Sustainability **2015**, *7*, 5628-5647; doi:10.3390/su7055628

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Changing Food Consumption Patterns and Impact on Water Resources in the Fragile Grassland of Northern China

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Academic Editor: Yu-Pin Lin

Received: 29 December 2014 / Accepted: 22 April 2015 / Published: 7 May 2015

Abstract: A burgeoning population, pressing development needs and increasing household consumption are rapidly accelerating water use in direct and indirect ways. Increasingly, regions around the world face growing pressure on sustainable use of their water resources especially in arid and semi-arid regions, such as Northern China. The aim of this research is to obtain an overview of the cumulative water requirement for direct (domestic) water use and indirect water use for the basic food consumption of the households in the Inner Mongolia Autonomous Region (IMAR), in order to reduce the pressure on grassland of Western China by encouraging sustainable water consumption. For indirect water use, we use VWC (virtual water content) analysis theory to analyze the total consumption package of 15 basic food types that were identified and quantified based on the household survey in 2011. In this survey, domestic water consumption data and food consumption data were collected from 209 representative households with spatial variation across three sub-regions (including meadow steppe in Hulun Buir, typical steppe in Xilin Gol, and semi-desert steppe in Ordos) and temporal variation from 1995 to 2010. The results show that the total amounts of food consumption per capita in three sub-regions all show an increasing trend, especially in Hulun Buir and Ordos. Compared to the direct water consumption, the indirect water consumption behind food production made up a major portion of total water consumption, which is affected (1) geographic locations (grassland types); (2) economic development levels and (3) grassland use policy measures. From 1995 to 2010, indirect water consumption displays a decreasing trend in Xilin Gol and Ordos due to the decrease of meat consumption and increase of fruit and vegetable consumption. When considering the amount of land per household, the grassland in Ordos still faces the great threat of high water consumption pressure. Such water consumption may affect water conservation services and productivity of grassland. Therefore, changing diet behavior and reducing the population can be considered options for sustainable use of water.

Keywords: virtual water content; water use; household survey, food consumption pattern; grassland; Inner Mongolia; adaptive management

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1. Introduction

Humans depend on the integrity of ecosystems to provide the goods and services they need for survival [1]. In many parts of the world, the limited availability of clean and fresh water is a major constraint to further social and economic development, especially in arid and semi-arid regions, such as Northern China [2]. Drought is a matter of vital importance to the grassland of Inner Mongolia Autonomous Region (IMAR), Northern China. A burgeoning population, pressing development needs and increasing household consumption are rapidly increasing the amount of water use [2]. From previous research [3], limited water resources and overuse of water for grazing/cultivation are the main reasons for grassland degradation in the IMAR. To reverse the increasing tendency of water stress and grassland degradation, suitable water consumption in an efficient way needs to be put forward to alleviate anthropogenic stress at national level. Household water use is a combination of both direct water consumption (e.g., domestic water consumption for drinking, washing, flushing and cooking) and the indirect water consumption behind the food production system. Producing food involves large amounts of fresh water use in the processes of plant transpiration, interception loss from vegetation canopies, soil evaporation and channel evaporation in irrigated systems [4]. Therefore, humans' consumption of food items is coupled with intensive use of water resources in indirect ways. Increasingly, regions around the world face growing pressures on their water resources. Great concerns have been raised on this issue, especially in the agricultural sector, which accounts for about 70% of human water use [5].

Several scientists have described the complex links between sustainable water consumption and the limited availability of water resources [2]. Accessible fresh water is scarce and an essential input for many societal, economic and natural systems. For example, China uses 7% of accessible freshwater to feed 22% of the global population, and it is likely that this quantity will decrease in many regions with overconsumption due to the reduced water conservation function of ecosystems [6,7]. While demand increases, supplies of clean water are limited and diminishing [8]. These trends are leading to an escalating competition over water in both rural and urban areas. Particularly important will be the challenge of simultaneously meeting the food demands of a growing human population and expectations for an improved standard of living that requires clean water to support domestic and industrial uses [9,10].

Previous studies showed that even small changes in food consumption patterns can have large impacts on the ecosystem due to the water required to produce this food [11]. For example, in the Netherlands, a hot meal mostly includes some meat, potatoes, noodle and vegetables. Gerbens-Leenes and Nonhebel [12] reported that even small changes in food-consumption patterns can trigger large impacts on ecosystems due to the agricultural area required to produce this food. For example, a slight increase in the consumption of meat (one mouthful or 10 g/capita/day) will require the increased use of water of 73 m^3/household/year, whereas the same increase of potato consumption will result in an increase of water use only 0.5 m^3/capita/year. The previous researches indicated that changing diet behavior can be considered as an option to reduce total water use. Changing consumption patterns from non-meat-dominant to meat-dominant patterns in many countries will lead to high pressure on water resources required to produce those products [13].

The analysis of the specific water consumption for food production can be quantified by different methods in the present study, such as the crop water productivity (CWP, typically in m^3/kg)—which is the ratio between produced crop yield and the amount of water consumed (evapotranspired) for that production [14]—or the inverse ratio, the virtual water content (VWC, typically expressed in m^3/kg). VWC and CWP differ not only among crop types, but also among regions for an individual crop. For example, Zwart and Bastiaanssen [15] found that with 1 m^3 of water it is possible to produce higher wheat yields in Wangtong (China) or Grand Valley (USA) than in Meknes (Morocco) or in Tel Hadya (Syria).

In order to change consumer behavior effectively, water uses should be associated with different food consumption patterns of households. In this manner we can find out which household consumption types are eligible for water saving and hence ecosystem degradation reduction. The purposes of this study was to estimate householders' total water consumption, including direct domestic water consumption like human drinking, cooking and washing, and indirect water consumption for production of food items consumed; to investigate the spatial and temporal distribution of total water consumption at the household level over different grassland types (meadow steppe, typical steppe, and semi-desert steppe) along the grassland transect in the IMAR; and to explore the impact of the grassland-use policy on livelihoods and household adaptive strategies. This process is threefold: firstly, the basic food consumption (the foods items commonly consumed by herders to maintain their daily life and substantial livelihood currently) patterns of the households will be investigated, using household questionnaire surveys and statistical analysis; secondly, the direct and indirect water consumption behind the food consumption patterns will be analyzed, and its spatial and temporal variations will be explored, using the VWC approach; thirdly, use of water resources will be traced based on the water consumption analysis.

2. Materials and Methodology

2.1. Area Description

The IMAR is located in the southern part of the Mongolian Plateau, which covers an area of approximately 11.8 million km^2 with an elevation between 86–3522 m. The IMAR is characterized by an arid to semi-arid continental climate [16] with strong climatic gradients and grass land-use dominated practices (Figure 1). Precipitation decreases and temperature increases from east to west ranged from 100 mm to 500 mm. The annual mean, minimum and maximum temperatures in the IMAR are 1.6, −18.3, and 18.7 °C, respectively [17]. The IMAR is more than 70% covered with native grassland ecosystems, which corresponds to 20% of China's total grassland area [18]. Typical steppe and meadow steppe are the major types of grassland ecosystems found in the IMAR, and are most commonly used for grazing and animal production, especially in the last 20 years [11,19]. In the northeast, meadow steppe is the most productive type of grassland ecosystem [16], developing in areas with moist fertile soils rich in organic matter and includes *Stipa baicalensis*, *L. chinensis*, and *Cleistogenes mucronata* [19]. The north central area of the IMAR borders the semi-desert and is dominated by typical steppe [20]. Typical steppe is capable of drought tolerance, and includes *Stipa grandis*, *Leymus chinensis*, and multiple species of *Artemisia* and *Festuca*. The southwestern area is dominated by semi-desert steppe, in which is the most arid ecosystem, with the least biomass [16]. Some of the species found include perennials such as *Stipa krylovii*, *Stipa bungeana*, and *Artemisia ordosica* [16].

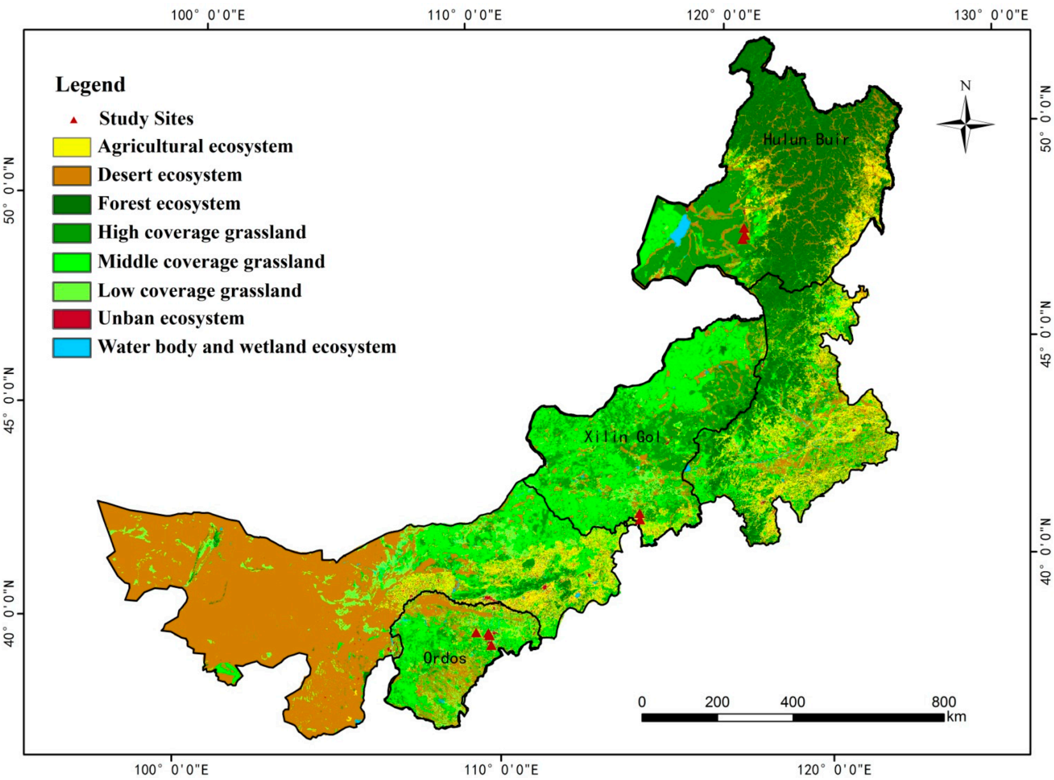

Figure 1. The geographic location and coverage rate of grassland in the IMAR.

Grassland degradation is a widely observed problem, and estimates for the IMAR's grassland reported 30%–50% to be degraded [20]. In a semi-arid region like the IMAR, available water through the hydrological process undoubtedly plays a key role in the functioning of the grassland ecosystems. The effects of water use mechanisms are extremely important to grassland degradation. For example, water shortages affect water transport through changing the soil physical structure and energy balance of the soil, affecting the performances of plant species and root architecture, with consequences for degradation [3,21].To reverse the increasing tendency toward water stress and grassland degradation, a series of policies and countermeasures have been put forward and enforced to alleviate the anthropogenic stress at national to household levels in the last decade, the most important of which implemented in badly degraded areas is called the "Returning Grazing to Grassland" restoration policy [22]. The grassland restoration policy was brought out around 1998 and broadly extended after several years of experimentation, and the herders' livelihood has been significantly affected through the implementation of the policy. The main measures of this policy are seasonal grazing and rotational grazing (e.g., in Hulun Buir), grazing prohibition and limiting thenumber of livestock according to the carrying capacity of degraded grassland (e.g., in Xilin Gol and Ordos).

Increasef agriculture water consumption for food provision will increase the water stress on the grassland ecosystems. From the statistics in 2010 and 1995, the IMAR's total water resources amounted to 412.1 billion m^3, with a decrease of 24.5% from the level in 1995 (513 billion m^3). The region's total water consumption in 2010 was 175.8 billion m^3, including agriculture irrigation water to 70.2% (123.4 billion m^3); next was industrial water consumption and urban domestic water consumption, which were 11.7% (20.5 billion m^3) and 4.8% (8.5 billion m^3); the ecological water consumption (water used directly for physiological processes of the ecosystem) was only 3.7% (6.5 billion m^3). Compared to the level in 1995, water consumption for agriculture increased significantly, three times higher (43.1 billion m^3 in 1995) in 2010. We selected three typical sub-regions from southwest to northeast in the IMAR to capture gradient discrepancies in water resource consumption, including Dongsheng District and Ejin Horo Banner (in Ordos), located in the south-west of the IMAR and mainly characterized by semi-desert steppe, Zhangxiangbai Banner (in Xilin Gol) located in the central IMAR and characterized by typical steppe, and Evenk Banner (in Hulun Buir) located northeast of the IMAR and characterized by meadow steppe (Figure 1). The spatial distribution of water resources is different. In Hulun Buir has abundant water resources, but utilization is extremely low and about 60%–80% of total annual precipitation falls between June and September; Ordos has serious problems with water shortages due to the dry climate. In Xilin Gol, the proportion of agricultural water (agriculture water includes three parts: (1) irrigation water (rainfall, artificial watering); (2) water use for animal husbandry (animal drinking water, animal and manure cleaning); and (3) cleaning water for agricultural product processing.) is large, in which leads to issues from excessive extraction of groundwater for most cities and rural areas [23]. Therefore, water resource stress is serious, especially in the central and western areas of the IMAR.

Major land use types include grassland, arable land, forest and others (including unban area, water body and wetland) (Figure 1 and Table 1). The percentages of land use in the three sub-regions are distributed differently and statistical data of invested banners or districts were explored to distinguish the differences between land uses. In Evenk Banner, the grassland and forest are the majority of land use and occupied 56.8% and 34.6% of total land. The arable land only accounts 0.9% of total land. Evenk Banner is a traditional pastoral area and is famous for livestock and poultry cultivation. The Hulun Buir has become the largest milk and meat export center in China. In Zhengxiangbai Banner, the grassland dominates 94% of total land, and the percentage of arable land is larger than Evenk Banner (accounts 2.2%); more than half of them grow grains. The forest area in Zhengxiangbai Banner has a lowest percentage, only 1.5%. Half of Zhengxingbai Banner is a traditional pastoral area and half is a farming area. In recent years, the scale of cultivation has been greatly increased, from livestock husbandry from traditional farming to modern cultivation. Dongsheng District and Ejin Horo Banner in Ordos were investigated; grassland was still the dominant land use, 67.4% and 60.7%, respectively. The second largest area was forest, 27.1% in Dongsheng District and 33.1% in Ejin Horo Banner. Dongsheng District and Ejin Horo Banner take the leading role for booming economic development with the rapid development of mining. The general trend in livestock husbandry and crop farming activities is moving away from individual participation to larger-scale operations, and the population engaged in husbandry and farming has decreased greatly over the last 15 years.

Table 1. Land use patterns in the study sites.

Land Use	**Hulun Buir (ha)**	**Xilin Gol (ha)**	**Ordos (ha)**	
	Evenk Banner	**Zhengxiangbai Banner**	**Dongsheng District**	**Ejin Horo Banner**
Grassland	1,063,013 (56.8%)	585,700 (94.0%)	203,000 (67.4%)	435,593 (60.7%)
Arable land	16,436 (0.9%)	13,867 (2.2%)	7865 (2.6%)	31,891 (4.4%)
Of which: grain	9245 (0.5%)	7066 (1.1%)	5735 (1.9%)	21,621 (3.0%)
fruit-vegetable	269 (0.0%)	2667 (0.4%)	103 (0.0%)	3841 (0.5%)
Forest	647,160 (34.6%)	9087 (1.5%)	81,670 (27.1%)	238,000 (33.1%)
Others *	143,386 (7.7%)	14,246 (2.3%)	8654 (2.9%)	12,471 (1.7%)
Total	1,869,995	622,900	301,189	717,955

Source: Statistics of 2010 yearbook in Evenk Banner, Zhengxiangbai Banner, Dongsheng District and Ejin Horo Banner; a banner is a county (rural area) or administratively equivalent district (city or suburbs area) in China, and is specifically used for the IMAR. * Others are including water body, wetland and urban areas.

In the past two decades, the IMAR's human population and its GDP grew significantly. According to the Chinese sixth census, the total population of the IMAR was 24.71 million people in 2010, compared with the fourth census of 21.46 million people in 1990, a total increase of 3.25 million people, with a growth rate of 13.15%. However, the rural population has decreased, especially in Ordos. According to the report of Chinese National Statistic Bureau, the total immigrated population in the IMAR from rural to city increased by 0.48 million from 1997 to 2006. In 2013 the IMAR's GDP totaled 2.71×10^{12} USD, an enormous increase from the estimated 2.56×10^{9} USD in 1987 [24,25]. Farming and animal husbandry, particularly sheep and goat herding, are the traditional approaches for subsistence. However, emphasis on industrial and economic growth during the last two decades has greatly transformed in the IMAR, and caused increasing pressure on natural ecosystems. The ability to maintain a balance between economic growth and ecosystem stability, and thus foster long term societal sustainability, has become a serious challenge facing the people of the IMAR.

2.2. Research Design, Questionnaire and Data Collection

A survey of 209 households ($n \approx 70$ per sites) was conducted by questionnaire surveys to assess their direct water and food consumption. In addition, information on household characteristics and major production activities were collected to assess the total water consumption per household. We used a stratified random sampling method [26] to select the villages in our study. We selected three villages in Hulun Buir (Evenk Banner), two villages in Xilin Gol (Zhengxiangbai Banner) and four villages in Ordos (Dongsheng District and Ejin Horo Banner). The survey was conducted from June to July 2010; simple random sampling was adopted for the household survey. For each household we visited, we asked the head of each household or a family member who was familiar with the household to answer the questions. We interviewed over 65% of total households and 70% of total population of each village with appropriate sample sizes based on the suggestion of Tabachnick and Fidell [27] that a sample should be over 50% when the total households of the survey unit group are lower than 100. Because the survey was carried out using face-to-face interviewing of the respondents or having the respondents complete the questionnaires under the research group members' guidance, we obtained a high response rate of 90.5%.

Prior to the formal surveys, we conducted test surveys using individual interviews and family group discussions with herders and other key informants, and the information collected in the test surveys guided the development of the formal questionnaire. Closed-ended questions were primarily applied for a formal survey, which included questions in the following areas: (a) demographics, land characteristics, financial conditions and the socioeconomic characteristics of the households related to household composition, levels of education, livestock owned, the area cultivated and crops grown; (b) their consumption of domestic water and food in 2010; (c) their consumption of domestic water and food around the year 1995 (as recalled by the respondents). Because a series of policies and counter-measures of grassland restoration have been put forward and enforced around 1998, this intervention may cause great changes in the use of natural recourses and its subsequent issues. In China, many data are updated every 5 years. This is why 1995 (before restoration policy) and 2010 (recent, after restoration policy) have been chosen to make comparisons. In the survey, we asked the households to categorize and quantify the foods they had consumed in the year prior to the survey (2010) and 15 years ago (1995). In this case, 15 foods as basic food types for consumption have identified according quantities of household food consumption for the analysis, namely wheat, rice, glutinous millet, potatoes, vegetables, fruit, cooking oil, bean products, mutton, beef, pork, chicken, fish, milk products and eggs. The respondents reported the variety and quantity of the consumed foods. These 15 foods were further grouped into seven categories based on clarification of Chinese dietary guidelines (2007), namely staple foods (wheat, rice and glutinous millet), potatoes, vegetable-fruit, mutton-beef, other meats (pork, chicken and fish), oil-bean products and milk-eggs. Quantities of consumed food include home grown food and purchased. The survey revealed that households could accurately recall their consumptions in the year prior to the survey and the main consumption patterns in 1995.

2.3. Calculation of Water Consumption

2.3.1. Specific Water Requirement per Food (Crop or Meat) Type

The direct water consumption of a household is defined by the domestic water required for drinking, flushing, washing and cooking. The indirect water consumption of a household is defined by the water required to produce all the food products included in this study. To calculate the cumulative indirect water consumption per capita ($W_{indirect}$), we used data generated from the VWC method [28] and measured data of Specific Water Demand (SWD) per food (crop) item consumed by taking into consideration variations in the elevation, precipitation, temperature and economic development level from east to west of the study sites, and by using site-specific SWD for each of the sites under study [12,29,30]. The total water consumption is the sum of the direct and indirect water consumption.

In our study we first determined the direct water consumption according to the results from the questionnaire survey, which was provided by household respondents in unite of tons per capita per year. Next, we determined the indirect water consumption for producing the specific food items that consumed by the households. The 15 basic food types are collected to estimate the indirect water consumption ($W_{indirect}$) in the household survey by using the following Equation (1):

$$W_{indirect} = \sum_{i=1}^{15}(SWD_i \times S_i) \tag{1}$$

where SWD_i is specific water demand (m^3/kg) of a specific type of food (i); and S_i is the quantities of food consumption in categories (i) (kg/capita/year). For indirect water consumption derived from meat consumption, we defined it as total amount of water consumed from the beginning of life to the end of its life period, including the daily drinking water and water contained within the feed (fodder) for livestock. The indirect water consumption of feed (fodder) includes water consumption during the period per specific fodder (grass fodder and crop fodder) growing processing. Indirect water consumption of different animal products (e.g., meat, milk and eggs) is based on the distribution ratio containing the water consumption in the animal products. The calculation method of fodder water requirement (in m^3/ha) is same as the crop water requirement.

2.3.2. Pressure of Total Water Consumption on Their Land

For this purpose, we hypothesize that all the water consumed is from the local ecosystems, and the pressure index of total water consumption on their unit land is express by water consumption per capita.

$$P_{index} = W_{total}/A_{land} \tag{2}$$

in which W_{total} is the reference the total consumption of domestic water consumption and indirect water consumption from food production items, A_{land} is the area of total land ownership (farmland, grass and forest) per capita (ha/capita).

3. Results and Discussions

3.1. Background Information of the Respondents

The average household size of three adult equivalents (AE) is consistent with the national average in China reported by the National Bureau of Statistics, China (NBSC) [31]. Table 2 indicates that the average age of all respondents was approximately at 51, in which herders in Hulun Buir, Xilin Gol and Ordos had average ages of 43.2, 55.8 and 54.6 respectively. The average age of farmers and herders in Xilin Gol were the oldest with an average age of 55.8; 57% of the respondents were older than 50. This can probably be explained by the fact that since the grassland in Xilin Gol was seriously degraded, the basic daily consumption needs cannot be relied upon from the land only, and the sub-regions do not have industries like mining that herders and farmers can work for, so more young people immigrated to the city to find jobs while older people without special work abilities had to stay at home. Another reason accelerated the immigration: the government established a policy of converting most farmland to grassland and forest, and nomadic grazing was strictly forbidden in Xilin Gol.

Table 2. The characteristics of the households that participated in the survey.

	Study Area	**Hulun Buir (*N* = 66)**	**Xilin Gol (*N* = 71)**	**Ordos (*N* = 72)**	**Total (*N* = 209)**
	Family size	3.2	3.2	3.4	3.3
	Average age	43.2	54.6	55.3	51.4
	Average education level	7.8	6.3	4.7	6.3
Land use		A1 (%)	A1 (%)	A1 (%)	A1 (%)
	Farmland	0.0 (0)	0.1 (1)	0.4 (9)	0.2 (1)
	Grassland	24.4 (100)	9.4 (94)	2.6 (63)	11.5 (94)
	Forest	0 (0)	0.4 (4)	1.1 (28)	0.5 (4)
	Total land area	24.4(100)	9.9 (100)	4.1 (100)	12.2 (100)
Income		A2 (%)	A2 (%)	A2 (%)	A2 (%)
	Crop production	97 (1)	2656 (14)	500 (1)	1082 (6)
	Livestock	13,438 (72)	7188 (38)	1765 (3)	7109 (38)
	Non-agriculture [1]	5250 (28)	8844 (47)	17,425 (96)	10,705 (57)
	Total income	18,784 (100)	18,688 (100)	19,690 (100)	18,896 (100)

[1] Non-agriculture includes income from migrant job, subsidies and land expropriation; A1: Average area of land per capita in unite of ha; A2: Average amount of income per capita in unite of CNY.

Herders in Hulun Buir own the use-right of farmland and grassland, with per capita ownership of 0.03 and 24.4 ha, respectively. Most of their land is covered by meadow steppe; only small pieces of land in their back yards are used to grow potatoes and vegetables during the spring and summer. However, in Xilin Gol, the total amount of land owned is less than Hulun Buir, only 9.9 ha per capita in overall, including 9.4 ha (94%) grassland, 0.4 ha (4%) forest and 0.1 (1%) ha farmland. The inhabitants of Xilin Gol rural area are a combination of one-half herders and one-half farmers settled in different villages. In Ordos, the inhabitants have more diverse land use of grassland, forest and farmland, with per capita ownership of 2.6 ha (63%), 1.1 ha (28%) and 0.4 ha (9%), respectively.

Total annual income per capita in the research area is 18,896 CNY (approximately 3000 USD) per capita over all income sources, including 6% from crop production, 38% from livestock herding, 33% from migrant jobs, 7% from subsidies and 17% from land expropriation for mining and forest planting (ecological corridor construction project). Results show that per capita income in Ordos is highest with average per capita of 19,690 CNY (approximately 3126 USD); followed by Hulun Buir (18,784 CNY, approximately 2983 USD); the lowest is Xilin Gol with 18,688 CNY (approximately 2967 USD). In our samples, livestock herding still is the most important source of income in Hulun Buir, accounting for 72% of total income. Comparing to Hunlun Buir, the most significant difference in Xilin Gol is the income from livestock has decreased to 38% of total, but the income from crop products, non-agriculture works has increased to 14% and 47%, respectively. The income from migrant labor increased greatly, occupying 37% of total income. This may indicate that the inhabitants in Xilin Gol do not strongly rely on their grassland due to the degradation and herders and farmers are beginning to find new sources of income, such as the income from employment. In Ordos, off-farm income accounts for 96% of this total. A significant component of income is land expropriation, which makes up almost 79% of total income.

3.2. Spatial and Temporal Variation of Food Consumption

Results have shown significant spatial variations in consumption. In Hulun Buir, the households consume more meat products, especially mutton and beef which represent over 76% of total meat consumption, accounting for an annual average per capita of 53.9 kg and 43.3 kg, respectively in 2010 (Table 3). This is due to the fact that Hulun Buir dominated with high coverage of meadow steppe and that average size of grassland per household in Hulun Buir is the highest (24.4 ha in 2010), which greatly exceeds the average level of 11.5 ha of the three sub-regions. In addition, in Hulun Buir, herders rear significantly more sheep and goats than herders in Xilin Gol, and hence consume more mutton (43.3 kg/capita/year/) than the rest in 2010. Although Hulun Buir herders raise significantly more cattle (18 *vs.* 4.2) than those in Xilin Gol, they use the cattle primarily to earn income from selling milk rather than for meat production and consumption; as a result, their consumption of beef did not differ significantly from that in Xilin Gol in 2010 (per capita totals of 53.9 and 46.4 kg/year, respectively). Compared to Hunlun Buir and Ordos, herders and farmers in Xilin Gol consumed more staple foods, especially flour in 2010 (102.7 kg/capita/year in Hulun Buir; 108.1 kg/capita/year in Xilin Gol and 62.1 kg/capita/year in Ordos). Ordos shows a significant difference in food consumption from Hulun Buir and Xilin Gol. The inhabitants in Ordos consume more potatoes (70.9 kg/capita/year in Hulun Buir; 50.6 kg/capita/year in Xilin Gol and 168.4 kg/capita/year in Ordos), vegetables (66.7 kg/capita/year in Hulun Buir; 50.2 kg/capita/year in Xilin Gol and 119 kg/capita/year in Ordos) and fruits (19.8 kg/capita/year in Hulun Buir; 25.5 kg/capita/year in Xilin Gol and 40.6 kg/capita/year in Ordos) instead of staple foods (183.2 kg/capita/year in Hulun Buir; 184.4 kg/capita/year in Xilin Gol and 111.8 kg/capita/year in Ordos) and milk products in 2010 (96.9 kg/capita/year in Hulun Buir; 88.8 kg/capita/year in Xilin Gol and 27.2 kg/capita/year in Ordos). This discrepancy towards the consumption of foods is associated with what they produced or cultivated locally. However, in Ordos, most of the farmers and herders were liberated from their land due to degrading ecosystems and the restoration policy for returning the farmland to forest and grassland (implementation of grazing prohibition). Their livelihood is not to rely on the land, and their consumption depends more on market trading.

Table 3. The variation of food consumption per capita per year (unite: kg/capita/year).

Research Area	**Hulun Buir**		**Xilin Gol**		**Ordos**	
Year	**1995/2010**	***t*-test**	**1995/2010**	***t*-test**	**1995/2010**	***t*-test**
Staple food [1]	152.2/183.2	*	188.8/184.4	*	161.2/111.8	***
Oil and Beans	16.9/25.1	**	20.4/26.6	*	19.2/22.5	*
Potato	55.9/70.9	**	50.9/50.6	*	202.2/168.4	**
Vegetable-Fruit	45.8/86.5	***	44.4/75.7	**	56.7/159.6	***
Egg-milk	90.2/108.5	*	119.5/107.6	**	22.1/38.2	***
Mutton-Beef	75.7/97.2	**	82.8/65.5	**	51.6/35.7	***
Other meat [2]	20.4/30.1	**	11.8/13.9	*	45.6/54.7	**
Total (kg/year)	457.1/601.4	**	518.6/524.4	*	558.6/590.9	**

[1] Staple food is including flour, rice and glutinous millet; [2] Other meat is including pork, chicken and fish; * $p \geq 0.05$ (No significant changes); ** $0.01 < p < 0.05$ (Significant changes); *** $p \leq 0.01$ (High significant changes).

It is found that the consumption patterns of foods have changed in Hulun Buir, Xilin Gol and Ordos from 1995 to 2010. The diet of Hulun Buir still involves high meat consumption, with an amount of 127.2 kg/capita/year in 2010 compared to 96.1 kg/capita/year in 1995. Although the pastoralists turn to settlement away from nomadic grazing, the livelihoods of herders still relies on livestock products and large numbers of livestock. However, in Xilin Gol, consumption of mutton and beef decreased from 82.8 kg/capita/year in 1995 to 65.6 kg/capita/year in 2010; whilst vegetable and fruit consumption increased greatly from 95.3 kg/capita/year in 1995 to 126.3 kg/capita/year in 2010; and staple foods remained similar. This is caused by a great reduction in livestock grazing due to implementation of a restoration policy measures of limiting the number of livestock based on the land carrying capacity (one sheep unite per 40 mu, equal 2.7 sheep unite per hector); a household in Xilin Gol on average consumes approximately 25 sheep (equal to five cattle). In Ordos, the consumption for each item of food changed dramatically (Table 3). By 2010, the consumption of staple food in Ordos dropped significantly, especially flour and rice from 90.6 kg/capita/year in 1995 to 62.1 kg/capita/year in 2010 and from 56 kg/capita/year in 1995 to 36.8 kg/capita/year in 2010, respectively; Meanwhile, vegetables, fruits, eggs and milk maintained an increasing trend, in which from 40.1 kg/capita/year in 1995 to 119 kg/capita/year in 2010, from 16.6 kg/capita/year in 1995 to 40.6 kg/capita/year in 2010, from 8.1 kg/capita/year in 1995 to 11 kg/capita/year in 2010, from 14 kg/capita/year in 1995 to 27.2 kg/capita/year in 2010, respectively; Within the category of meat, consumption of pork (from 36.6 kg/capita/year in 1995 to 41.2 kg/capita/year in 2010), chicken (from 7.8 kg/capita/year in 1995 to 8.1 kg/capita/year in 2010) and fish (from1.2 kg/capita/year in 1995 to 5.4 kg/capita/year in 2010) rose slightly in Ordos, but the consumption of beef and mutton has decreased from 35.7 kg/capita/year in 1995 to 23.2 kg/capita/year in 2010, and from 15.9 kg/capita/year in 1995 to 12.5 kg/capita/year in 2010, respectively. This may be due to more people engage in off-farming activities in Ordos, such as milling, transportation and urban construction that improved the economic purchasing power of the herders and market development. As a consequence, their consumption is less reliant upon their land and more affected by market trading. The herders and farmers have to buy meat from markets, and pork, chicken and fish are cheaper than mutton and beef.

3.3. Water Consumption per Household

3.3.1. Direct (Domestic) Water Consumption Pattern

In 2010, average annual amount of water consumed per capita were 13.1 ton/year, and total daily domestic water intake ranged from 49.3 to 17.9 m^3/capita/year in surveyed households. In Hulun Buir, all respondents used ground water from private wells, and the water use is free of charge. They consumed higher amounts of water (in average of 14.0 m^3/capita/year) in 2010 than those in Xilin Gol and Ordos due to relatively more rain for ground water recharge compared to other areas of the IMAR [32]. After 2005, a national tap water construction project in rural areas was implemented by the government in some parts of the IMAR, and about 37% and 42% of surveyed households in Xilin Gol and Ordos respectively able to use tap water. The project did not cover the area of Hulun Buir. Decreasing trends in the amounts of water consumed were exhibited in all survey sites. In Xilin Gol this trend was more apparent, where water consumption decreased from 15.3 m^3/capita/year in 1995 to

12.5 m^3/capita/year in 2010. While in Ordos, water consumption was stable and reduced slightly from 13.7 m^3/capita/year in 1995 to 13.2 m^3/capita/year in 2010. Although there were no significant changes for the direct domestic water consumption, the water consumption shows a little slight decreasing trend in Hulun Buir, Xilin Gol and Ordos, mainly due to severe drought in 1995. This discrepancy may also be caused by the water payment mechanism for using the tap water. In 2010, water from privately-owned wells was totally free in all three sub-regions, but tap water must be paid for according to the actual quantity of water they consume (water price is 2.6 CNY/m^3) which results in households saving the water on their own initiative. This phenomenon suggests that the market price of water can reduce water consumption.

3.3.2. Indirect Water Consumption from Food (Crop) Consumption

The calculation results show that the discrepancy of indirect water consumption for specific food consumption was large. The spatial variations of SWD in three sub-regions of Hulun Buir, Xilin Gol and Ordos have been identified according to previous research [11,29,30]. The top five foods for SWD are beef, mutton, oil produce, marine products and pork, and the bottom five foods for water demand are vegetables, potatoes, flour, fruit and rice (Table 4). With accumulation of indirect water consumption for annual total food consumption, the results show that the herders in Hulun Buir consumed the highest amount of indirect water for food production, 2307.3 m^3/capita/year in 2010. The Ordos consumed the lowest indirect water with amount of 1553.8 m^3/capita/year in 2010. Compared to the level of 1995, the indirect water consumption shows a decreasing trend in both Xilin Gol (2377.7 m^3/capita/year in 1995 and 2054.3 m^3/capita/year in 2010) and Ordos (1838.5 m^3/capita/year in 1995 and 1553.8 m^3/capita/year in 2010) (Table 4). The main reason is the changes in food patterns from 1995 to 2010 leading to more vegetable and fruit consumption instead of meat consumption, and meat consumption switching from a combination of mutton and beef to more diverse meat consumption including fish, chicken and pork.

Although the amount of vegetable and fruit consumption in all three sub-regions shows a high significant increasing trend when comparing the food consumption in 1995 and 2010, due to the SWD of vegetable and fruit being relative low (in average 0.1 for vegetable and 1.2 for fruit), the indirect water from agri-food production item remains at a relatively low level. The changes in indirect water consumption driven by mutton and beef are significant in all three sub-regions in large proportion (Table 4). In Hulun Buir, the total indirect water consumption increased 31.2% from 1758.8 m^3/capita/year in 1995 to 2307.3 m^3/capita/year in 2010, for which the contribution from beef is the highest (469.6 m^3/capita/year) among total variations, and indirect water from mutton contributed negatively (−87.6 m^3/capita/year) to total changes.

In Xilin Gol, the indirect water consumption from beef and mutton products has decreased 446.6 m^3/capita/year (21.5% of the level of 1995) from 1995 to 2010. In Ordos, the mutton and beef consumption both declined comparing to 1995, which contributed −225.0 m^3/capita/year and −68 m^3/capita/year of total indirect water consumption changes. Therefore, changing diet behavior and reducing the population can be considered an option for sustainable use of water.

Table 4. Indirect water consumption from major food consumption items.

Type of Foods	SWD (m^3/kg)			$W_{indirect}$ (m^3/capita/year)					
	Hulun Buir [1]	Xilin Gol [2]	Ordos [3]	Hulun Buir		Xilin Gol		Ordos	
				1995/2010	Changes in % [6]	1995/2010	Changes in % [6]	1995/2010	Changes in % [6]
Staple food [1]	1.0–3.2	1.4–3.2	1.5–3.6	213.1/256.5	20.4	339.8/331.9	−2.3	322.4/223.6	−30.6
Oil and Beans	1.7–4.2	3.2–6.2	1.0–5.8	60.8/90.4	48.5	77.5/101.1	30.5	74.9/87.8	17.2
Potato	0.8	0.2	1.1	44.7/56.7	26.8	10.2/10.1	−1.0	222.4/185.24	−16.7
Vegetable-Fruit	0.1–0.8	0.1/1.4	0.3–1.3	9/20.5	127.8	16.1/40.7	152.8	33.6/88.5	163.4
Egg-Milk	1.8–3.8	2.2–2.7	2.2–2.9	177.8/218.5	22.9	268/246.2	−8.1	54.3/91.7	68.9
Mutton-Beef	15.1–17.2	18–20	18–20	1198.9/1580.9	31.9	1623/1273.6	−21.5	960.6/667.6	−30.4
Other meats [5]	1.9–3.8	3.1–5	3.7–5	54.4/83.8	54.0	43/50.7	17.9	170.3/209.4	23.0
Indirect water consumption from food production item				1758.8/2307.3	31.2	2377.6/2054.3	−13.6	1838.5/1553.8	−15.5

[1] The data of SWD are from Xiao *et al.* [12]; [2] the data of SWD are from Li and Wu [29]; [3] the data of SWD is from Xu *et al.* [30]; [4] Staple food includes flour, rice and glutinous millet; [5] Other meat includes pork, chicken and fish; [6] "Changes in %" were calculated based on levels in 1995.

3.4. Water Consumption Pressure for Grassland Ecosystems

In the IMAR, grassland is the dominant ecosystem; it is one of the most important terrestrial ecosystems on the earth, provides fundamental goods and services for humans such as internal nutrient cycling, soil protection, biodiversity conservation, climatic regulation, and water supply [22,33]. Many studies have pointed out that water is treated as a service provided by ecosystems as well as a system (inland waters) [34,35]. Therefore, the sustainable use of water can be critical issue for grassland. Overuse of water resources can be one of the main drivers for grassland degradation, because of water expressed as a comprehensive regulation through various hydrological processes of the grassland ecosystem, including canopy interception, stem flow, litter interception, water storage in soil and permeability, runoff and vaporization [4]. The water conserved in the local ecosystem is the main source for the human's direct and indirect water consumption. The pressure index of grassland can be estimated by accounting total water consumption per hector in ecosystems to identify areas that are critical to human well-being as well as those that require particular attention in designing strategies for sustainable grassland management.

In this research, the degree of intensive consumption of water resources can be measured by the amount of water intake from local grassland ecosystems in the land unit to indicate the pressure for local grassland. Figure 2 shows the results for water consumption intake from grassland ecosystems per hectare. In Hulun Buir, humans took in 95.1 m^3/ha/year of water in 2010 and 72.7 m^3/ha/year in 1995 from local grassland ecosystems, which was the lowest comparing to Xilin Gol and Ordos. Although Hulun Buir has the highest total water consumption per capita, the herder has abundant grassland resources, which results in low pressure from water consumption on their grassland. On the contrary, Xilin Gol and Ordos have higher degrees of water consumption per land unit which creates high pressure on their grassland. Such high water consumption pressure may affect water conservation services and productivity of grassland ecosystems and the grassland will be exposed to degradation.

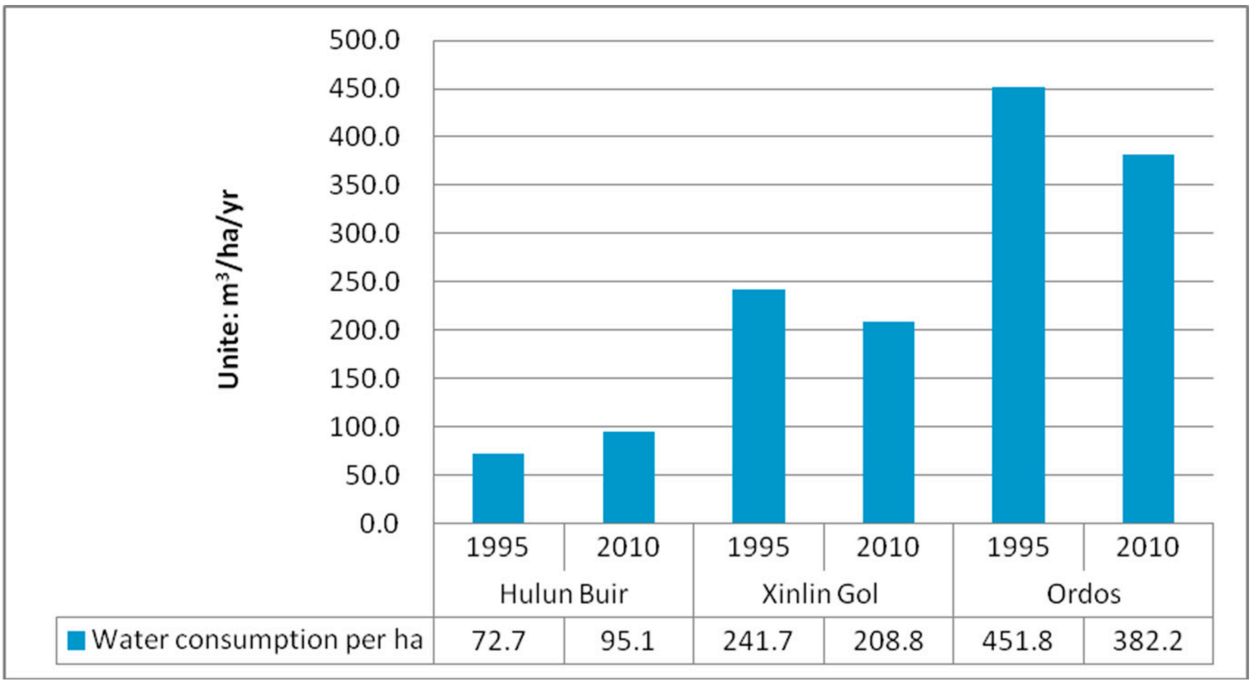

Figure 2. Water requirement per unit of land area for producing consumable items.

Due to the changes of food consumption patterns recently, the water consumption per unit area shows a decreasing trend in 1995–2010 in Xilin Gol and Ordos from 241.7 m^3/ha/year to 208.8 m^3/ha/year, and 451.8 m^3/ha/year to 382.2 m^3/ha/year, respectively. Since the 1980s, the economic development of the IMAR was so fast that the total water requirement increased greatly due to increased meat consumption [36]. With the subsequent issue of overuse of grassland, ecosystems degraded seriously in the IMAR in the 1990s. In 2010, the water shortage issue limited their farming and grazing, and the grassland ecosystems in the IMAR could not support the needs of inhabitants, which meant people started to purchase food from outside of the ecosystem to reduce dependency on local ecosystems [37,38]. The purchase activities resulted in diversified consumption, especially increased vegetable and fruit consumption, but purchased food highly depended on economic levels. Better economic income improved purchase power of herders and market development, such as in Ordos, and high income level causes diversified food consumption patterns. Beside the influences of different natural environment conditions and economic development, the grassland restoration policy measures have deeply changed pastoral tradition and basic household consumption patterns. Grazing activity was less affected by policy measures of seasonal grazing and rotational grazing than the other policy measures, thus more herders preferred to maintain most of their food/water consumption patterns (e.g., in Hulun Buir). However, in the context of grazing prohibitions and limited number of livestock-rearing policy measures (e.g., in Xilin Gol and Ordos), the food/water consumption patterns changed greatly. Therefore, the implementations of grassland ecosystem restoration policy aggravated the herders and farmers in the IMAR, who changed their diet by reducing their meat consumption and starting to purchase food to reduce indirect water consumption for conservation of the local grassland.

3.5. Advantage, Uncertainties and Future Improvements

The method for estimating the total water consumption in direct and indirect ways according to quantities and types of household food consumption can be widely applied for many cases, which is useful in explaining the effects of household consumption and livelihoods on grassland's water conservation services, improving herder awareness of the environmental effects from their daily consumption activities, and in providing guidelines for sustainable grassland management, and it provides a viewpoint on ecosystem adaptive management at a household level, especially in linking micro-level livelihood (alternative diets) responses to macro-level environmental/policy procedures, which facilitates the further review of policies and enables policy adjustment and amendment through feedback from livelihood outcomes.

The realistic total water consumption is difficult to estimate, due to the complexity of ecological processes in our world. This approach tries to show the actually total water use of humans, but it is still a partial estimation; the water use for fuel consumption is not included. Many steps of the calculation are general estimates, for instance of (1) selection of data of SWD per food (crop); it still needs more field experiment data to establish accurate results; (2) we gathered the data on direct water consumption and indirect water consumption for 1995 and 2010 in one survey of 2011 (recalled by the respondents); although the herders were able to recall the situation in 1995 and answered the questions properly, there are is still the possibility of overestimates or underestimates because of we did not actually weigh the consumed foods.

Most areas of the world show economic development results increased purchasing power, causing increased demand for meat products [39–41], especially in developing countries like Brazil and China; populations continue to increase, and combined with economic growth, demand for animal products is predicted to increase and would require more water consumption. These show different trend with our results, which may be because most food consumption research is on the national or global scale, based on statistics or trading data, while the results of this paper are based on the household level of consumption in a specific pastoral area under different circumstances. It is hard to make real comparisons. Moreover, understanding the likely structure and trends of the water consumption from food consumption can give policymakers a better picture of sustainable water management. Therefore, future research is highly encouraged to assess how diet composition will change with household level under different cultural backgrounds and constraint conditions.

4. Conclusions and Suggestions to Management

Because at least 99% of the total water consumption of households consists of indirect water consumption behind food production, the large differences between the specific water requirements of the various foods (crop) types for consumption indicate that the total water consumption can be reduced if we change our food consumption patterns. The results show that beside the influences of different natural environment conditions and economic development, the grassland restoration policy measures deeply changed pastoral tradition and food consumption patterns. When comparing the food and water consumption in 2010 to 1995, although the amount of vegetables and fruits in all three sub-regions show a highly significant increasing trend when compared to food consumption in 1995 and 2010, the water consumption behind the food production displays an decreasing trend in Xilin Gol and Ordos due to the decrease of meat consumption and increase in fruit and vegetable consumption.

The changes for mutton and beef are significant in all three sub-regions, which contribute the large proportion of variation in indirect water consumption. In Hulun Buir, total indirect water consumption has increased over 31.2% by comparing the level 1995, in which beef-mutton contributes the highest proportion. In Xilin Gol, the indirect water consumption from beef-mutton has decreased 21.5% of the level of 1995. In Ordos, the mutton-beef consumption all declined greatly (30.4%) comparing to 1995, which beef and mutton contributed 79% and 23.9% of total decreased indirect water consumption. In Hulun Buir, the pressure of local grassland was lowest comparing to Xilin Gol and Ordos. Although Hulun Buir has highest total water consumption per capita, the herder has abundant land resources which mean a low amount of water intake from local ecosystems. On the contrary, Xilin Gol and Ordos have high pressure on grassland due to a higher degree of water consumption per land unit. However, due to the changes in food consumption patterns recently, the water consumption per unit area shows a decreasing trend in Xilin Gol and Ordos from 1995 to 2010.

Compared to direct water consumption, indirect water consumption from food production made up the major part of total water consumption, which is affected by (1) geographic location (grassland types), (2) economic development level and (3) grassland-use policy measures. The grassland ecosystem degradation in the IMAR leads to a shortage of meat production that result in people starting to purchase food from outside of the ecosystem to reduce dependency on local ecosystems. These purchase activities resulted in diversified consumption, especially increased vegetable and fruit consumption, but purchased food highly depends on the economic level. In Ordos, high income level causes a reduction in direct water consumption through adoption of diversified food consumption patterns. In addition, the grassland restoration policy measures deeply changed pastoral tradition and basic household consumption patterns. In the context of grazing prohibitions and limited number livestock-rearing policy measures (e.g., in Xilin Gol and Ordos), the food/water consumption patterns changed greatly from meat-dominated consumption to more diverse staple and vegetable consumption patterns.

The reductions in indirect water consumption can reduce the pressure on local grassland, and grassland conservation can be achieved by changing food consumption patterns. Under the current scale of restoration policy, subsequent policy measures need to increase livelihood diversity and mitigate livelihood dependence on grassland ecosystems. A variety of strategies need to be employed, such as provided off-farm works, skill training, establishment of food trading market and education on healthy diets. Therefore, accounting for direct and indirect water consumption is critical to human well-being and requires particular attention in designing strategies for sustainable development of natural resources.

Acknowledgments

This research was funded by the National Key Project for Basic Research (973) (No. 2014CB954302), the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX2-EW-306) and the Technical Support Program (No. 2013BAC03B04) of the Ministry of Science and Technology of China. We are grateful for the support provided by these organizations.

Author Contributions

Manuscript writing: Bingzhen Du performed the manuscript preparation (e.g., data analyses, literature review), wrote the manuscript and approved the final version; Lin Zhen substantially contributed to the conception of this research, revised the manuscript and gave her constructive comments on manuscript drafting, and approved the final version; Rudolf de Groot revised the manuscript and gave his suggestions on the earlier versions of the manuscript; Chuanzhun Sun contributed the map demonstration. Field Data collection: Lin Zhen and Bingzhen Du designed the field survey, and together Xin Long, Xiaochang Cao, Ruizi Wu, Chuanzhun Sun, Chao Wang finished the field survey and acquired household data for this manuscript. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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