subsistence with profits coming from other industry; Typically only the grandparent generation farms and takes care of grandchildren while children moves to the city to do migrant labor	Incomes in the region come from migrant labor, raising animals, conventional agriculture, and subsidies from the government under the Land Conversion Program	Farming is the main source of income but it is supplemented with a family business and migrant labor	Trend is for younger people to work as migrant laborers in the cities while the elder people stay in the village and farm

Table I(Continued): Summary of Interview Points Organized Categorically

	Zhang Dian Village, Shaanxi	Long Men Village, Shanxi	Fan Cun Village, Shanxi
Water	Lots of problems with drought; Recently had to increase the depth of their well; 400 families access the same well; Water storage facilities dry up in the summer; People who could afford it (usually migrant laborers) generally rely on bottled water as well water is inconsistent; Water prices have increased	Companies tend to create their reservoirs; Large wells are created to provide drinking water; Water seems to be clearer now; Yellow River started drying up in the 1990's for the first time	The village has two wells that are 150-180m deep. Drinking water is only used from a well depth of at least 100m.
Land Reformation (Terracing)	No need for terracing, soil stability is fine and the land is already flat	No need for terracing, soil stability is fine and the land is already flat	No need for terracing, soil stability is fine and the land is already flat; Encouraged to grow fruit trees through a greenification program
Demographic Changes	Primary source of income comes from service work; Migrant labor is only temporary as everyone comes back to help during harvest	Young people tend to migrate to the cities for service jobs. There is high rate of inland migration to Long Men, and many college-educated young people would return to work in the village's coal or aluminum industries	Young people tend to migrate to the cities

The proportion of groundwater in total water usage for Shanxi province (Figure 1) suggests that groundwater use is increasing each year. Without an increase in the water table recharge rate, this suggests that the outflow from the water table is increasing while the inflow stays the same. This trend would suggest that there is a potential drop in the water table occurring. Moreover, comparing the amount of surface water and the amount of groundwater used in Shanxi each year (Figure 2) suggests that groundwater is now relied on more than surface water.

Though the volume of used surface water is decreasing relative to the volume of used groundwater, the nature of surface water resources appears to be shifting as well. Figure 3 shows that the amount of water stored in reservoirs is increasing each year. This indicates that surface water is increasingly being diverted from river systems and stored behind dams.

Though interviews varied based on geographic setting, socioeconomic conditions, and level of government presence (Table I), general trends emerged that largely corroborated the statistical findings. Interview data suggests that groundwater use is very prevalent and new water problems are arising that people have never seen before. For example, each village visited had wells of one hundred meters or more and made comments about how wells had to be dug deeper year after year. Farmers from villages closer to the Yellow River also mentioned that for the first time in their lives, sections of the river have begun to run dry. Management and land restoration efforts (such as terracing) that attempt to address water and other environmental problems appear to be centrally mandated, yet inconsistently implemented. At the same time, interviewees indicated that there is a demographic shift away from farming which leaves the future of agriculture and, in turn, China's food and environmental security uncertain.

Conclusion

Previous studies tend to group the entire Loess Plateau into one homogeneous region with the same social and environmental conditions. This is a misleading assumption. There are some similarities throughout the region like the attributes associated with loess soil and a comparable climate. But the region is far more complex.

The physical geography of the region varies dramatically ranging from steep slopes to gentle terracing. Many of the locations visited during this study varied between highlands and flatlands, terraced areas and severely eroded slopes, lush vegetation, and bare ground. The social environment also was variable; some communities were able to acquire wealth through non-agricultural industry while others struggled to make a living off of crop sales.

Thus, the Loess Plateau must be treated as a mosaic of unique environmental and social conditions with some similarities. This new perspective requires a rethinking of the restoration planning for the region. Instead of looking for a “fix-all” model that can be applied to the entire region, each section of the plateau must have a plan tailored to the unique milieu. Though much more labor intensive than previous models, each community visited in the study faces different environmental problems and has different resources available for a solution. For example, one village received plenty of government funds to terrace the land, yet suffered from an abundance of rain, while another village lost its most fertile land to highway development, leaving less fertile lands to grow less profitable crops. Perhaps the biggest finding of this study is that a single solution for the development problems of the Loess Plateau simply does not exist.

In looking at self-reported groundwater usage rates (Figure 1) it appears that groundwater is becoming increasingly important. In 2009, the most recently reported data, groundwater actually accounts for more than half of the water used in Shanxi. A nationwide groundwater report concluded that Shanxi groundwater fluctuates quite a bit in terms of water table depth and water quality (2009 Groundwater Report of China’s Major Cities and Regions). With an increased reliance on groundwater and an inconsistent water table, it is unclear what sort of water security can be relied on in the future. Interviews with older farmers corroborated the problem of digging wells deeper year after year.

In addition to a potentially unsustainable reliance on groundwater, more and more surface water is being diverted into reservoirs. Data on reservoir capacity suggests that the amount of water stored in reservoirs has been steadily increasing (Figure 3). Taking water out of river systems while removing massive amounts of groundwater appears to have taxed river flow rates (Gates *et al.* 2011). Interviews further confirmed this point as people mentioned that the Yellow River was running dry in certain places for the first time in their lifetimes.

This trend of unsustainable water use seems to corroborate the idea that the Loess Plateau must be treated as a non-homogeneous region: land moderation, like terracing, appears to have a negative effect on groundwater recharge rates. Gates *et al.* looked at how soil conservation practices affect groundwater recharge rates. The study found that approximately 20% of the entire Loess Plateau is being managed with soil conservation as the primary objective. Of that 20%, about 30% is land reconstruction (such as terracing or dams) while 50% is ecological modification (such as reforestation). All of these methods are intended to reduce soil erosion and halt water runoff. Naturally, if there is less water runoff there must be more water remaining. This water must be divided in some way between increased groundwater recharge and evaporation. Certain methods of soil conservation prevented water from recharging bodies of surface water (further contributing to the desiccation of rivers) and reduced groundwater recharge rates by almost 50% (Gates *et al.* 2001). This is a clear example of one method of restoration that may be successful in one area of the Loess Plateau actually furthering the problem in another.

Discussion

In recent years, the World Bank and other institutions have proposed a one-size-fits-all terracing model to reduce siltation across the Loess Plateau. These projects ought to be examined in the context of each community's distinctive social and geophysical conditions. Treating the plateau as a heterogeneous landscape negates the existence of a one-size-fits-all solution. In fact, this study suggests that environmental solutions and policy approaches would be more effective if they were executed as small-scale projects and catered to the specific geophysical conditions of the region. Provincial and even municipal levels of government ought to have the right to interpret agricultural policy set at the national level. Perhaps the most effective way of resolving large-scale environmental setbacks across the Loess Plateau is through a series of small-scale, grassroots projects. However, even with the implementation of grassroots projects, organizations must consider the opportunity cost of individuals in the community to take on new responsibilities. A 51-year-old farmer in Liang Jia Ta village in Shaanxi described her inability to participate in a government-subsidized pig farming program as “impossible” due to her commitments at home, such as taking care of her grandchildren, fixing the roof on her house, and farming.

Though terracing may not be the best solution for the entire region, the agricultural benefits of terracing conversion are profound, with some studies reporting a threefold increase in grain production from a hectare of land with slope greater than 25° into a fully horizontal, terraced hectare (Feng *et al.* 305). Horizontal terrain is better suited to retain irrigation water, loose soils like loess, and the root structures of crops; these factors promote more productive agriculture. However, there is little incentive for a farmer to individually terrace a region that is very steep and varied in slope. This is because the opportunity cost of terracing is more significant here than in a flatter area. A farmer must input greater units of time and labor to render the land flat, and even after doing so he or she may find that the soil is infertile after years of erosion. In general, such areas will be left deserted and uncultivated. Unfortunately, these areas may be some of the most crucial to terrace when reducing overall soil erosion of the Loess Plateau and siltation into the Yellow River. Thus, terracing is less of an agricultural, village-level problem than one that must be dealt with by environmental agencies.

Certain policies have progressed from the agricultural sector into the non-agricultural sector, such as the 1999 Slope Land Conversion Program. However, these policies lack a direct incentive to terrace non-agricultural land. The Slope Land Conversion Program, also known as the Grain-for-Green Program, is a nationally-established policy that grants food and financial subsidies to farmers who convert cultivated slope land back into forest and pasture (People’s Daily).

By providing grain and monetary payments, the government incentivizes farmers to restore vegetation on marginal slope land. Often, these government subsidies provide more profit incentive than agriculture itself. The effect has been an increase in the labor endowment of rural households from “on-farm work to the off-farm labor market (Uchida *et al.* 2009).” The government ought to extend this sectoral shift in the labor market to terracing. By coupling slope conversion with vegetation conversion, the people of the Loess Plateau can most effectively reduce soil erosion and siltation. Because the Grain-for-Green program is already established in China and addresses off-farm work payment, terracing incentives should be built into the already-existing policy framework.

Unfortunately, terracing is not a viable solution to all of the environmental problems of the Loess Plateau. As mentioned above, certain soil conservation practices can actually reduce the groundwater recharge rate. This is perhaps of greatest concern to farmers as the water table is simultaneously facing a decreasing recharge rate and an increasing outflow. The decline of the water table manifests in villages in the form of water shortages, requiring farmers to dig even deeper into the earth's surface to extract well water.

This study opens the door to future studies that look at water table trends and alternative methods of environmental restoration planning and implementation. It confirms that environmental and social problems are complex and fundamentally unique from areas facing similar problems. Though projects like mass terracing may work in certain regions of the Loess Plateau, different areas face different problems (like unsustainable groundwater use) and require other forms of management. Future studies should also investigate the effectiveness of small-scale management schemes because even in a geographic area such as the Loess Plateau, environmental and social conditions vary so greatly that one form of restoration cannot be applied ubiquitously. Thus, the unique milieu must be considered in order to develop a solution that accounts for the resources available, meets the needs of the community, and addresses the precise source of the environmental problem. Tailoring solutions to the specific environmental and social contexts will most effectively advance the Loess Plateau's sustainable development in years to come.

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