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Original Contribution

Water Management Challenges in the Context of Agricultural Intensification and Endemic Fluorosis: The Case of Yuanmou County

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Abstract: Yuanmou County in Yunnan Province, China is situated in a dry hot valley where annual evaporation is almost six times the annual rainfall and thus the county suffers from chronic water shortages. Since the early 1980s the county has taken advantage of local warm climate and focused its economic development strategy on commercial vegetable plantations. This strategy successfully brings high income to the local government and farmers, but increases water consumption and adds an extra stressor to the already diminished water resources. Yuanmou County is one of the endemic fluorosis hotspots in China where both dental and skeletal fluorosis cases have been found among local villagers that were diagnosed as being water-borne. Despite measures to adapt to water shortages and control fluorosis taken by the local government and communities, new challenges are emerging. Herein, we describe the water management challenges facing the county as well as document the coping strategies adopted by the government and communities, analyze remaining and emerging challenges, and suggest an ecohealth framework for better management of water resources in Yuanmou.

Keywords: water management challenges, agricultural intensification, endemic fluorosis, Yuanmou County

Introduction

Water is crucial to every aspect of human life. Demand for freshwater worldwide has escalated with population growth and increasing human activity. Meanwhile, freshwater availability is decreasing due to environmental degradation and unsustainable human development, both of which deplete water resources. Increased demand and reduced availability threaten not only sectors that rely directly on water, such as agriculture and hydropower, but also challenge human health and the sustainability of human life.

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How to use and manage water in an efficient, equitable, and sustainable manner is a huge challenge.

China has experienced rapid economic growth in the last three decades. During this period, the state has encouraged a shift toward agricultural intensification—demanding greater yields and efficiency from the same, limited plots of arable land—to ensure food security for China's 1.3 billion people. However, agricultural production, which already consumes the largest share of water among all production systems and industries, is increasingly threatened by water stresses and shortages. While northern China's water scarcity has been emphasized in research studies and the news, many places in southern China are also suffering from severe water shortages and droughts (Gleick 2009).

Yuanmou County is located in Yunnan Province, in southwest China. The county has a total area of 2021 km^2, 85% of which is mountainous terrain. The elevation ranges from 980 to 2,836 m and the landform is basin-like: flatland surrounded by mountains (see Fig. 1). There are 15 perennial rivers and 23 seasonal rivers in Yuanmou; the two most significant of these are the Jinsha River and the Longchuan River. The Jinsha River, a tributary of the Yangzi River, flows through Yuanmou County for 46.5 km, and the Longchuan River for 63 km. These rivers provide important water resources for agricultural and domestic use to local farmers. The county has a population of 217,000 with 30,872 ha of arable land, divided into 10 townships and 78 administrative villages as of 2009.

Yuanmou County is a hot and arid valley; the annual average temperature is 21.5°C. There are three cropping seasons per year. However, because the annual rainfall is only 615.1 mm and the evaporation is 3 911.2 mm (Wang et al. 2005), the county suffers from chronic water shortages, exacerbated by periodic severe droughts. For instance, there were 12 major droughts between 1950 and 1990. In 2005 and 2009–2010, the county experienced the two worst droughts of the last 100 years. In addition to water

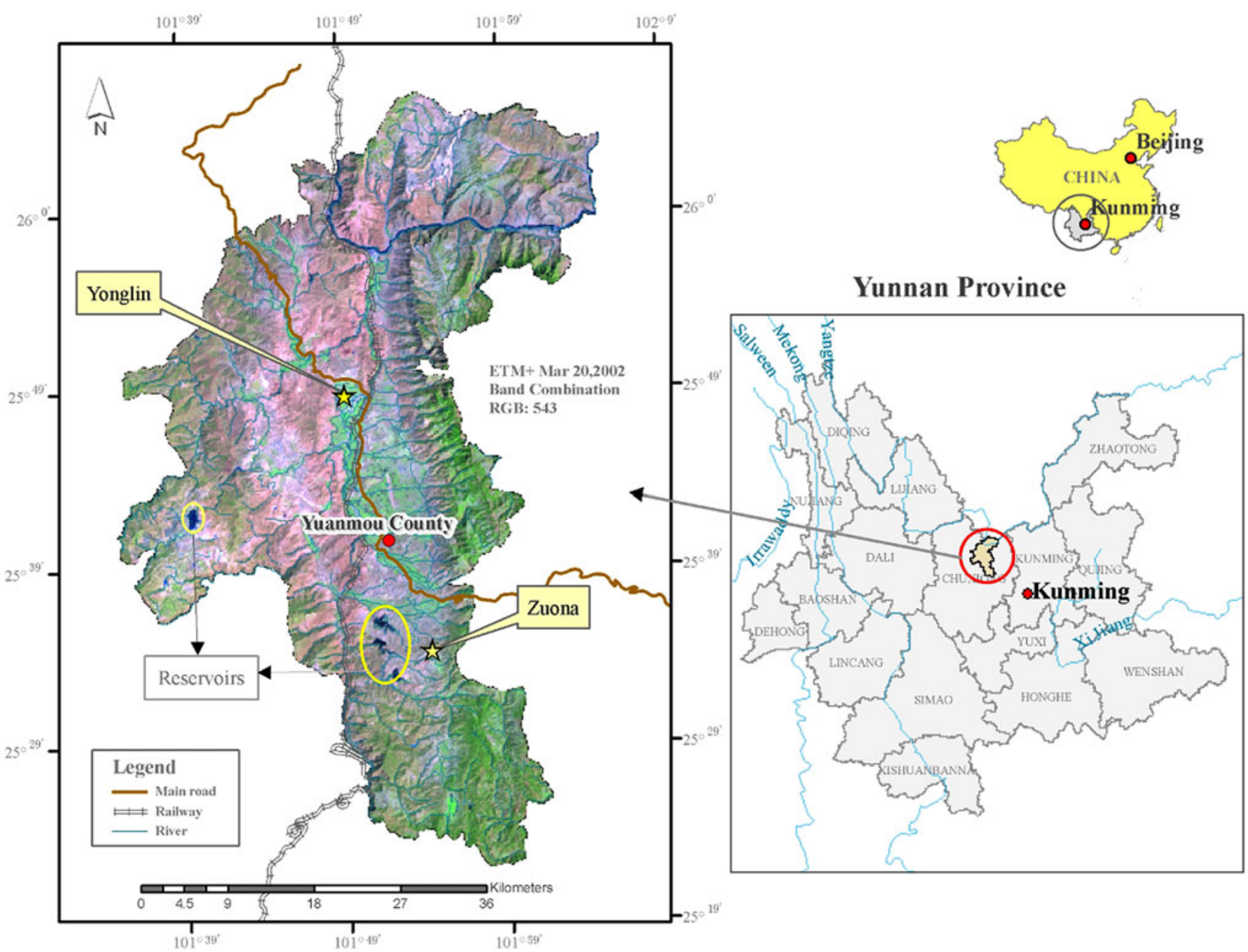

Figure 1. The Geographic location of Yuanmou County.

shortages, 90% of the rainfall occurs between June and Oct, and the heavy downpours during this period cause erosion and sometimes landslides.

Agricultural production is the county's main economic activity. Before rural economic policy reform in 1978, the county was administered under a communal productive system that mandated farmers cultivate two crops per year. In the early 1980s, the county government began to promote vegetable cultivation and made off-season vegetable farming the primary economic development strategy. While this strategy took advantage of the warm weather, it also increased water consumption.

Over the last 30 years, many new vegetable varieties were introduced into the county and are now cultivated year-round, including onions, garlic, tomatoes, cucumbers, eggplants, chilies, beans, melons, and leafy vegetables. In 1990, the land area used for vegetable planting in the county was 56,512 μ (1 $\mu = 0.067$ ha) and 0.1 million tons of vegetables were sold outside Yunnan Province accounting for 50% of the total vegetables sold by Yunnan sources to other provinces of China. In 1995, the vegetable production value in Yuanmou exceeded 100 million Yuan. Starting in the winter season of 2008 through the spring of 2009, Yuanmou County cultivated vegetables on 135,200 μ of farmland and sold 0.21 million tons of vegetables to more than 150 cities across 25 provinces in China, as well as exporting to several foreign country markets. This generated revenue of 469 million Yuan. Due to its famed capacity for vegetable production, Yuanmou has been named the "natural greenhouse," "the China winter vegetable garden," and the "vegetable basket hung on the Jinshajiang River." In direct correlation with the vegetable cultivation strategy, farmer incomes have increased and living standards have also improved.

However, this agricultural intensification may have severe consequences for water resources and management. What are the impacts of this development strategy on the local water regime and human health in this already water-poor county? And how is it possible to maintain economic growth while protecting human health and the integrity of the ecosystem?

In this article, we explore answers to these questions, using the data collected through an EcoHealth research project conducted in Yuanmou County.

Methodology

In 2006, we commenced the implementation of an EcoHealth project entitled "land use change and human health in eastern Himalayas". This project was funded by International Development Research Centre (IDRC) and implemented by the International Centre for Integrated Mountain Development (ICIMOD) together with its partners in China and Nepal. EcoHealth is defined as approaches that "formally connect ideas of environmental and social determinants of health with those of ecology and systems thinking in an action-research framework applied mostly within a context of social and economic development" (Charron 2012). This approach addresses complexity and systems thinking (Allen et al. 1993; Kay et al. 1999; Waltner-Toews et al. 2008) and focuses on the interactions between the ecological and socio-economic dimensions of a given situation, and their influence on human health, ecosystems, and sustainability (Charron 2012). Yuanmou was selected as one of the three study sites in this project due to the change in land use from subsistence farming to intensified agricultural production, with a focus on commercial vegetable farming. We did a scoping study in the county, collecting existing data from various government departments and conducting small-scale surveys where needed. During this period, the issue of water management was observed. Guided by "systems thinking," an EcoHealth principle, we describe the water management challenges facing the county, document the coping strategies adopted by government and farmers to address the challenges, analyze remaining and emerging challenges, and suggest an EcoHealth framework for better management of water resources in Yuanmou.

Data used in this article comes from several sources: interviews with local health officials, agricultural and water resource departments; existing data collected from the above-mentioned departments; one questionnaire survey of 188 farmers, ages 18 years and older, in two villages, in which we asked questions relating to knowledge, attitude and practices of pesticide use; one household survey of 363 households investigating water and basic sanitation in four villages across three townships; participatory rural appraisal in four villages; and laboratory testing of 61 water samples collected from drinking water sources.

Findings

Water Management Challenges

While commercial vegetable farming in Yuanmou brings benefits to local farmers and government, it stresses already strained water resources and brings new challenges to local water management regimes.

Water Shortages and Scarcity

Agricultural production needs water, and vegetable farming requires even more water than other agricultural activities. Although, the rivers running through Yuanmou provide water for farming, they are only accessible by villages located in the river valley. Furthermore, due to intensified vegetable cultivation and arid weather, water from these rivers is now inadequate. Upstream villages have better access to river water than downstream villages. Occasionally, upstream villages build small dams to collect water for agricultural production that can reduce or even stop the river flow to downstream villages. The latter must then rely on other water sources, such as wells and reservoirs. There is therefore tension between upstream and downstream villages over water allocation. Although, this tension has not developed into any observable conflict, farmers living downstream have begun to complain about the small dams built by upstream villages. When water use is further intensified and farmers' awareness of water rights increases, conflict over water allocation may yet occur, as has happened in other parts of China (Gleick 2009). This presents a challenge to local authorities. Moreover, those farmers living in Yuanmou's mountainous areas must rely on rainfall and other water sources for agricultural production and domestic use; they face even more severe water shortages and scarcity.

Water Pollution by Agricultural Runoff and Domestic Waste

An additional stress on water resources is the pollution caused by chemical fertilizers and pesticides and by domestic waste. Before the 1950s, the major crops were rice in the spring and wheat and beans in the autumn. Cattle were used to plow the land and organic compost derived from human and animal waste was the only fertilizer used. Cotton and sugar cane were introduced into the county in 1958 as cash crops and, at the same time, the application of chemical fertilizer and DDT began. Using large amounts of chemical fertilizers started in 1978 when the government implemented a project demonstrating the use of ammonia as a fertilizer for agricultural production. In that year, 3,546 tons of ammonia was applied across Yuanmou. The government put great effort into promoting ammonia use from 1978 through 1981. In 1982, the use of ammonia was terminated when the factory that had supplied ammonia to Yuanmou farmers closed. However, new chemical fertilizers, including potassium, phosphate, nitrogenous, and compound fertilizers, were introduced and have been increasingly applied since 1982 due to large-scale vegetable farming. The application of chemical fertilizers in 2000 in the county was about 35,000 tons, around 1.13 tons per hectare of farming land.

Pesticide use increased significantly between 1990 and 2000 and peaked in 1999 and 2000, with a nearly threefold increase from 112 tons in 1990 to 270 tons in 1999. After 1999, there was a sharp decrease in pesticide use, followed by a slight increase, but rate of use has relatively stabilized. The change in the pesticide use can be attributed to a new agricultural policy adopted in this county. We will describe this in the next section. Our survey of 188 farmers in Yuanmou found that different varieties of pesticide are easily accessible at small village shops, and most farmers use mixed pesticides, applying 3–4 varieties of pesticides at once. Around 63.6% of farmers use pesticides 10–30 days per year; and more than 30% of them use pesticides more than 30 days per year. 41% of those farmers surveyed reported that they waited 6–7 days between applications and 39.3% said they waited 7–14 days.

Using chemical fertilizer and pesticides may contribute to high agricultural production yields, but they can cause serious, non-point source water pollution. We tested 61 water samples collected from drinking water sources in four villages in Yuanmou County and the results showed that 6.6% of the samples contained excessive nitrate and 62.3% of the samples contained bacteria at a level that exceeded the China Rural Drinking Water Standard allowable levels (see Table 1). This demonstrates that some drinking water sources are polluted with nitrates and bacteria, which may come from chemical fertilizers and human and animal waste, respectively.

Our survey found that many water sources lack basic structural protection, and are contaminated by agricultural runoff and domestic waste. Meanwhile, most villagers, particularly students at school, still drink untreated water drawn directly from these water sources. The 1974–2007 records of the Infectious Disease Reporting System of Yuanmou County Centre for Disease Control and Prevention (CDC) shows that dysentery, pulmonary tuberculosis, hepatitis (without the differentiation of types of hepatitis), and typhoid were the first four reported infectious diseases in the county. They accounted for 95.38% of all reported infectious diseases during this time period. For example, since 1978, dysentery has become the top reported infectious disease in Yuanmou (see Table 2). These data

Table 1. Laboratory test results of 61 drinking water samples in Yuanmou County

Tested items	Range of results	The national standards	Number of qualified water samples	Percentage of qualified water samples
Chroma	10–25	20	60	98.4
Turbidity	0–21	3	54	88.5
Nitrate-nitrogen	0–64.4	20	58	95.1
Fluoride	0.4–5.9	1.2	29	47.5
Arsenic	0–0.04	0.05	61	100.0
pH	7.2–8.6	$\geq$6.5 to $\leq$ 9.5	61	100.0
Chloride	4–969	300	41	67.2
Oxygen consumption	0–3.4	5	61	100.0
Manganese	1.73	0.3	57	93.4
Iron	0	0.5	61	100.0
Hardness	162–1,345	550	47	77.1
Sulfate	23–783	300	45	73.8
Total dissolved solids	229–2,398	1,500	48	78.7
Colony forming unit	20–4.0 $\times$ 10^4	500	24	39.3

indicate that poor water quality has caused a large proportion of diseases throughout the county.

The household questionnaire survey of 363 farmer families revealed that 97% of homes have a toilet and family members do not practice open defecation. However, 35% of the surveyed households dumped their garbage freely and only 56% households put their garbage in designated places. Regarding domestic wastewater, 61% of households discharge waste water freely into rivers, irrigation channels, or village streets. Observations made by the EcoHealth project team in the four project villages and other villages revealed that although many farmers have built new houses in the last three decades, they did not install sewage systems along with their homes. Many villages paved their local roads with cement as part of the New Countryside Construction Program, but no sewers were built. So far there is not any wastewater treatment factory in the county, let alone in rural villages. As a result, water pollution by domestic wastewater is unavoidable.

High Fluoride Concentration in Water

Yuanmou County was identified in the 1980s by the health department as one of China's endemic fluorosis areas where both dental and skeletal fluorosis were identified and fluoride concentrations were higher than 1 mg/l in some drinking water sources. The Chinese drinking water standard stipulates that fluoride in drinking water should be lower than 1 mg/l. Thus, fluorosis in Yuanmou was diagnosed as being water-borne. A survey conducted in 1984 by the local health department, covering 613 natural villages and 860 water sources, identified 41 natural villages as hotspots of endemic fluorosis. In the last two decades, the government has consistently built water improvement facilities to bring low-fluoride water to these villages as a major measure to control fluorosis. In 2006, the local health department conducted another survey to assess the effects of water improvement projects on fluorosis control. 1,404 children, aged 8–12 years, in 41 villages, were checked for dental fluorosis; 341 were diagnosed with the disease; the prevalence rate was 24.29%. 179 children, aged 8–12 years, in seven villages, took a urine fluoride test; their average urine fluoride concentration was 1.47 ppm, higher than the 1.4 ppm standard. The health department also checked 16,284 farmers aged 17 and older, in the 41 villages for skeletal fluorosis and found 148 cases (second degree), with a prevalence rate of 0.91%. More alarmingly, water sources with high fluoride concentrations used by villagers for drinking and irrigation were again found in the 41 villages as well as in new villages. Furthermore, around half of the 61 water samples tested by our EcoHealth research team in four villages in 2008 had fluoride higher than 1 mg/l (see Table 1). All of these results reveal that after 22 years of efforts to control the disease, fluorosis still exists in this county though to a less severe degree. The combined effects of high evaporation caused by hot weather, large-scale vegetable planting, and high fluoride concentrations in some water sources reduced the amount of safe water

Table 2. Reported infectious disease cases in Yuanmou County from 1974 to 2007

	1974–1977			1978–1987			1988–1997			1998–2007		
Rank	Disease	Reported cases	%	Disease	Reported cases	%	Disease	Reported cases	%	Disease	Reporter cases	%
1	Flu	28,066	53.72	Dysentery	36,190	52.96	Dysentery	2,861	42.39	Dysentery	1,817	30.10
2	Dysentery	10,602	20.29	Flu	15,995	23.41	Hepatitis	1,462	21.66	TB	1,788	29.62
3	Measles	7,293	13.96	Measles	7,882	11.53	Typhoid	1,078	15.97	Hepatitis	1,397	23.14
4	Whooping cough	4,168	7.98	Hepatitis	3,709	5.43	Measles	384	5.69	Typhoid	756	12.52
5	Hepatitis	1,283	2.46	Whooping cough	2,626	3.84	Malaria	287	4.25	Gonorrhea	63	1.04
6	Meningitis	560	1.07	Typhoid	1,027	1.50	TB	233	3.45	Syphilis	56	0.93
7	Typhoid	101	0.19	Meningitis	391	0.57	Japanese encephalitis	155	2.30	Japanese encephalitis	40	0.66
8	Malaria	66	0.13	Malaria	296	0.43	Cholera	125	1.85	AIDS	37	0.61
9	Japanese encephalitis	58	0.11	Anthrax	152	0.22	Anthrax	69	1.02	Anthrax	36	0.60
10	Anthrax	27	0.05	Japanese encephalitis	57	0.08	Flu	53	0.79	Measles	25	0.41
11	Others	18	0.03	Others	8	0.01	Others	42	0.62	Others	22	0.36
	Total cases	52,242	100	Total cases	68,333	100	Total cases	6,749	100	Total cases	6,037	100

Data source: Surveillance data collected by the Yuanmou County Centre for Disease Prevention and Control.

available for local consumption, which has negative implications for people's health. These health concerns pose an additional challenge for water management in this county, as controlling fluorosis requires fresh drinking water with fluoride concentrations under 1 mg/l.

Adopted Coping Strategies

In response to water shortages and endemic fluorosis, the government and local farmers have taken steps in the last decades to adapt to the situation.

Construction of Water Storage Facilities at Different Levels

By 2006, there were, in total, 1,627 reservoirs and ponds in Yuanmou, four of which were mid-scale reservoirs, 65 small-scale reservoirs, and 1558 ponds. The total water storage capability of these facilities was 108 million cubic meters and the actual water storage was 69.6 million cubic meters, sufficient to irrigate 10,600 ha of land; around one-third of the arable land in this county. Another two larger reservoirs are being constructed, belonging to the National Western Region Development Program and the Yunnan Provincial Key Projects, respectively. The plan is to add the two new reservoirs to existing water facilities to be able to irrigate all the farmland across Yuanmou. These water facilities have enabled vegetable cultivation in places where it was not possible before due to water shortage.

Mining of Groundwater by Local Farmers

Facing water shortages, local farmers also dug wells to access groundwater for irrigation and domestic use. There is no accurate data on the number of wells in the whole county, but our survey investigated the wells in the four project villages, which we felt were representative of the county. The survey shows that in one village with 79 households, there are 31 wells, and in another village with 316 households, there are 111 wells (see Table 3).

Table 3. Wells in four villages

Village	Number of households	Number of population	Number of wells
Palang	79	326	31
Dajinheshui	316	1,309	111
Hexi	343	1,468	114
Binglong	88	358	3

Water-Saving Agricultural Technology

Water-saving agricultural technology, such as drip irrigation, was introduced in the county in 2005. By 2010, there were 6,545 μ of farmland irrigated by the drip system. In addition, water-saving greenhouses were constructed, which covered 559 μ. Plastic film was additionally used to cover more than 30,000 μ of land to save water. According to the County Agricultural Bureau, a drought-resistant and a water-saving fertilizer was sprayed on an area of 40,000 μ in 2009. This is a chemical fertilizer with a fulvic acid structure that was first used by the Chinese agricultural department in late 1990s in agricultural production. There are several research articles published in Chinese agricultural journals that demonstrated this fertilizer can reduce water evaporation of plants and increase yields. Drought-resistant crops, such as corn and wheat, were planted to replace crops that required more water, such as paddy rice. These strategies and technologies were particularly useful in 2009 and 2010 and effectively reduced the losses caused by drought. However, they have not yet been widely applied throughout Yuanmou County.

Farmer Water-Usage Association

In the last decade, farmer water-usage associations were promoted in rural China by the central government in Beijing. This promotion was part of an effort to increase farmers' participation in the management and maintenance of government-sponsored water facilities so as to maintain the use of these facilities. The Yuanmou County government has been actively implementing this policy, and many villages have set up farmer water-usage associations. The current focus of the farmer water-usage associations is on the management and maintenance of government-sponsored water facilities, but they may play a bigger role in other aspects of water management, such as saving water in the future.

Building Water Facilities to Control Fluorosis

To control fluorosis, the local government began in 1985 a major measure: to undertake water improvement projects that find water sources with qualified fluoride concentrations, and connect them to the 41 identified high-fluoride villages. By 2007, 28 out of the 41 villages had received government-sponsored water improvement projects. This measure reduced the prevalence of both dental and skeletal fluorosis; however, both conditions continue to exist, as revealed by the survey conducted in 2006.

Controlling the Use of High-Poisoning Pesticides

In 2000, the county government became aware of the economic importance of "green vegetable food" and decided to shift its vegetable cultivation to the "non-harmful and green" system. "Green vegetable food" is a specialized vegetable brand issued by the Ministry of Agriculture (MoA), China. There are standards issued by the MoA for the production of green vegetables that include the standards on productive environment and technology, and the use of fertilizers and pesticides. Green vegetables have to be certified by the government. These vegetables are not organic ones, but contain less chemical fertilizers and pesticides compared with ordinary vegetables. There are A-level green vegetables and AA-level green vegetables; the AA-level vegetables are better than A-level ones. Since 2001, a number of measures have been taken by the government to control, eradicate and ban the use of highly toxic, highly concentrated and highly residual (3H) pesticides. Instead, low toxic, low residual, and highly efficient pesticides have been promoted. The government has also taken measures to punish those who sell and use 3H pesticides. For example, 128 tons of 3H pesticides were sequestrated in 2001. The punishment for selling banned pesticides was a fine of 4,000 Yuan, and 2,000 Yuan for being caught using them.

In 2003, the county was recognized by the China Ministry of Agriculture as one of the 100 demonstration counties that produced "non-harmful" vegetables in China. Currently, the county government is promoting the production of "green vegetables" and aims to upgrade its products from "A-level green vegetables" to "AA-level green vegetables." Although, the main objective of the local government is to increase the competitive capacity of its vegetable products on the market so as to generate more revenue, this program benefits the health of both people and ecosystems. For example, water pollution from highly toxic pesticides will be greatly reduced. This demonstrates that economic incentives can be used to protect the environment. However, no measures have been yet taken to deal with water pollution by chemical fertilizers and domestic waste. In 2009, the Yuanmou County government began a pilot project entitled "Application of Fertilizers Based on Tests of Soil Quality," which is part of a national project led by the Ministry of Agriculture with the goal of more efficient, effective, and reasonable use of chemical fertilizers via formula fertilization services. This project may reduce the use of chemical fertilizers and the pollution they contribute to bodies of water.

Discussion

Remaining and New Challenges

Yuanmou County has elements of being a successful story, in terms of resilience in the face of water shortages and achieving high economic growth from agricultural production. However, one should look beyond economic growth by taking into account the remaining and new challenges in water management that will have implications for the long-term well-being of local people and the environment.

Water Shortages, Associated Social Tensions, and Second-Generation Problems of Coping Strategies

Despite the many water storage facilities in Yuanmou, water shortages remain a formidable challenge. This will worsen with the expansion of vegetable cultivation and may cause tensions and conflicts over water resources among farmers. In addition, the mining of groundwater, a coping strategy adopted by many farmers to manage water shortages, is poorly regulated. Farmers can almost freely dig a well on their farmland if they can afford the initial economic cost. This may meet immediate needs for water, but the long-term impact on groundwater is harmful and the sustainability of this coping strategy is questionable. Even now, some farmers dig wells in search of water, but fail to find water even up to 90 m in depth. The dual burden facing local water management authorities is to deal with water shortages while at the same time ensuring the sustainability of water resources and preventing future problems caused by current adaptive measures.

Water Pollution from Chemical Fertilizers, Pesticides, and Human and Animal Wastes

Our data cannot provide direct evidence of water pollution from chemical fertilizers and pesticides in Yuanmou County, but laboratory test results of the 61 drinking water samples, along with the reported cases of infectious diseases from the county CDC, provide indicators that the water sources in this county were polluted by organic or inorganic nitrates, possibly from chemical fertilizers and/or animal or human feces. In fact, non-point source pollution of water bodies is widespread in China and causes eutrophication of many freshwater lakes, such as Dianchi Lake and Taihu Lake (Huang 2008; Avraham 2008; Patrik 2008). A report on the use of nitrogenous fertilizer in China noted that around a quarter of applied nitrogenous fertilizer in China leaches into non-farming land and causes widespread pollution (Greenpeace 2010). China's first national census on pollution sources, released in February 2010, revealed that the total discharge of chemical oxygen demand (COD), a major water pollution indicator, was about 30 million tons in 2007, 43% of which was from agricultural sources (Xinhua News Agency 2010). Wastewater remains a big challenge to water management, not only in Yuanmou County but also in many other counties in China. The lack of wastewater treatment facilities and sewage systems is a widespread problem in rural China that increase people's risk of exposure to infectious and parasitic diseases, as well as a growing volume of industrial chemicals, heavy metals, and algal toxins (Wu et al. 1999).

Controlling Endemic Fluorosis

Water improvement projects have been the main measure taken by the local government to control fluorosis, which to some extent mitigate the problem of fluorosis, but the condition remains. This suggests that traditional measures taken by local government to prevent and control fluorosis are inadequate and ineffective. In one case, the water brought into a village by the water improvement project contained bacteria at a much higher level than allowed by drinking water standards, although the fluoride concentration was acceptable. On one hand, this reflects the difficulty in finding qualified water sources under conditions of water scarcity, and on the other hand, demonstrates that a single-indicator approach (in this case, the fluoride concentration in water) can certainly generate new problems.

More importantly, fluoride can enter the human body through food intake. Our EcoHealth research in Yuanmou reveals that some vegetable and grain samples collected from the four project villages contained higher fluoride levels than allowed by the national food standard. Given the excessive fluoride in the environment, it is not surprising that the crops also contain excessive fluoride. The studies conducted in other parts of China revealed that some plants can absorb fluoride from soil and this bio-concentration causes higher fluoride in certain plants (Lv 2004; Zhu et al. 2001; Wu et al. 2008). One study conducted in the Gaomi District, Shandong Province, reported that after drinking low-fluoride water for 15 years, local people still developed fluorosis by consuming local grain and vegetables grown in a high fluoride environment (Ge et al. 2003). This suggests that controlling fluorosis in Yuanmou will require not only providing safe drinking water, but also the management of irrigated water to reduce the fluoride in crops. This poses a new challenge to local water management and health departments. Figure 2 summarizes the water management challenges and coping strategies found in Yuanmou.

Towards an EcoHealth Framework for Better Water Management

The case of Yuanmou County clearly demonstrates that water management challenges in the context of agricultural intensification are multidimensional, complex, and dynamic, and that the measures to meet these challenges should be designed from the perspective of systems thinking. The study also suggests that not only should immediate effects be considered in dealing with water shortages but also the long-term impact of these measures on the environment, people's livelihoods, and their well-being, so as to avoid second-generation problems caused by current coping strategies.

The effective prevention and control of fluorosis and other water-borne diseases and the sustainable use of water resources in this context requires a system approach that places the problems into a broader water management framework that takes into account the ecological, social, and health aspects as well as the complex interaction among those factors. Here, we propose an EcoHealth framework for Yuanmou County that outlines the role and responsibilities of involved institutions and stakeholders. Figure 3 elaborates on this framework.

There are five main stakeholders in this framework: individual farmers and the farmer water-usage association, the agricultural department, water resource department, environmental protection department, and public health department. To achieve better water management in the county, each stakeholder should perform the assigned role well and also closely collaborate with others.

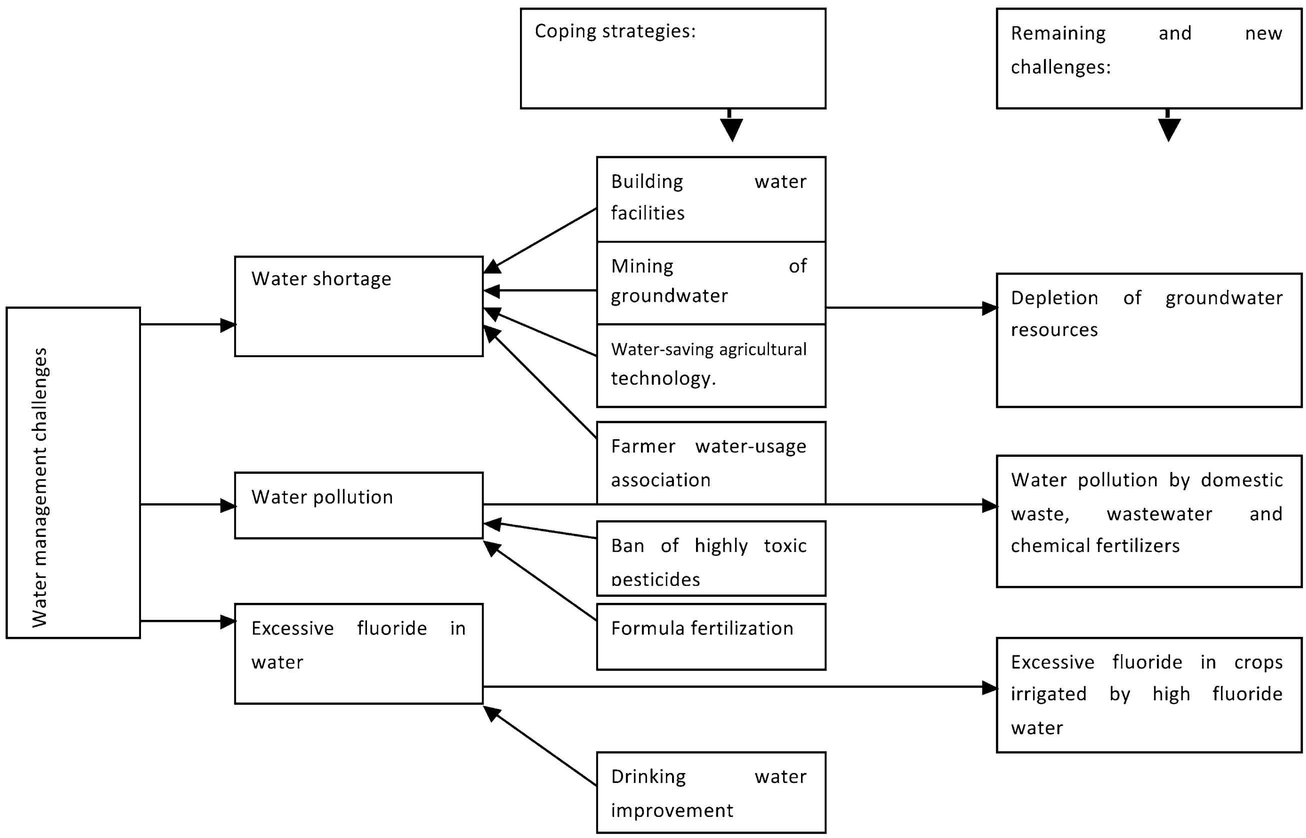

Figure 2. Water management challenges and coping strategies in Yuanmou County.

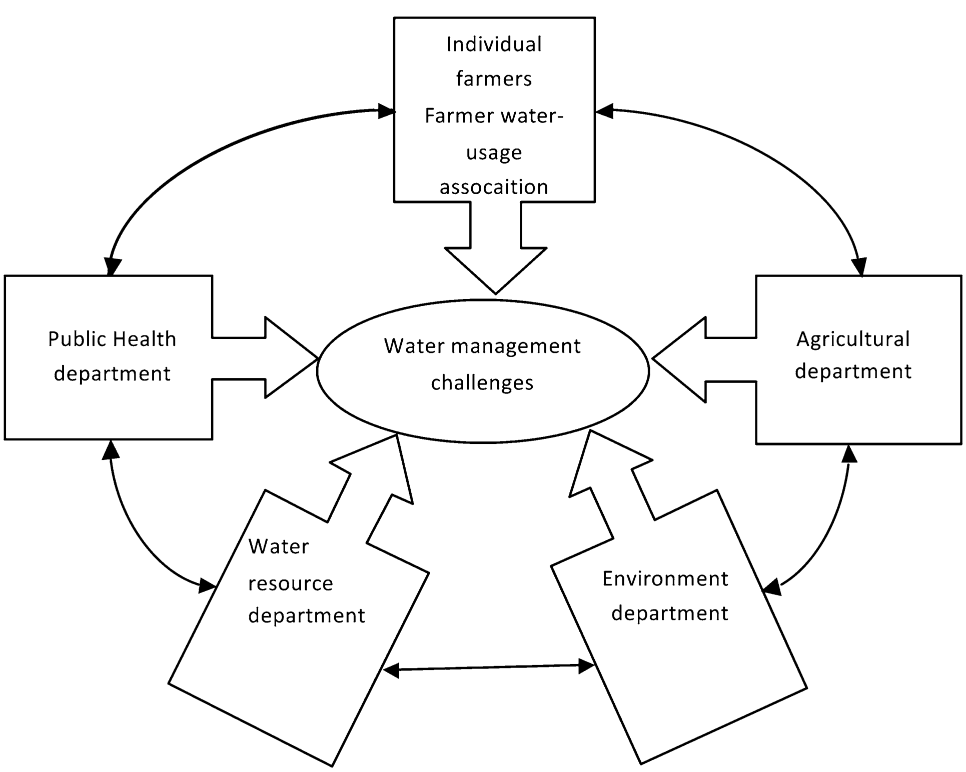

Figure 3. An ecohealth framework for dealing with water management challenges.

First, villagers should be informed about the health impacts of high fluoride and other pollutants in water through health education and be encouraged to actively participate in the maintenance of water facilitates and water resource management. Farmer water-usage associations can serve as a platform for this purpose and they can also play a role in resolving water-related conflicts and other issues. Second, the health department should deliver health education and regularly test the quality of all water sources (for fluoride and other basic indicators). It should also make this information available to villagers and other departments to help them make informed choices in selecting water sources for domestic use and irrigation. Third, the environmental protection department should study simple sewage systems and wastewater treatment facilities that are suitable for use in rural areas. This may require cooperation among environmental, health, agricultural, and water resource departments. Fourth, the water resource department should advise villagers to avoid geographic conditions that have high risk for excessive fluoride and other harmful chemicals in the selection of sites for digging new wells.

The water resource department also should manage water resources under a comprehensive framework that not only considers the present economic and social needs for water but also the future implications for current water use for health and environmental sustainability. Regulations should be put in place to control the use of groundwater and to encourage saving water. Economic mechanisms, such as water pricing and the trade of water quotas can be employed to provide incentives for farmers to use water more efficiently. Fifth, the agricultural department should study and promote water- and fertilizer-saving techniques that can help farmers use water and chemical fertilizers more effectively during crop production. Integrated pest management (IPM), piloted in Yuanmou County in the last few years, is also needed to reduce the use of pesticide. The agricultural sector's efforts contribute not only to save water but also to reduce water pollution from agricultural practices.

Finally, water resources should be used in a planned, regulated, equitable, and sustainable manner as promoted by the integrated water resource management approach (Mazvimavi et al. 2008). This can optimize the beneficial aspects of water use and reduce its detrimental elements. The implementation of this framework will require a new water governance structure, institutional arrangements, and appropriate technology that can enable all stakeholders to work in a coordinated and cooperative way. These will be the greatest challenges in water management in rural China.

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