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A Case Study in Xizhuang, Yunnan, China

As development and population increase, efficient use and management of water in mountain watersheds is of growing concern in Asia. The work presented in this article applied hydro-meteorological monitoring and participatory action research on water availability to improve water management in Xizhuang watershed in Yunnan Province, China. With an area of 34.56 km^2 and a population of 4501, Xizhuang watershed is typical of the watersheds in the middle mountains that feed the Salween River. Although this catchment provides plentiful water (rainfall and runoff), the temporal and spatial distribution of this supply is uneven. Together with uneven distribution, major issues include water shortages for irrigation, domestic use, and livestock; poor water quality; and conflicts among different stakeholders. To improve sustainable use and conservation, this paper suggests developing integrated water resource management and water harvest technology.

Keywords: *Water issues; integrated water resource management; middle mountains; Xizhuang watershed; Salween River; Yunnan; China.*

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Introduction

More than half of humanity relies on freshwater from mountain regions (Liniger et al 1998) and the term 'water tower' has been widely adopted to express the importance of mountains in providing freshwater for downstream areas (Liniger et al 1998). Given the importance of these systems, the People and Resource Dynamics in Mountain Watersheds of the Hindu Kush–Himalayas Project (PARDYP) was implemented in 1997 to examine natural resources and water management within five watersheds in China, India, Nepal, and Pakistan. One of the objectives of PARDYP is to assess rural water resources in the middle mountains (ie 1000 to 3800 m). The middle mountains are one of the most fragile and vulnerable areas in the Himalayan region. This zone is characterized by high rainfall and high rates of specific runoff during monsoon and little rainfall during the long dry season, as well as by high population densities and intensive human activities (Alford 1992).

Xizhuang watershed (XZW), Yunnan, is the PARDYP study site in China. This site lies within the Southeast Asian karst zone, which forms an important part of the montane watersheds feeding the Salween River across Montane Mainland Southeast Asia (MMSEA). The government has initiated large-scale watershed protection programs since the 1980s to secure water for irrigation, drinking and industrial uses downstream (Xu et al 2005). However, the issue of water scarcity remains. This study explores mountain hydrology to answer the following research questions: What is the seasonal variability of runoff in the XZW? Who (upstream or downstream population) is affected most by great seasonal runoff variability? What management options are available to overcome periods of shortfall in water resources?

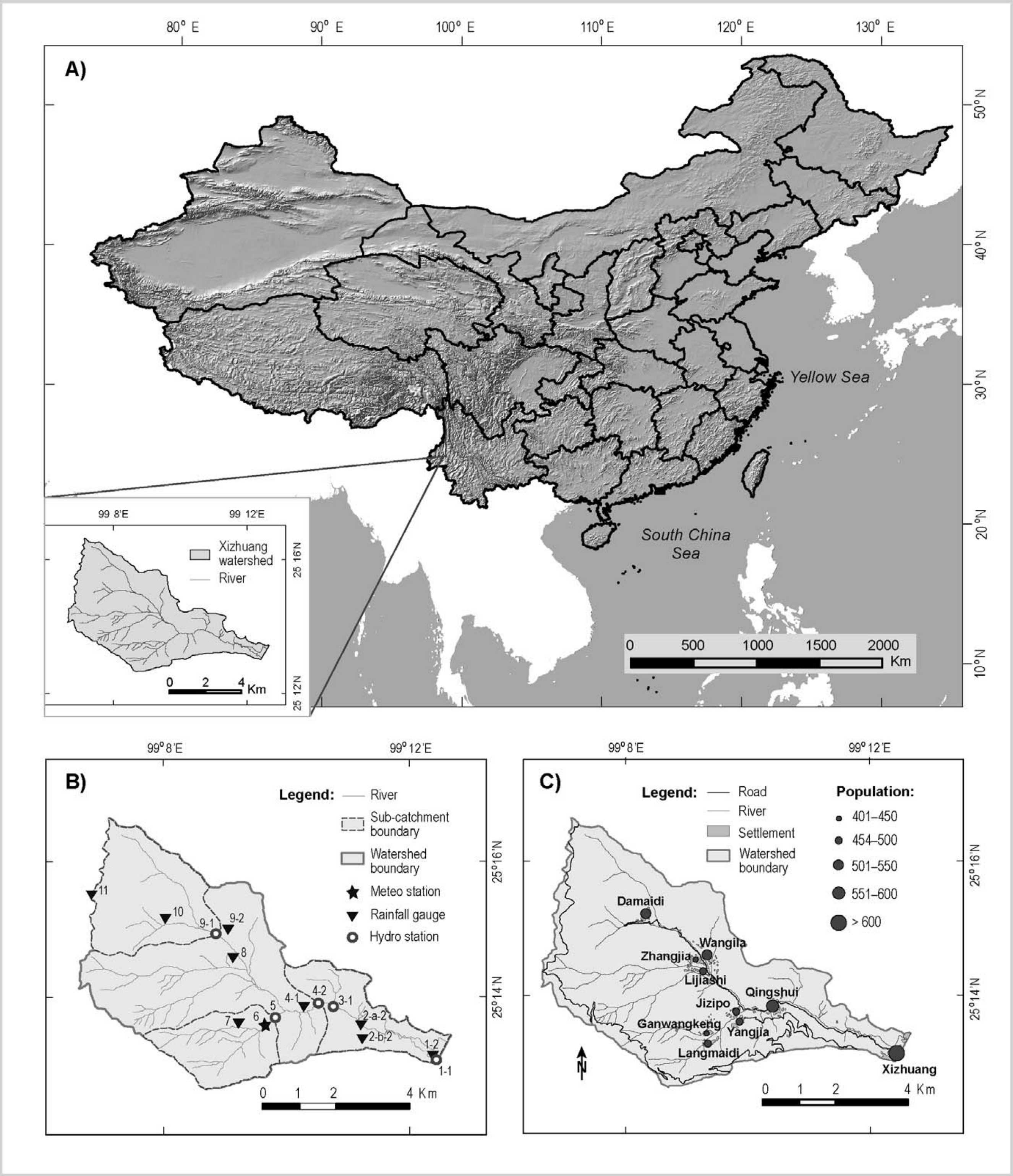
Study area

Xizhuang watershed (XZW) lies in the middle mountains in the Baoshan region of southwest China (25°12′32″ to 25°16′34″ N and 99°06′36″ to 99°12′36″E; see Figure 1A). It covers 34.56 km^2, with elevations ranging from 1695 to 3060 m. The main river runs 14 km from northwest to southeast. The major types of land cover are forest, shrub, and farmland, with the remainder consisting of grassland, tea gardens, and settlements. A monitoring hydro-meteorological network in place from 1997 to 2003 consisted of 5 hydrometric stations, one main meteorological station, and 9 rainfall gauges (Figure 1B). There are three sub-catchments—Sangoushui (SGS), Shenjiahe (SJH), and Qingshui (QS)—monitored by Site 9-1, Site 5, and Site 4-1, respectively.

The geologically complex and carbonate rocks of the XZW account for 40% of the watershed (Yang et al 2000). The high amount of carbonate is important, as Adhikari et al (2003) showed that 75% of high spring yields occur in carbonate rocks such as limestone, dolomite, and marble beds. Consequently, the XZW is rich in underground water.

There are three administrative villages in the watershed supporting 4501 people, mainly Han Chinese (Figure 1C): Lijiashi village, located in the upperstream region, is composed of four communities, Damaidi, Wangjia, Zhangjia, Lijiashi; Qingshui village in the mid-stream region comprises five communities, Langmaidi, Ganwangkeng, Jizipo, Yangjia, and Qingshui; and Xizhuang village, located downstream, contains a third of the total population in the watershed. Most rural households are dependent upon farming; however, land holdings in the watershed are small and fragmented (holdings average less than 0.04 ha). Farming often cannot meet family consumption needs, so most households depend on tea plantations and off-farm work for extra cash income. Of the three villages, Xizhuang has the most accessible and extensive transportation and irrigation network.

FIGURES 1A TO 1C A) Location of Xizhuang watershed in China; B) Monitoring network in the Xizhuang watershed; C) Villages and population in Xizhuang watershed. (Maps by Ulla Gaemperli, based on GIS data from authors)



Methodology

Meteorological and hydrological data

At the hydrometric stations, water level was recorded and discharge was measured with the current metering and dilution method. The main meteorological station (Site 6; Figure 1B) recorded rainfall, temperature, evaporation, sunshine, relative humidity, and wind speed. Water samples were collected from 7 locations and water qualities were analyzed for pH, chloride, ammonia, nitrate, reactive phosphorus, calcium, magnesium, carbonate, total alkalinity, and total coliforms.

Conditions and consultation in the watershed

Participatory action research on public water sources, water demand, and supply was conducted in 2002, based on household interviews with 44 respondents in the XZW. User water demands (ownership, type, location, household/people, and water availability) were noted and the physical parameters of water (yield, temperature, conductivity, odor, color and taste) were tested. To better understand socioeconomic status, a participatory assessment was undertaken in 1998 by project staff, in concert with local villagers. This assessment utilized a range of techniques, including key informant interviews with government officials, farmers, and village leaders; village meetings; field observations; matrix score methods; participatory mapping on water availability and access to water resources for domestic and agriculture use; and policy review and analysis. Stakeholder meetings were organized in natural villages, administrative villages, and townships to introduce the principles of integrated water resource management and participatory action research at watershed level.

Data analysis

The annual runoff was calculated using HYMOS software, developed by Delft Hydraulics, based on the hydrological data collected. The annual point rainfall (of the nine stations) was also calculated using HYMOS software; these data were then used in ArcView GIS 3.3 (Anderson 2003) to draw the annual isohyets and calculate the areal rainfall of the watershed.

The reference evapotranspiration (PET) was estimated using the FAO Penman-Monteith equation (Allen et al 1998):

$$\mathrm{PET} = \frac{0.408\Delta(R_n - G) + \gamma 900 / (T + 273) u_2 (e_s - e_a}{\Delta + \gamma(1 + 0.34 u_2)} \qquad \text{(Equation 1)}$$

where: PET = the reference evapotranspiration (mm/day); R_n = the net radiation at the crop surface (MJ/m^2/day); G = the soil heat flux density (MJ/m^2/day); T = the mean daily air temperature at 2 m height (°C); u_2 = the wind speed at 2 m height (m/s); e_s = the saturation vapor pressure (KPa); e_a = the actual vapor pressure (KPa); Δ = the slope of vapor pressure crop (KPa/°C); γ = the psychometric constant (KPa/°C).

The actual evapotranspiration (AET) was computed by multiplying the vegetation coefficient (K_c) with PET.

Hydrological water balance was applied to determine underground inflow in the watershed. Under karst area, the components of water balance are areal precipitation (P), areal runoff (R), areal evapotranspiration (E), natural underground inflow and outflow (I), and change in water storage (ΔS). Assuming that the change in storage is negligible over the study period, the water balance can be described as:

$$\mathrm{I} = \mathrm{P} - \mathrm{R} - \mathrm{E} \qquad \text{(Equation 2)}$$

where: P = rainfall (mm); R = runoff (mm); E = evapotranspiration (mm); I = net underground flow (mm).

Water requirements for the main crops were calculated using CROPWAT 4 (Clark 1998). Water demand for domestic use and livestock was calculated using recommended consumption values (Li 1980).

Results

Rainfall is the only input water source. The annual rainfall, evapotranspiration and runoff are listed in Table 1. The total annual rainfall ranges from 1500 to 1660 mm and the total annual runoff between 600 and 920 mm. About 39 to 61% of the rainfall produces runoff available in the watershed. According to water balance calculations (Equation 2), the net groundwater flow in the XZW is negligible (2.3 mm). Underground outflow was captured by the biggest spring (Yang et al 2000) and was measured as a part of runoff in the river. This means there is no underground inflow in the XZW. The 40 springs identified provide the majority of potable water sources for the farmers in the watershed. The total annual spring yields are about 2.3×10^7 m^3, although the biggest individual spring, with a yield of 9.5×10^6 m^3, is located in the downstream area (Ma et al 2004).

Uneven distribution of water

Precipitation, evapotranspiration and runoff all vary considerably (Figure 2). There are distinct wet and dry season distributions; about 88% of the annual rainfall occurs during the wet season (from May to October), and the majority of runoff (79%) occurs from July to December. September is the wettest month. The monthly reference evapotranspiration is higher during the pre-monsoon season (March, April, and May); it peaks in April when rainfall and river levels are low.

Total annual rainfall is greater in the up- and mid-stream (SGS, QS) than in the low-stream. However, the total annual runoff is greater in the lower areas (Table 1).

TABLE 1 Mean annual rainfall, evapotranspiration, and runoff (in mm) in Xizhuang. Figures are given for two sub-catchments, Sangoushui and Qingshui, and for the whole Xizhuang watershed.

Area Variable	Sangoushui sub-catchment	Qingshui sub-catchment	Xizhuang watershed
Areal rainfall	1652.5	1547.0	1503.1
Areal AET	624.4	601.1	585.5
Annual runoff	689.5	605.1	914.8

Water shortages

The total annual water demand for crops is 4.0×10^6 m^3 (equivalent to 115.6 mm). This amount is well below the potential water supply, but only 10% of the farmland can be irrigated: most croplands are on higher terraces and lacking irrigation systems. The villagers identified agricultural water shortages as a major concern; crop irrigation was very labor-intensive, often requiring manual water transportation from the river.

Water demand for domestic needs and livestock use is also very low, totaling about 5.4 mm. Domestic consumption includes water for drinking, cooking and washing for the population of 4500, while there are 10,000 head of livestock. Springs are an important source of potable water. Since 1990, most households have had a bibcock in the yard piping water from nearby springs. For Lijiashi villages in upper-stream areas, there is no problem with the domestic and livestock needs because springs are abundant. But water is limited in mid-stream areas: springs are inconveniently located and the villagers lack the technology (and capital) to pipe the water from the distant springs. For example, there is only one small ephemeral spring near the Yangjia community; during winter, the villagers in Yangjia have to fetch water from the river.

Quality of domestic water

The main drinking water quality issues in the XZW are isolated cases of unsafe levels of coliforms and active phosphorus (WHO 1997). Coliforms are due to human and animal waste and phosphorus pollution is caused by overuse of fertilizers, pesticides, and washing detergents. Due to connections between runoff and underground water in the watershed, the application of pesticides in farmlands or tea gardens in upstream areas has immediate impacts on water quality in springs downstream, particularly during monsoon. Downstream villagers were reported to be frequently ill due to increasing use of chemicals in the watershed. It must be noted, however, that our water quality results are likely to be conservative because water samples were collected 3 times each year and we did not sample when most pesticides are sprayed over the tea gardens; this could degrade water quality.

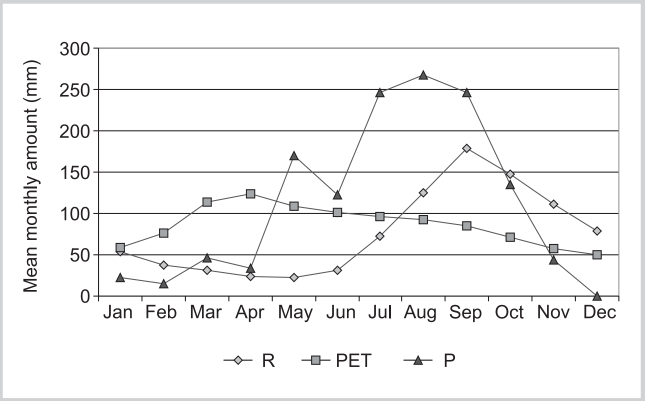
Stakeholder conflicts

Conflict over water use is a major issue in the XZW. At the village level, conflicts occurred between Xizhuang and Lijiashi/Qingshui villages, even within each village. Blocking water flow has become a common practice due to water scarcity and privatization of land use. In essence, the poorer farmers in the upper and mid-stream areas feel that they are being given short shrift by the richer villagers in the downstream areas. In other conflicts the mid-stream villagers of Yangjia competed with villagers from Langmaidi to pipe water from the springs; finally the water pipe was blocked. In the lower areas, Xizhuang community is in ongoing competition with the water company for a supply of drinking water to Banqiao Town and the cement factory for industrial use downstream. Household conflicts mainly occur between powerful villagers and marginal villagers. For example, some Damaidi villagers irrigate farmland using drinking water during the dry season; this caused a drinking water shortage for some of the community.

Discussion

The water supply issues in the XZW reflect the general conditions in the mountain areas of the Salween watershed in Yunnan. Annual runoff is plentiful (overall runoff is 3.2×10^7 m^3 and total estimated use is 4.2×10^6 m^3), but, as is typical in these monsoonal regions, rainfall distribution is highly uneven (88% falls in 6 months). This seasonality of water availability is similar to other PARDYP watersheds in the Himalayan region,

FIGURE 2 Mean monthly rainfall (P), reference evapotranspiration (PET), and runoff (R) in Xizhuang watershed.



such as Jhikhu Khola and Yarsha Khola watersheds in Nepal, where precipitation is highly seasonal, with 75 to 80% of rainfall occurring during monsoon season and the evapotranspiration rates peaking during the pre-monsoon, making March to April the driest time of the year as runoff is also at a minimum (Merz et al 2005).

The XZW is geomorphologically typical of 70% of the Baoshan region (Sha 1993). Indeed, these types of middle mountain watersheds account for 80% of the Salween basin, so the main problems found in the XZW are likely to be indicative of those in similar water catchments in MMSEA and the Himalayan region. These issues boil down to problems due to the seasonality of water availability (climatic) and the behavior of water users (management of supply). There is little that can be done about the seasonality of rainfall; however, water management options have been explored and discussed in public through modified user behavior, infrastructure development, and good governance. The local township government has neither mandates nor discretionary power for integrated watershed management, although integrated water resource management (IWRM) professes that water must be viewed from a holistic perspective, both in its natural state and in balancing competing demands, including domestic, agriculture, hydropower, industrial, cultural, and environmental requirements (Jønch-Clausen 2004). More equitable, efficient, and sustainable regimes of water management can be achieved through participation by water service providers and negotiation among different water users.

Infrastructure development for improving water supply and quality

The productivity of rainfed agricultural land depends on rainfall patterns, particularly the early arrival of the monsoon. Any delay in rainfall can result in a delay of the main crops, which may not mature due to low temperatures in the autumn. Surplus rainfall can be stored for irrigation. This has been achieved in the Damaidi community, where a series of cisterns funded by PARDYP were constructed in 2000; 38 small cisterns (2–6 m^3 capacity) and one big cistern (93 m^3) can store a total of 300 m^3 water a year (Li 2005). This storage system can meet about 90% of the community's agricultural water needs. The cement and stone cisterns were constructed with the farmers at a cost of US$ 12.20 per m^3. Similar water harvesting schemes to meet irrigation needs were expanded in the entire watershed. Both project and government agencies have supported local villages with cement to protect drinking water sources from springs and with galvanized metal for water pipes, which reduces water leakage and offers protection against pollution.

Changing behaviors and land use practices for improving watershed management

It is important to increase farmers' consciousness of environmental protection. With help from PARDYP, a small local library was established in the watershed; it contains books on water sanitation, agriculture, forestry, planting, and illustrated guides to community-based education and environmental protection. These books are intended to introduce farmers to sustainable land use practices and water management techniques, as well as to highlight the negative effects of pesticides and fertilizers. In order to reduce the use of pesticides and fertilizers and increase the output of tea, some new varieties of tea were introduced. Farmers were trained on-site for chemical use by PARDYP and cross-farmer visits were organized to enable villagers to see good practices in other places.

Facilitating dialogues for good watershed governance

Growing demand and polluted water have triggered a water crisis in China. Chinese environmentalists campaign for a greater voice for local people in water projects, such as dam construction (Dore and Yu 2004). Conflicts over water increase while there is no participation by local people in decision-making. To solve the conflicts among different stakeholders, first, it is essential to set up a watershed management committee by involving the stakeholders concerned, including local communities, to monitor watershed management, and to ensure equitable access to water resources, which has been successfully demonstrated in Lashai watershed of Yunnan Province (Igbokwe et al 2003). Capacity building for integrated watershed management and participatory decision-making should be based on carefully defined roles and responsibilities for the various stakeholders. Furthermore, establishing a reward system between water service beneficiaries and service providers can improve relations among people living in the uplands and the lowlands. Apart from tree plantation, financial incentives should also be considered; the current policy-driven "Sloped Land Conversion Program" and "Grain for Green" are examples. This idea was welcomed by local farmers in the XZW (Xu et al 2005).

Conclusions

Although water demand for agriculture, domestic, and livestock needs in the XZW is relatively low, water shortages still exist. Limited access to water is the main constraining factor in improving the standard of living in this mountainous watershed, so integrated watershed management and water harvest technology are imperative to achieve high water productivity and higher rural income. But any such improvement is dependent upon good baseline data and an ongoing monitoring network linked to community surveys to delineate site-specific water demands and limitations in supply.

Integrated water resource management (IWRM) would be desirable, but as this study highlights, there are several obstacles to achieving this. Decentralization of decision-making power to locally elected committees is essential to address local concerns. Moreover, there has to be collaboration and equity in the establishment of any compensatory system—downstream users are unlikely to cooperate unless the benefits that they derive from responsible upstream management can be clearly demonstrated. Integrated water resource management depends on people's participation (both water service providers and beneficiaries), guided by responsive institutions, government policy, and education, together with technical support and facilitation from researchers and development practitioners.

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