



How does smallholder farming practice and environmental awareness vary across village communities in the karst terrain of southwest China?



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ABSTRACT

Worldwide, karst terrain is highly sensitive to human activity due to extensive areas of thin soil and rapid water flow to groundwater. In the southwest China karst region, poor farming decisions can promote land degradation and reduce water quality with negative consequences for livelihoods in a region where farmers already suffer from the highest national poverty rates. Targeting management advice to farmers through knowledge exchange and decision support can help alleviate land use impacts on the karst environment but first requires baseline knowledge of how local farming communities understand and approach soil and water management. We used a catchment-wide survey ($n = 312$ individuals in seven villages) to investigate differences in environmental awareness, catchment understanding, and farming practices amongst farmers and community leaders in a typical karst catchment in southwest China. Age, gender and village of residence of farmers showed an association with the type of challenges perceived to be most serious. Access to labour, issues of water quantity and/or quality affecting irrigation, and fertiliser costs were recognised as being particularly problematic for the viability of farming. Sources of information used to learn about farming practices, the environment and fertiliser use were more diverse for younger (< 40 yr old) farmers and levels of training and acquired knowledge regarding land management practices varied significantly between villages in the catchment. The identification of significant associations between villages or sample demographics, and a variety of questions designed to understand farmer attitudes and their environmental awareness, provide clearer insight upon which knowledge exchange and training programmes can be co-designed with catchment stakeholders. This has the potential to lead to improved farming practices with co-benefits for farmers and the environment; helping sustain ecosystem services for impoverished communities in fragile karst ecosystems.

1. Introduction

The southwest China karst region (SCK) accommodates 532,600 km² of exposed carbonate rock and forms one of the largest continuous karst landscapes in the world (Cao et al., 2015). This region is experiencing rapid population and economic growth and has many competing demands on soil and water resources to support livelihoods and deliver food security (Peng and Wang, 2012; Green et al., 2019). Karst landscapes in southwest China are highly sensitive to human activity due to extensive areas of thin soil and rapid water flow through the conduit structure of the underlying geology into groundwater i.e. through the critical zone. For example, agricultural practices have led

to extensive land degradation in the form of karst rocky desertification (Wang et al., 2004), with environmental and socioeconomic impacts compounded further by inefficient inorganic fertiliser use (Lu et al., 2019). Populations residing here are also highly vulnerable to climate change impacts on water supply and quality. Subsistence-farming is found where soils allow (e.g. terraced gentler hillslopes / valley floors) and is of central importance to supporting many of those who live in the SCK (Chen et al., 2012). However, poor farmland management decisions coupled with rocky desertification can lead to adverse effects on livelihoods in a region where local farmers already suffer from the highest national poverty rates (Zhang et al., 2016).

Social and economic factors alongside agricultural policies influence

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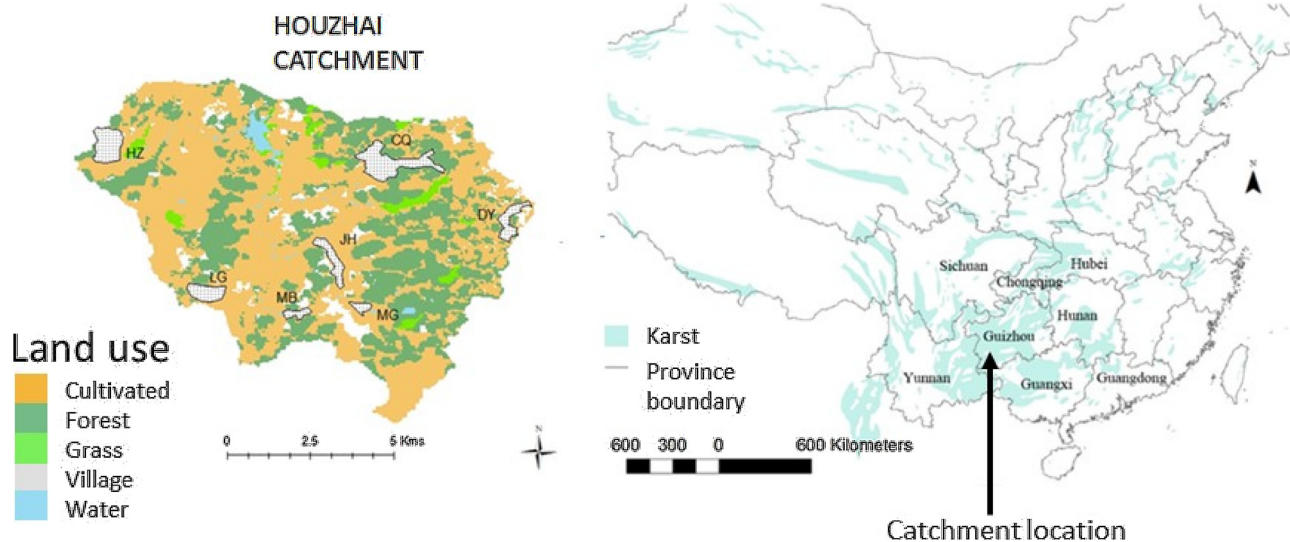


Fig. 1. The Houzhai catchment and its wider geographic setting, with land use and the land boundaries of study villages; CQ = Chenqi, HZ = Houzhai, JH = Jinhe, MB = Mabao, MG = Maguan, LG = Liugu and DY = Dayou.

farmer fertiliser use and manure management in Chinese agroecosystems (Smith and Siciliano, 2015). Nutrient use efficiency is often low in Chinese farming and nutrient inputs could be reduced without a significant loss in crop yields in many farming systems (Bellarby et al., 2017). In 2015 the Chinese Ministry of Agriculture stipulated that there must be zero growth of chemical fertiliser consumption by 2020 (TBT, 2015), which signals a need to capitalise on nutrient inputs from currently underutilised organic sources (Chadwick et al., 2015). Average per unit application of fertilisers on farmland in China is 2.8 times the world average (Ministry of Environmental Protection, 2011) and manure management is rare across large areas of China, with direct manure inputs to water a common practice (Strokal et al., 2016).

To sustain their livelihoods many farmers in the karst region are likely to prioritise economic rather than environmental benefits. The degree to which farmers will be reluctant to reduce the rate of fertiliser application to land has been linked to many factors including age, gender and level of diversification of farm income (Jin et al., 2017). Failings in the agricultural advisory service are often attributed to the overuse of fertilisers in China and a lack of knowledge about crop nutrient requirements amongst farmers (Smith et al., 2017; Pan et al., 2017). There is growing recognition that farmers are a heterogeneous community and accommodate a wide variety of attitudes and behaviour in terms of environmental management due to sociodemographic, farming culture or income influences (Blackstock et al., 2010; Jin et al., 2017; Wang et al., 2018). There appears very limited research (and practice) in exchanging knowledge between scientists and local populations in China, suggesting that mechanisms to share knowledge between these two groups is low and thus, the opportunity for farmers to gain expert knowledge from recent science is limited (Zheng et al., 2019).

Influencing change in farming practice to help alleviate land use impacts on environmental quality requires the building of trust and development of human capacity in farming communities (Cui et al., 2018). However, there is also an essential need for baseline knowledge of how farmer attitudes and environmental awareness vary (Aregay et al., 2018; Jin et al., 2017). In the SCK land surface is often repeatedly heavily-cultivated and/or farming practices are not well-suited to fragile karst ecosystems, thus problems can arise such as poor water quality, often with very-high levels of nitrate (Yue et al., 2015). Understanding how farming communities perceive their impacts on the environment and approach soil and water management in the SCK is therefore a prerequisite for helping to spatially target advice. This is especially important for supporting Sustainable Development Goals to

improve environmental quality and food security; reducing soil erosion and improving soil fertility can also deliver important economic benefits by improving farmer livelihoods through increased household income and poverty reduction (Teshome et al., 2016). How farmer knowledge and environmental awareness varies across village communities is particularly important in China given that a population of ~500–600 million live in expansive rural areas considered essential for agricultural production (Li et al., 2019).

The aim of this study was to undertake a catchment-wide survey to investigate how, where and why environmental awareness, catchment understanding, and farming practices may differ amongst farmers and community leaders in a typical catchment of the SCK. It forms part of a wider UK-China research initiative to understand fragile karst ecosystems and to identify the typical methods for exchanging environmental management knowledge with farmer communities (e.g. Zheng et al., 2019). The specific objectives were to: (i) determine whether spatial patterns in awareness and understanding of soil and water management exist amongst farmers from different villages in a typical mixed land use catchment of the SCK; (ii) evaluate whether sociodemographic factors (e.g. age, gender) affect awareness and understanding of environmental management and farming practices in the catchment; and (iii) identify recommendations for improved knowledge exchange in the catchment by reflecting on the responses from the farming communities and village and town leaders.

2. Materials and methods

2.1. Study catchment

The Houzhai catchment (26° 13' 3" - 26° 15' 3" N and 105° 41' 27" - 105° 43' 28" E) drains an area of 73.5 km² and is located within Guizhou province in the SCK (Fig. 1). The catchment is characterised by a subtropical monsoonal climate and has a mean annual temperature of 20.1 °C. Steep karst cone-depression landforms dominate the topography in the east of the catchment, transitioning to rolling plains in the west. Most of the catchment has a soil depth of less than 0.4 m. The catchment is typical of mixed-land-use paddy farming in the SCK with approximately half of the land used for growing crops such as rice, rapeseed, maize, soybeans and fruit and vegetables. Organic (cattle and pig manures) and inorganic fertilisers are applied to land as part of general farming practices. The catchment has a population density of approximately 400 people per km², with 95% of inhabitants living in agricultural areas (Yue et al., 2015). The Houzhai catchment is also a

particularly useful catchment to investigate with respect to levels of environmental awareness and understanding among smallholder farmers given the long-history of scientific study of water, soil and agriculture in the catchment and the acute need of the population to improve their livelihoods (Li et al., 2010; Yue et al., 2015; Zhang et al., 2017).

2.2. Farmer survey

A questionnaire was designed and used to survey opinions of smallholder farmers involved in small-scale production within the Houzhai catchment. Seven villages were selected for the survey to provide a spatial distribution of data representative of local environmental and socio-economic conditions from across the catchment (Fig. 1). Each village is associated with one of three larger towns: Chenqi and Houzhai are in Huangtong town; Mabao, Maguan, Jinhe and Liugu are in Maguan town; Dayou is in Baiyan town.

The surveys were conducted in November 2016 as one-to-one interviews using a team of Chinese graduate students from Anshun University with the assistance of UK-based scientists. The students (who spoke the local dialect) were trained on how to administer the surveys and were also used to pre-test the phrasing of the survey questions. The final version of the questionnaire is available as supplementary information. The use of face-to-face interviews ensured a high response rate of 312 farmers across 7 villages. In addition, 32 community leaders (24 village and 8 town leaders) also completed questionnaires (Table 1). All surveys were conducted in village squares where people gather to socialise. Community leaders informed participants about scheduled dates for the surveys and encouraged them to take part. The farmer survey comprised three sections: (i) farmer sociodemographic information; (ii) farming practice and environmental awareness regarding soil and water management; (iii) experience and attitudes towards learning to farm differently. In the community leader survey, respondents were asked about their perceptions of issues facing farmers, how best to support farmers and the advice that they provide about environmental management issues.

2.3. Statistical analysis

All statistical analyses were undertaken using Minitab 18.1 (Minitab Inc., PA, USA) and associations / differences at the $p < 0.05$ level (95% confidence interval) were considered statistically significant. The Chi-square test was used to test for associations between farmer's village of residence and/or farmer sociodemographic characteristics (age group, gender and number of dependents) and perceived views on farming challenges, experience of learning and support in farming, environmental awareness and actual farming practices (e.g. fertiliser and manure management). These tests were supported with 2-sample proportional tests where appropriate.

Table 1
Village populations and number of survey respondents.

Town	Village	Village Population	Respondents	
			Farmers	Leaders
Huangtong	Chenqi	3000	57	4
Huangtong	Houzhai	2713	56	2
Maguan	Mabao	2380	52	3
Maguan	Maguan	5000	50	5
Maguan	Jinhe	3900	34	3
Maguan	Liugu	200	21	4
Baiyan	Dayou	2100	40	3

3. Results

3.1. Farmers survey

3.1.1. Sociodemographic characteristics

The gender, age, farming history and dependency characteristics of farmers from each village are provided in Table 2. In summary, the majority of farmers were female (67.6%) but there were notable differences between the villages. Maguan and Mabao had significantly more female farmers than Chenqi and Dayou. There was a significant association between village and number of dependents (i.e. children, infirm and elderly) ($p < 0.001$). Maguan (22.0%) and Houzhai (17.9%) had the greatest proportions of farms with > 10 dependents, significantly higher than all other villages. Farmers aged > 40 accounted for 81.9% of the people sampled and there was a significant association between village and age structure ($p < 0.001$). There were significantly greater proportions of farmers aged < 40 in Jinhe (50.0%) than in Chenqi (17.5%), Houzhai (12.5%), Mabao (15.4%), Maguan (6.0%) and Dayou (7.5%). The highest proportions of > 60 -year olds were in Maguan (58.0%) and Dayou (62.5%). The average farm size was determined to be 0.27 ha (std dev. = 0.17, range 0.03 - 0.93 ha).

3.1.2. Challenges affecting the viability of farming or farm productivity and income

Access to labour was identified by most farmers as their greatest challenge (45.6%) followed by water quantity and/or quality for irrigation (herein termed water source) (27.9%). Managing fertilisers and using technology were considered challenging to 14.8% and 9.2% of farmers, respectively (see Table 3). The specific environmental issues perceived to be problematic to farming in the Houzhai catchment included flooding and drought and are shown in Table 4. Age and gender of farmers both showed a significant association with the type of challenges perceived to be most serious. For example, a significantly lower ($p < 0.05$) proportion of the < 40 age group considered labour to be the greatest challenge compared to those > 40 . In contrast, those < 40 were significantly more likely to highlight water source as the greatest challenge (Fig. 2a). Women farmers were significantly more likely than male farmers to identify labour as the greatest challenge to farming ($p < 0.01$) (Fig. 2b). Key challenges identified by farmers were also found to be significantly associated with village ($p < 0.001$). For example, labour was the leading concern in Chenqi, Houzhai, Mabao and Maguan. Significantly fewer farmers in Jinhe (16.7%) and Dayou (10.0%) indicated labour as their greatest challenge relative to other villages; most farmers in Jinhe (41.7%), Liugu (52.4%) and Dayou (50.0%) indicated that water source was their greatest challenge. The majority of farmers in all villages identified fertiliser as their largest expense (Table 5), though labour was not included in the response options here. Farmer perceptions of the cost of different aspects of their farming did not vary by age or gender.

3.1.3. Training and financial support

There was a perceived lack of training by farmers: 70.7% indicated that they had not received any training or financial support; 23.8% said that they received financial support; 12.7% indicated they had received training. While gender, number of dependents, and age were not associated with likelihood of having received government support ($p > 0.05$) there was a significant association with village and support provision ($p < 0.001$). Jinhe was distinctive in that 75.8% of farmers indicated that they had received some form of farm-related support; 51.5% had received financial support and 54.5% had received training. Farmers from Dayou (47.4%) also received more support than those from other villages, excluding Jinhe: 42.1% financial and 28.9% training. Full details of farming support provision are provided in Table 6.

Table 2

Sociodemographic characteristics of the villages (values as %). Data source: survey of 312 farmers.

	Gender		Dependents				Years family has been farming					Farmer Age		
	F	M	1 - 3	4 - 6	7 - 9	> 10	< 25	25-50	51-75	76-150	> 150	< 40	41 -60	> 60
Chenqi	62.5	37.5	50.9	38.2	10.9	0.0	17.6	35.1	19.3	3.5	24.6	17.5	49.1	33.3
Houzhai	66.1	33.9	41.1	30.4	10.7	17.9	3.6	25.0	17.9	19.6	33.9	12.5	44.6	42.9
Mabao	80.4	19.6	34.6	42.3	19.2	3.8	13.5	38.5	5.8	30.8	11.5	15.4	46.2	38.5
Maguan	80.0	20.0	36.0	24.0	18.0	22.0	0.0	22.0	12.0	44.0	22.0	6.0	36.0	58.0
Jinhe	67.7	32.4	29.4	61.8	5.9	2.9	20.5	23.5	11.8	38.2	5.9	50.0	38.2	11.8
Liugu	61.9	38.1	47.6	33.3	19.0	0.0	14.3	14.3	23.8	19.0	28.6	38.1	47.6	14.3
Dayou	47.5	52.5	47.5	32.5	17.5	2.5	2.5	10.0	7.5	12.5	67.5	7.5	30.0	62.5
Totalsample	67.6	32.4	40.9	36.7	14.3	8.1	9.7	25.8	13.5	23.5	27.4	18.1	41.9	40.0

3.1.4. Sources of information for farming

Almost all farmers (98.1%) indicated that they learned their current farming methods from family and 70.7% exclusively so. Other sources complementing family knowledge were identified as friends (18.7%) and fellow farmers (12.3%). A minority of farmers (15.2% in total) also learned from 'formal' sources: 5.2% from farm cooperative, 5.8% from village committee and 4.2% from local government. Only 3 of the 312 respondents chose 'other' sources beyond those specified as a response and the answers were 'local farming company', 'self-practice' and 'hiring others'. Significantly fewer farmers aged < 40 learned about farming exclusively from family, 46.4% compared to 73.3% of 41 to 60-year olds ($p < 0.01$) and 79.0% of > 60 ($p < 0.001$). Significantly more farmers aged < 40 learned from friends and fellow farmers (37.5%) than those aged 41–60 (20.6%, $p < 0.05$) and > 60 (18.5%, $p < 0.01$). There was also a significant association between age group and learning from a formal source ($p < 0.01$). In total, 21.8% of farmers aged < 40 learned from a formal source, compared to 6.9% of those aged 41–60 and 6.5% of those > 60. A significantly greater proportion of farmers < 40 (14.3%) than those aged 41–60 (2.3%) learned from village committee ($p < 0.01$). There were significantly more farmers aged < 40 that learned from local government (14.3%) than those aged 41–60 (3.1%, $p < 0.01$) and > 60 (0.81%, $p < 0.001$). In terms of gender, significantly more men (79.0%) than women (66.5%) learn their farming methods exclusively from family ($p < 0.05$).

An association between village and learning from a formal source was identified ($p < 0.001$). Farmers from four of the seven villages, Jinhe (50.0%), Mabao (11.5%), Dayou (5.0%) and Chenqi (1.8%), indicated that they learned about farming methods from a formal source (Fig. 3). A significantly greater proportion of farmers from Jinhe learned from local government than all other villages ($p < 0.05$). In addition, Jinhe and Mabao had a significantly greater proportion of farmers who learned from farm cooperatives compared to Houzhai and Maguan ($p < 0.05$).

3.1.5. Manure and fertiliser management

Overall, 37.7% of respondents reported having been encouraged to complete a manure and/or fertiliser management plan during their farming career. Age, but not gender, had a significant effect on this response ($p < 0.05$), with older farmers less likely to have been encouraged to formally plan their fertiliser or manure management regimes. A significant association ($p < 0.05$) between village and

government encouragement to complete management plans was found. In line with other parameters, Jinhe was the only village in which the majority of farmers (61.8%) indicated that they had been prompted to complete a management plan. In other villages, a minority of farmers (22.5–43.6 %) indicated that they had been encouraged to do so, with the lowest proportion in Dayou.

There was a significant difference between villages in how farmers managed livestock waste. Farmers from Jinhe (52.9%) were most likely to store livestock waste undercover (e.g. in a barn) for manure composting compared to 27–37 % of farmers from other villages. The other villages were most likely to pile livestock waste in the field for manure composting (Chenqi 54.4%; Houzhai 61.7%; Mabao 55.8%; Maguan 56.0%; Liugu 52.4%; Dayou 52.5%). Some farmers (10.0% from Maguan and 8.9% from Houzhai) washed their livestock waste directly into a ditch or watercourse, compared to 0–3.9 % of farmers from other villages. Fig. 4 provides information on the proportion of farmers who considered their land and water management to potentially affect those farming further downstream while providing cross-comparison to other village statistics.

A higher proportion of the farmers who indicated that they had received training and/or financial support stored their livestock waste in a barn (50.0% and 34.7%, respectively) compared to those who had no support at all (31.9%). There was a significant difference between those who had received training and those who had no support in this regard ($p < 0.05$). A significantly greater ($p < 0.05$) proportion of those who learned from the farm cooperative also indicated that they moved their livestock waste to a barn (56.3%), compared to those who learned from other sources (30–41.4 %) or those who learned from family only (30.0%).

3.2. Awareness of pathogen risk from manures

Only 39.7% of farmers were aware of pathogens in livestock waste that may cause illness to humans and this awareness decreased with age ($p < 0.001$). Awareness was reported by 63.6% of farmers aged < 40, compared to 35.1% of those aged 41–60 and 33.8% of those > 60. There was no significant difference in awareness of pathogen risks arising from manures amongst male and female farmers. Farmers who indicated that they had received training or financial support were more likely to be aware of pathogens in livestock wastes ($p < 0.01$). Awareness of these microbial risks varied significantly by village

Table 3

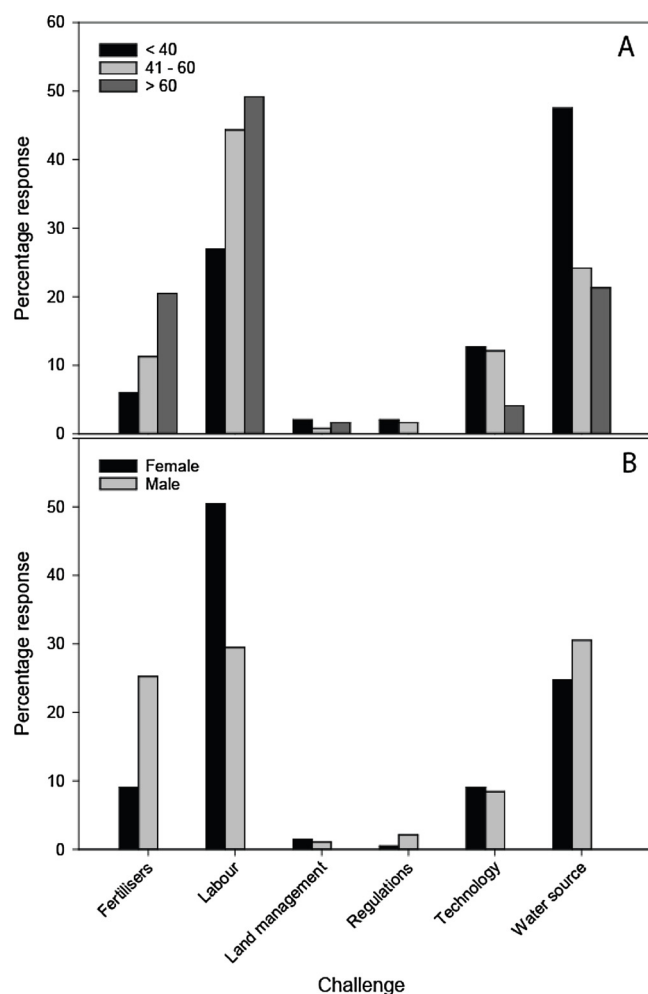
The greatest challenges to farming, by village (as %). Data source: survey of 312 farmers.

Challenge	Chenqi	Houzhai	Mabao	Maguan	Jinhe	Liugu	Dayou	Total sample
Labour	49.1	59.6	42.2	72.9	16.7	47.6	10.0	45.6
Water source	22.6	9.6	33.3	12.5	41.7	52.4	50.0	27.9
Land management	1.9	0.0	2.2	4.2	0.0	0.0	0.0	1.4
Technology	9.4	3.8	15.6	2.1	33.3	0.0	7.5	9.2
Fertilisers	15.1	25.0	6.7	8.3	8.3	0.0	30.0	14.8
Regulations	1.9	1.9	0.0	0.0	0.0	0.0	2.5	1.1

Table 4

Environmental issues perceived as being problematic to farming, by village (as %). Data source: survey of 312 farmers.

Environmental issue	Chenqi	Houzhai	Mabao	Maguan	Jinhe	Liugu	Dayou	Total sample
Flooding	38.6	46.4	15.7	38.0	26.5	40.0	27.5	33.4
Landslides	7.0	7.1	0.0	0.0	11.8	0.0	15.0	5.8
Soil erosion	17.5	3.6	7.8	0.0	5.9	0.0	15.0	7.8
Forest fire	7.0	0.0	0.0	0.0	2.9	0.0	0.0	1.6
Droughts	100.0	51.8	92.2	72.0	88.2	85.0	97.5	82.8
None	0.0	7.1	5.9	6.0	5.9	0.0	2.5	4.2

**Fig. 2.** The most serious challenge identified by farmers in the survey grouped by (A) age, and (B) gender. Data source: survey of 312 farmers.

($p < 0.05$). Jinhe was the only village in which most farmers (61.8%) recognised the potential risk of pathogens from livestock waste. Lowest levels of awareness were reported in Maguan (24.0%). Given the effect of age on farmer's awareness of pathogens and that a significant difference was found in the age structure of farmers between villages,

Table 5

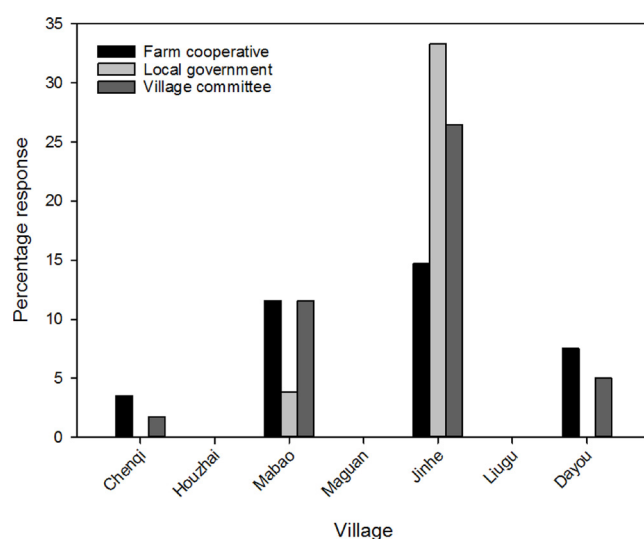
The most expensive aspect of farming, by village (as %). Data source: survey of 312 farmers.

	Chenqi	Houzhai	Mabao	Maguan	Jinhe	Liugu	Dayou	Total sample
Seeds	7.6	0	6.1	0	0	0	2.5	2.7
Fertilisers	77.4	77.8	73.5	76.6	75.9	76.2	80.0	76.8
Chemicals	1.9	1.9	0	0	10.3	0	2.5	2.1
Tools	1.9	20.4	6.1	23.4	6.9	9.5	15	12.3
Water for irrigation	11.3	0	12.2	0	3.5	14.3	0	5.5
Taking harvest to market	0	0	2.0	0	3.5	0	0	0.7

Table 6

Proportion (%) who have received government support for their farming practice, by village. Data source: survey of 312 farmers.

	Chenqi	Houzhai	Mabao	Maguan	Jinhe	Liugu	Dayou
None	85.5	83.9	66.0	84.0	24.2	81.0	52.6
Financial support	9.1	14.3	29.8	16.0	51.5	19.0	42.1
Training	3.6	1.8	12.8	0.0	54.5	0.0	28.9

**Fig. 3.** Percentage of farmers from each village that learned about current farming methods from formal sources. Data source: survey of 312 farmers.

further analysis was undertaken to evaluate any association between village and likelihood of pathogen awareness for only those farmers aged > 40. Jinhe remained the village with the greatest reported awareness (58.8%) with a significantly greater proportion of farmers over 40 years old who indicated awareness than in Chenqi (28.9%), Mabao (25.6%) and Maguan (23.4%) ($p < 0.05$).

3.2.1. Future learning

Most farmers indicated that they would like to learn how to farm differently (75.7%). Jinhe had the greatest proportion of farmers that indicated that they would like to learn differently (90.9%), whereas Mabao recorded the lowest interest (64.4% of farmers). The learning

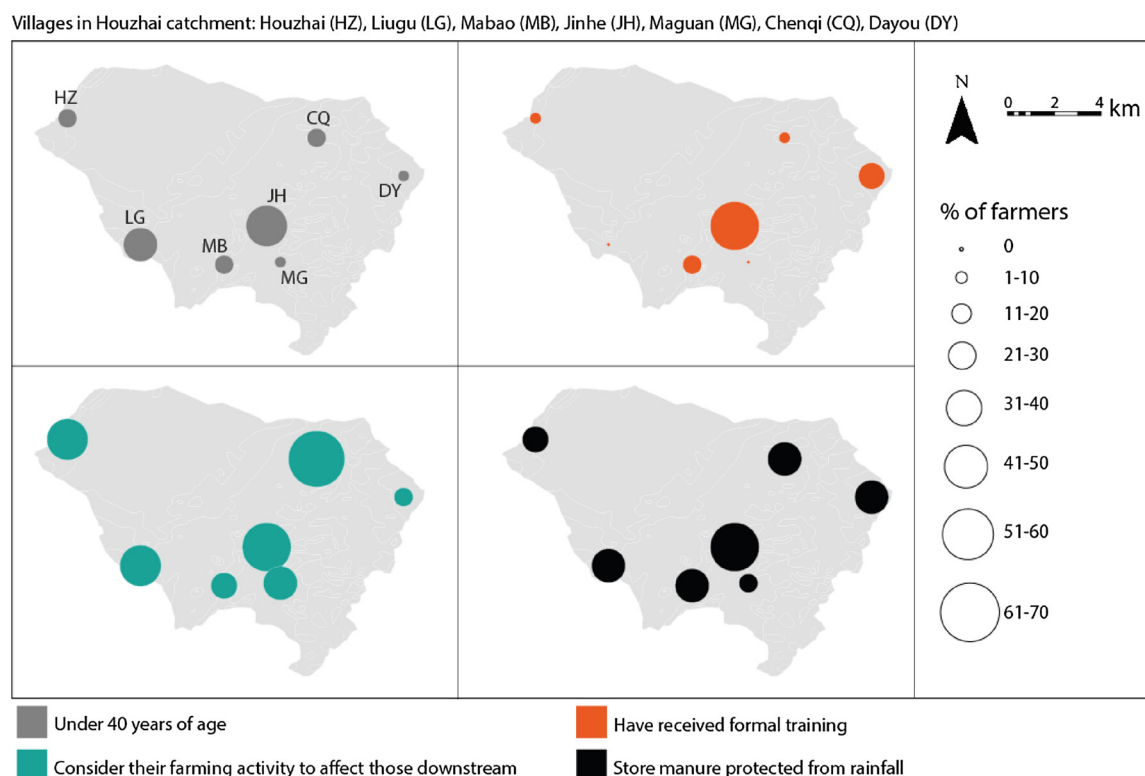


Fig. 4. Visualisation of village data across the Houzhai catchment to provide cross-comparison of farmer responses. Data source: survey of 312 farmers.

method chosen with highest frequency was a farm visit (60.4%), followed by a training course (30.4%), with written instructions or poster communications being less popular (8.0 and 4.0%, respectively).

3.3. Community leader survey

Most leaders identified earning an income as the greatest pressure on farmers (75%). Water and soil related issues were identified by 38.0% and 31.0% of leaders, respectively. More village leaders (41.7%) than town leaders (25.0%) identified water-related issues. Financial support and training were considered the best way to support farmers to change their farming practices. However, there were differences in perceived best practice approaches to do this between town and village leaders. Of those that responded, more town leaders (75.0%) than village leaders (29.2%) thought that training alone was the best way to support farmers but more village leaders (41.6%) than town leaders (0%) considered financial support the best way. A combination of training and financial support was considered best by 16.7% and 1.5% of town and village leaders, respectively. With respect to advice provision, leaders from all villages gave advice on soil conservation

(Table 7). Leaders from Mabao, Jinhe, Liugu and Dayou gave advice on a broader range of environmental management topics (including soil and water conservation, new farming techniques, and fertiliser and manure management) than those from Houzhai, Chenqi and Maguan. Leaders from Houzhai gave advice on only one topic – soil conservation.

4. Discussion

The sample demographics of this study were consistent with national population trends that report a large movement of working age males from rural areas to cities since the 1990s (Cao and Birchenall, 2013) and our sample characteristics were also confirmed as being representative of farming villages in this region by the county statistician (Zheng et al., 2017). There are distinct differences in the perceptions, attitudes and management approaches of farmers in the Houzhai catchment, influenced both by village and sociodemographic factors. Opportunities and challenges for improving farming practice thus exist and responses grouped by village can be used to help focus the nature of advice, training and decision support needed on a village-by-village basis. However, the identification of associations between villages or

Table 7

Type of Advice provided by leaders to farmers, by village and grouped for all village and town leaders (values as %). Respondents could choose multiple answers. Data source: survey of 32 community leaders.

	None	New Techniques	Soil Conservation	Soil Erosion	Water Conservation	Fertiliser Use	Manure Management
Chenqi	25.0	50.0	50.0	0.0	75.0	25.0	0.0
Houzhai	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Mabao	0.0	100.0	33.3	0.0	33.3	33.3	33.3
Maguan	20.0	60.0	20.0	0.0	0.0	40.0	0.0
Jinhe	0.0	33.3	33.3	0.0	33.3	33.3	33.3
Liugu	0.0	75.0	75.0	50.0	75.0	50.0	50.0
Dayou	0.0	0.0	33.3	0.0	66.7	66.7	33.3
Village level	8.3	50.0	45.8	8.3	45.8	37.5	20.8
Town level	12.5	50.0	50.0	0.0	50.0	75.0	37.5

sample demographics, and a variety of questions designed to understand farmer attitudes and environmental awareness, provide a more detailed level of insight upon which programmes of knowledge exchange and training can be co-designed (e.g. Zheng et al., 2019). Further, we recognise an existing science-policy-practice interface and approach to knowledge management in Puding county, where the Houzhai catchment is situated, as a means of sharing our findings (Zheng et al., 2018).

Labour was the greatest challenge for women and older farmers, particularly in Maguan and Houzhai, consistent with recognised patterns of employment migration due to family members leaving for lengthy periods of time in search of city-based employment (Smith and Siciliano, 2015). Resource constraints (such as access to labour) are widely-recognised to influence farmer/enterprise decision making around the world (Fish et al., 2009) and in China, farm labour shortages have been identified as a key barrier to efficient use of both inorganic fertiliser and organic manure (Chadwick et al., 2015). A lack of farm labour often results in fewer applications of fertiliser to land throughout the agricultural calendar to coincide with crop needs and therefore one-off applications are made but at loadings in excess of nutrient recommendations in a misjudged effort to compensate (Bellarby et al., 2017; Chadwick et al., 2015). In contrast, younger farmers considered water source to be their greatest challenge. The farmers' concerns with water quantity and quality for irrigation are associated with the frequent droughts that can affect the villages in the Houzhai catchment – 83% of farmers perceived drought as the most problematic environmental issue in the catchment. Even in the wet season, water availability can be a problem in the SCK due to its rapid transfer through the karst conduit system and thin soils having poor ability to retain water (Yang et al., 2019). The different challenges perceived by farmers of different age groups may reflect a greater environmental awareness acquired via the more diverse range of information sources used by younger farmers. Equally it could be that labour is simply a greater challenge for older farmers, despite issues of water scarcity. The concerns regarding water source quality and quantity do provide evidence that research is needed to help understand hydrological connections and water availability and quality in the SCK and that this needs to be communicated effectively to communities in the Houzhai catchment (Buckerfield et al., 2019a).

Few farmers in this study had received training from the government, a finding consistent with other research reporting on fertiliser use training delivered to Chinese farmers via the agricultural extension service (Yang and Fang, 2015). However, over half of the farmers from Jinhe had received training, which was far more than in the other villages. In Maguan, Chenqi and Houzai, farmers had received little-to-no training and so clusters of knowledge appear to be spatially distributed across the catchment. The underlying reason why a farming community within a particular village has benefitted more from training than elsewhere in the catchment is unclear. One possibility is that lines of communication between farmers and village leaders are particularly effective in Jinhe, and a proactive community has sought assistance from village leaders who, in this case, may have been more efficient in coordinating and mobilising resources to apply for government training and raise awareness of particular issues (c.f. Li et al., 2019). Jinhe is located in an agricultural demonstration area and has secured local government support in recent years to improve basic infrastructure and education (ADRC, 2018). There is further indication that this community may be proactive and self-motivated to learn given that over 90% of Jinhe respondents (relative to a catchment average of ~ 75%) acknowledged a desire to learn about new farming techniques. However, across all villages the majority of farmers did not perceive their farming activities to affect the landscape and/or downstream users of water. This suggests limited catchment understanding and a need for knowledge exchange among the farming communities to help improve awareness of the links between farm practice and water quality, as proposed by others (Buckerfield et al., 2019a).

Learning about farming practices from multiple sources was uncommon in the Houzhai catchment and almost exclusively learned from family. However, half of the farmers in Jinhe learned from the farm cooperative, village committee or local government and survey responses indicated a more active farm cooperative in this village relative to others. It is likely that some farmers did not consider manure and/or fertiliser management planning as learning from a formal source given that higher proportions of respondents had completed such plans than had acknowledged formal sources as a learning mechanism. The catchment-wide analysis highlighted that farmers who learned from a farm cooperative were more likely to manage livestock manures more effectively relative to those who learned about farming practice from other sources, suggesting that farm cooperatives can play an important role in influencing farming behaviour to deliver multiple benefits (both on-farm and to the environment) as noted elsewhere (Zhou et al., 2018). In addition, young farmers learned from formal sources, as well as more informal sources (friends and fellow farmers), more than older farmers did. Trends in younger Chinese farmers acquiring information and instructions about farming, the environment and fertiliser use from a greater number of sources than older farmers are recognised (Orderud et al., 2017).

Training provision can decrease fertiliser use amongst farmers in China (Hu et al., 2007; Huang et al., 2008; Cui et al., 2018), which is important given that 77% of all farmers surveyed in our study identified fertiliser as the most expensive component of their farming activity despite it being heavily subsidised by the government (Li et al., 2014). Hence, the variation in training between different villages has the potential to impact on how farm resources are managed across the wider catchment. In Jinhe, over half of the farmers reported a manure management approach involving the storage of livestock waste in a barn, whereas over half of the farmers surveyed from all seven villages reported that they leave livestock waste in the field where it is more vulnerable to nutrient loss, especially during heavy rainfall. The establishment of standards for improving farming practices for effective control of fertiliser applications has been advocated (Han et al., 2016) and China's first pollution survey in 2009 reported that 38% of nitrogen and 55% of phosphorus from agriculture entering watercourses originated from livestock waste (Chadwick et al., 2015). In the Houzhai catchment, nitrate levels in surface and groundwater have been shown to be elevated, particularly in the wet season, and isotopic analysis has previously indicated manure to be the main source of pollution in the dry season, with a mixture of manure and synthetic fertilisers in the wet season (Yue et al., 2015). The association between training and a tendency for farmers to store and manage manures within a barn environment provides some evidence to suggest that training is being effective in changing farmers' behaviour. The farmers with the poorest manure management practices were in Maguan and Houzhai, villages where less than 2% of farmers had received training, thus highlighting that provision of basic training in soil and manure management could deliver multiple benefits for the environment but also farmer livelihoods. Considered individually, villages may be overlooked and deemed unimportant in the context of the catchment scale water quality; however, advice targeted at village level is crucial given that this is the scale at which many of the management decisions relevant to water quality are made by farmers. Thus, improved management at village scales has the potential to hold just as much value to the effective management and planning of water resources as catchment-level planning (Winter et al., 2011). This is important given that policy and interventions often assume homogeneity over large areas given the history and characteristics of the Chinese landscape.

Spatial and sociodemographic differences in awareness of pathogen risks from livestock wastes were also identified, with awareness positively related to training provision. Acquiring knowledge to understand and manage such risks has been linked to wider peer-to-peer discussion and exchange of information amongst communities of farmers via training (Fish et al., 2009). There is some evidence to suggest that

farmers' awareness of environmental impacts of their practices can motivate them to change their behaviour to be more sustainable (e.g. Ma et al., 2014; Han and Zhao, 2009) and that environmental behaviour is strongly affected by knowledge (Aregay et al., 2018). However, results from the Houzhai catchment survey suggest that awareness of risks does not necessarily always convert to better management approaches of livestock wastes (e.g. undercover versus in-field storage) across all villages. This is likely due to changes in behaviour being dependent on other factors too, such as the availability of time and labour and associated financial costs, and importantly this is an observation common to other areas of the world, not just China (Blackstock et al., 2010).

Repeated catchment-wide surveys over time would reveal how environmental awareness changed with implemented environmental management policies (Du et al., 2018). Water quality measurements over time, downstream of villages, would offer a complementary perspective on how spatial patterns of pollutants are changing due to environmental management initiatives. There is evidence that water quality, e.g. nitrate and *E. coli* concentrations, does vary spatially across the catchment (e.g. Yue et al., 2015, 2019 and Buckerfield et al., 2019b, respectively) but this varies not only due to management decisions but also as a function of catchment hydrology and land use. Most farmers indicated that they would like to learn new techniques through a farm visit, which could be valuable as in-field training is more effective in changing farmers' behaviour around nutrient overuse than traditional one-off training sessions (Pan et al., 2017). Younger Chinese farmers have been advocated as farming role models in catchments (Orderud et al., 2017). As such they could act as local messengers to their larger networks and, as observed in the Houzhai catchment, their likelihood to learn from a greater number of sources could add significant value to such an approach for village-to-village knowledge exchange and the sharing of farming best practice. Of course, training should not only target young farmers; training of a village population, whatever their age, is especially important for those who choose to remain in their village because it can lead to a critical source of knowledge being retained and shared locally. Leaders from other villages could also be encouraged to learn about what Jinhe is doing differently, in a way recognising Jihne as a 'model village' in the catchment. More generally, China with its network of villages acting as collective units (Xiong and Payne, 2017) may provide an ideal scenario to promote this type of social learning within and between villages much more effectively than other parts of the world. However, the majority of village and town leaders maintain that earning an income is the greatest pressure on farmers, rather than soil- or water-related issues (c.f. Smith and Siciliano, 2015). Clearly, rural leaders face a difficult task of attempting to balance productivity, human subsistence and environmental protection at the local level.

5. Conclusion

The Houzhai catchment represents a typical landscape in the southwest China karst region and a comprehensive survey across seven of its farming villages offers important insight for future targeting of advice and knowledge sharing in order to help improve the livelihoods of farmers and alleviate their land use impacts on environmental quality. Our data show that increasing environmental awareness for all, from farmers to town leaders, is a key first step towards improved land and water management. More effective training on productive farming methods is needed given that over 70% of farmers perceived such support to be lacking, and family is still the dominant source for acquiring farming knowledge. The heterogeneity observed in methods of learning, levels of environmental awareness and approaches to farming practice across the seven villages reveal that positive steps have been taken in some areas of the catchment to improve land and water management. Thus there may be opportunities to extend environmentally-sensitive practices by encouraging/incentivising pro-

environmental villages to facilitate peer-to-peer knowledge exchange with farmers in catchment areas where farm management could be improved. A key challenge will be identifying the most suitable ways of empowering smallholder farmers and helping them convert this newly-acquired knowledge to on-the-ground behaviour change to ensure best practice and sustainable land management options are widely adopted throughout farmed karst catchments in China and beyond. Without broader awareness, neighbouring farms may jeopardise environmental quality (e.g. water) at the expense of others and this represents a land management challenge of relevance to all farmed landscapes and not just those of the SCK. The results from this survey of 312 farmers highlights key gaps in farmers understanding of their environmental impacts and in the availability of training to support them to develop and apply new approaches to farming. Data from this study can thus usefully inform larger scale (e.g. province level) training programmes that aim to work with farmers to help implement national-scale agricultural and environmental policy changes, such as the shift from chemical to organic fertiliser use. The data presented here suggest that understanding and incorporating local challenges and perspectives into the design of future training programmes will be most effective.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.agee.2019.106715>.

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