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Domestic Water Consumption under Intermittent and Continuous Modes of Water Supply

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Abstract Although an extensive literature emphasizes the disadvantages of intermittent water supply, it remains prevalent in rural areas of developing countries. Understanding the effects of water supply time restrictions on domestic water use activities and patterns, especially for hygienic purposes, is important for the elaboration of the water supply. We studied the influence of intermittent and continuous water supply on water consumption and related activities in villages in the central region of the Wei River basin, China. Data were collected from a survey of 225 households in the sampled villages. Compared with a continuous water supply of 24 h d^{-1} (hours per day), adopting an intermittent water supply can reduce domestic water consumption. However, it presents risks in terms of hygiene behavior, particularly the frequency of face, hands, and feet washing, as well as water sharing among family members. Outdoor water consumption is more affected than indoor water consumption under slight supply restriction (≥6 and<24 h d^{-1}), whereas indoor water use is most affected under moderate supply restriction (>1.5 and<6 h d^{-1}). Villages with high supply restriction (≤1.5 h d^{-1}) meet only the minimum basic requirements for domestic use, 33.6–34.7 L c^{-1} d^{-1} (liters per capita per day). We conclude that the determination of the daily water delivery duration for intermittent water supply in rural communities of developing countries should give greater consideration to differences in water use activities and patterns under the water supply time restrictions.

Keywords Intermittent water supply · Domestic water consumption · Household behavior · Wei River basin

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1 Introduction

In both developed and developing countries, water scarcity has been well documented. The problem of water scarcity is increasing and poses a serious risk to sustainable development and quality of life. Adequate water availability is closely linked to most targets of the Millennium Development Goals, such as poverty reduction and the improvement of human and environmental health (UNDP 2012). However, according to recent estimates, two-thirds of the world's population will be faced with water shortages by 2050 (OCHA 2010), including approximately 800 million people living in countries or regions experiencing "physical (absolute) water scarcity (<500 m^3 per capita per year for all agricultural, industrial, and domestic purposes)" as defined by FAO (FAO 2012). For domestic purposes, one-sixth of the world's human population do not have sufficient water supply, and two-fifths do not have access to adequate sanitation for domestic use. Eighty percent of those lacking adequate water live in rural regions (WHO and UNICEF 2000). In response to these problems, genuine concern has been raised regarding water scarcity and ensuring a secure water supply around the world (Cook et al. 2013; Lee et al. 2013). The International Conference on Freshwater held in Bonn, Germany, in 2001 and the Third World Water Forum held in Kyoto, Japan, in 2003 are just two examples attesting to the global concern about this issue (Osei-Asare 2004).

China is a water-scarce country with per capita availability of only one-fourth the world average. In parts of northern China such as the Yellow River basin, the per capita availability is less than one-eleventh of the world average (Jiang 2009). The Wei River basin is the largest tributary of the Yellow River, and it is already experiencing "physical water scarcity," with the water presently available per capita at 401 m^3. This is predicted to decline to 305 m^3 by 2030 because of economic and population growth (annual growth rates of 10 % and 0.65 %, respectively) (Gu 2009). Meanwhile, heavily polluted surface water makes the shortage worse, resulting in poor water quality mid and downstream (V and V+by China's water quality standards) (Ge 2004). As described by Jiang (2009), grades IV, V, and V+are "poor" and cannot support drinking or domestic use. The poorest amongst these grades is not even suitable for irrigation. Water for domestic use in rural areas mainly comes from underground sources and upstream reservoirs where pollution is somewhat less severe and water quality is better than grade III. In 2009, the average annual water deficit was 1.43×10^9 m^3, and the accumulated over-exploited groundwater was 6.96×10^9 m^3 (Gu 2009). Water safety and shortages have become important factors affecting the potential for socio-economic and residential living standards improvements in the area.

In the rural Wei River basin area, domestic water supply has radically improved in the last decade with the implementation of the Mother Cisterns Project (2001–2011) and the Chinese Safe Drinking Water Project (2005–2015), which has enabled 160 million rural residents to have increased access to safe drinking water (MWRC The Ministry of Water Resources of China 2011). As a result, tap water from independent water supply systems run by villagers is now the major domestic water supply, reaching 87 % of the local population. As in other developing countries in south Asia, India, and Latin America, the local water distribution systems have been designed to ensure a continuous water supply. However, in practice, many of these areas have restricted access, receiving water only in the mornings and evenings (intermittent water supply) because of a shortage of water and inefficient management in utility operations (Vairavamoorthy et al. 2007; Andey and Kelkar 2009). Many studies have shown that restricting water supply distribution by physically cutting off the water supply for most of the day and limiting the ability of consumers to collect water is one of the most common approaches to controlling water demand (Vairavamoorthy et al. 2007). However, this approach also has deficiencies, especially the potential for water sanitation risks brought on in part by the

inconvenience of collecting water for daily needs. The development of management strategies for such situations is a major issue for governments.

At present, no empirical studies exist on the effects of restricted hours of water supply on household water use activities and patterns in China. Existing empirical works on domestic water use behavior have reported on complex processes and factors (water availability, price, household characteristics, education, attitude, etc.) that affect water use behavior and consumption (Molinos-Senante et al. 2013; Richter and Stamminger 2012; Jorgensen et al. 2009), but not on the effect of duration of intermittent water supply. The present study focuses on the Wei River area, and explores how limitations in water supply time affect domestic water consumption, the process by which limited water supply time influences domestic water use activities, especially for hygienic use, and the basic water needs for household use. Based on the findings, strategies are suggested for better domestic water management in the rural districts of the Wei River basin. This study can also serve as a reference for identifying the appropriate duration of intermittent water supply in rural areas of developing countries.

2 Materials and Method

2.1 Study Areas and Water Supply Description

The study was conducted in villages within the Yangling district(34° 17′ N–34° 20′ N, 107° 57′ E–108° 04′ E, 500–600 m altitude, 35 km^2 area). This district is located in the center of the Shaannxi plain and in the middle of the Wei River basin, 74 km west of Xi'an city in northwest China (Fig. 1). The climate is temperate semi-humid, with a mean annual temperature of 12.9 °C, average frost-free period of 213 day, average annual precipitation of 635 mm, and annual evaporation of 1200 mm. The area is flat, with 84 % of the land serving as cropland, in which wheat and corn are the main crops.

Up to 93.3 % of the 45 villages in the study site obtain their water supply via pipelines from the 19 water supply systems scattered across the region. Each system has its own water tank, well, pumping station, and water supply network, and is shared by one to three villages. Village committees are responsible for water supply strategies and daily management. Most villages use intermittent water supply as a management practice in order to avoid water wastage and leakage along the pipelines. Although the study region is less than 35 km^2 in size, there are great differences in the daily water supply times among the villages (Fig. 2).

2.2 Survey Design and Data Collection

Data were collected during October and November 2010. First, a survey was used to collect general data for all 45 villages. One leader from each village was interviewed to collect information on village size, average family income, household size, water supply patterns, prices, water supply time(s) per day.

For deeper analysis, we selected one village for each water supply time (24, 6, 3, 1.5, and 1 h d^{-1}) based on the results of the survey (Fig. 1, Table 1). The five selected villages (Jiangjiazhai, Yanghou, Xixiaozhai, Jiadao, and Liujiatai) were similar in terms of socio-economic status, family size, and water price (Tables 1 and 3). Up to 45 families from each of these villages were randomly selected for detailed interviews using the questionnaire. From each household, one family member older than 18 was interviewed.

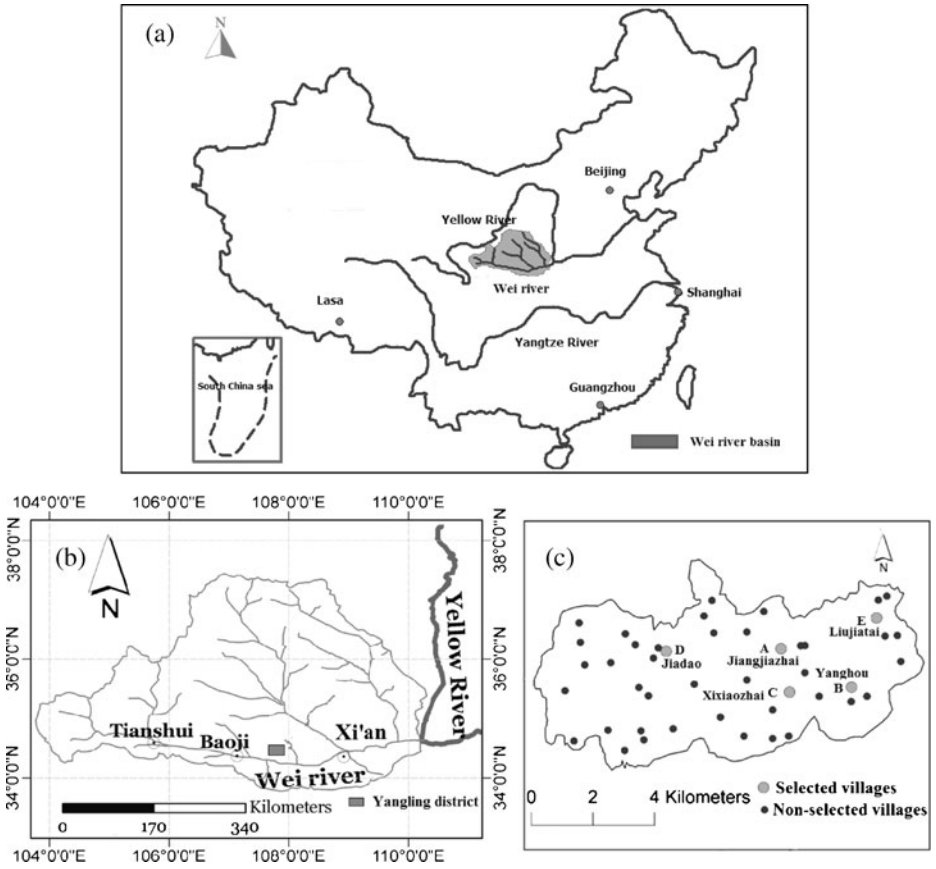

Fig. 1 Location of the study region. Note: **a**, **b** and **c** represent the location of the Wei River basin, the Yangling district and sample villages (selected+non-selected)

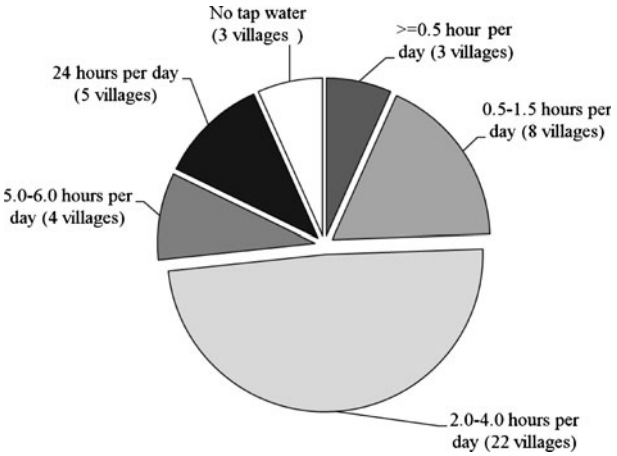

Fig. 2 Duration of water supply per day

Table 1 Details of the selected villages (n=5, water supply: pipeline)

Villages name	Total families	Water supply time (h d^{-1})	Water price (US \$ m^{-3})
Jiangjiazhai (A)	389	24	0.23
Yanghou (B)	129	6.0	0.20
Xixiaozhai (C)	98	3.0	0.29
Jiadao (D)	152	1.5	0.20
Liujiatai (E)	123	1.0	0.29

Exchange rate of currency: 1 Chinese yuan=0.1585 US dollars

The following information was collected in the questionnaire:

(1) Domestic water consumption - Indoor: drinking and personal hygiene, kitchen, showering and laundry; Outdoor: vegetable and garden watering, livestock and house and yard cleaning,
(2) Household water use activities - Indoor: doing laundry, showering, washing of face, hands and feet, and using of shared water while washing face, hands, and feet; utilization of water use appliances and bathroom (Table 2). Outdoor: vegetable and garden watering, and house and yard cleaning;
(3) Socio-economic characteristics - household size, family income, vegetable and garden area, yard area, livestock, possession of washing machine, bathroom and solar water heater.

Meanwhile, each family was persuaded to keep a water use diary for 4 days (3 weekdays and 1 day in the weekend) (Krantz 2005), in which they were to record when, where, how, and who used water in those specific days in the family. The measurement results were used to verify the interview results and obtain detailed information from the respondents.

Table 2 Interview questions for main indicators of water use activities

Indicators of water use activities	Interview questions
Indoor water activities	
Doing laundry/household	How many times per week does your family do laundry?
Showering/person	How many times per week do your take a shower or bath?
Face, hand and feet washing/person	How many times per week do you wash your face, hands and feet?
Sharing water while washing hands, feet and face/person	How many times per day do you wash your face, hands and feet by sharing water with your family members?
Outdoor water activities	
Vegetable and garden watering/household	How many times per week does your family water your vegetable and garden land?
House and yard cleaning/household	How many times per week does your family clean the house or yard?
Utilization of appliances and apparatus	
Washing machine utilization/household	How many times per week does your family use the washing machine?
Bathroom utilization/person	How many times per week do you take a bath or shower in the bathroom?
Solar water heater utilization/person	How many times do you take bath or shower with hot water from solar water heater?

2.3 Data Analysis

We used the data from the 225 completed questionnaires in our analysis. We compared the data of families with different water supply times. Data were analyzed by one-way analysis of variance (ANOVA) with socioeconomic characteristics (household size, family income, vegetable garden area, yard area, livestock, washing machine, bathroom and solar water heater), water consumption (total, indoor, and outdoor water consumption); water use patterns and activities (drinking and personal hygiene, kitchen, showering, laundry, vegetable and garden watering, livestock, and house and yard cleaning); utilization of water use appliances (washing machine and solar water heater); bathroom usage. Tukey's HSD was used post hoc to make multiple comparisons. All statistical analyses were performed using SPSS software, version 15. Differences at $p\text{-}value<0.05$ were considered statistically significant.

3 Results

3.1 Socioeconomic Characteristics of the Selected Villages

More than 14,300 residents live in the 45 villages scattered throughout the region, with an average family size of 4.8 persons. The five villages selected with different water supply times of 24, 6, 3, 1.5, and 1 h d^{-1} are similar in terms of family size (3.8–4.1 persons), annual household income (US$ 3850–4270), yard area (45.4–50.1 m^2), livestock (1.0–1.4 animals) as well as percentages of household owning a washing machine (93 %–96 %), bathroom (62 %–76 %), and flush toilet (7 %–13 %) (Table 3). Solar water heaters are not popular in local households, the possession of them is significantly affected by restrictions in water supply time because of the extra fees, energy, and time required to collect water for them in non-24-h supply villages. The area used for vegetable planting and gardening is also strongly influenced by water supply time, and it is significantly lower in villages with a water supply of less than

Table 3 Average socio-economic characteristics of households in the selected villages (n=225 families, water supply: pipeline) (Mean±SD)

Socio-economic characteristics	Village and duration of water supply (h d^{-1})				
	A-24 h	B-6 h	C-3 h	D-1.5 h	E-1.0 h
Family size (persons/household)	3.9±0.44^a	3.8±0.45^a	4.0±0.36^a	4.1±0.45^a	4.0±0.38^a
Annual household income (US $)	4270±280.2^a	3850±245.8^a	3970±248.2^a	4260±212.1^a	4090±271.5^a
Vegetable and garden area (m^2/household)	37.3±12.62^a	24.5±7.24^b	19.8±9.18^b	18.7±8.32^b	21.4±6.80^b
Yard area (m^2/household)	46.1±8.42^a	48.1±8.30^a	45.4±9.53^a	48.8±6.38^a	50.1±10.61^a
Number of livestock (animals/household)	1.1±0.68^a	1.4±0.62^a	1.0±0.84^a	1.3±0.67^a	1.0±0.45^a
Washing machine/household	0.96±0.21^a	0.98±0.15^a	0.93±0.25^a	0.96±0.21^a	0.96±0.21^a
Bathroom/household	0.76±0.44^a	0.69±0.47^a	0.71±0.46^a	0.76±0.44^a	0.62±0.49^a
Solar water heater/household	0.24±0.41^a	0.13±0.32^{ab}	0.07±0.25^b	0.04±0.21^b	0.04±0.21^b
Flush toilet/household	0.13±0.34^a	0.11±0.32^a	0.11±0.32^a	0.07±0.25^a	0.07±0.25^a

Means with different superscripts within each row differ significantly ($P<0.05$) a>b>c; A, B, C, D and E represent the villages of Jiangjiazhai, Yanghou, Xixiaozhai, Jiadao and Liujiatai respectively; Exchange rate of currency: 1 Chinese yuan=0.1585 US dollars

6 h d^{-1} (24.5 m^2/household) than in villages with a 24 h d^{-1} water supply (37.3 m^2/household) (Table 3).

3.2 Water Supply Time and Consumption

Domestic water consumption can be classified into outdoor (e.g., livestock, garden vegetable, and yard cleaning) and indoor use (e.g., showering; washing of the face, hands, and feet) (Jorgensen et al. 2009). The total daily water consumption per capita varies greatly between the villages. It is significantly higher in Jiangjiazai village at 71.4 L c^{-1} d^{-1} on average with a 24-h supply than in Xixiaozhai (45.8 L c^{-1} d^{-1}, 3-h supply), Jiadao (34.7 L c^{-1} d^{-1}, 1.5-h supply), and Liujiatai (33.6 L c^{-1} d^{-1}, 1-h supply) (Table 4). When households are faced with water supply time restrictions, water consumption for outdoor purposes is first to be reduced. The outdoor water consumption is significantly lower in villages with a slight supply restriction (6 h d^{-1}) than in villages with a 24-h d^{-1} supply. Indoor water consumption is affected under moderate and high supply restrictions (1.5–6 h d^{-1}), and is significantly lower in villages where the water supply is less than 3 h d^{-1} compared with those with a supply of 6 h or more per day. Under high supply restriction (≤ 1.5 h d^{-1}), total per capita water consumption showed no significant association with duration of water supply per day (Table 4). This result is observed because the local people are used to careful water use, and the amount of water stored by the families is sufficient only for their basic needs.

3.3 Water Use Patterns and Activities Related to Water Supply

Water use patterns in villages with different supply times vary significantly. Up to 32.8 l (24 h supply) and 33.1 l (6 h supply) of water are used for indoor activities of laundry, showering, and other personal hygiene. When water supply time is 3 h or less, consumption for these three activities is significantly lower at 22.3 l (3 h supply), 15.2 l (1.5 h supply), and 15.4 l (1 h supply) (Fig. 3a). Water consumption in the kitchen does not show significant differences in households with different water supply hours. The basic water need for cooking, washing vegetables, and cleaning utensils was stable compared with other water use patterns. For doing laundry and showering, there are no differences recorded by water supply times per day, but water use for the personal hygiene activities of face, hands, and feet washing is significantly more frequent in villages with continuous water supply (24 h d^{-1}) than in those with intermittent water supply (6, 3, 1.5, and 1 h d^{-1}). The traditional behavior of sharing water with family members is also significantly more common in villages with limited water supply (3, 1.5, and 1 h d^{-1}) than in those where the water supply is less limited. The ratio of sharing water for

Table 4 Total, indoor and outdoor water consumption per capita per day under different of daily water supply regimes (n=225) (Mean±SD)

Water consumption (L c^{-1} d^{-1}) (means and SD)	Village and duration of water supply (h d^{-1})				
	A-24 h	B-6 h	C-3 h	D-1.5 h	E-1.0 h
Indoor water consumption	41.3±7.2^{a}	42.5±7.4^{ab}	32.1±9.1^{bc}	23.5±6.4^{c}	22.9±7.0^{c}
Outdoor water consumption	30.1±10.2^{a}	17.4±8.7^{b}	13.7±5.2^{b}	11.4±5.1^{b}	10.7±4.9^{b}
Total water consumption	71.4±16.8^{a}	59.9±15.3^{ab}	45.8±10.9^{bc}	34.7±6.6^{c}	33.6±8.3^{c}

Means with different superscripts within each row differ significantly (P<0.05) a>b>c; A, B, C, D and E represent the villages of Jiangjiazhai, Yanghou, Xixiaozhai, Jiadao and Liujiatai respectively

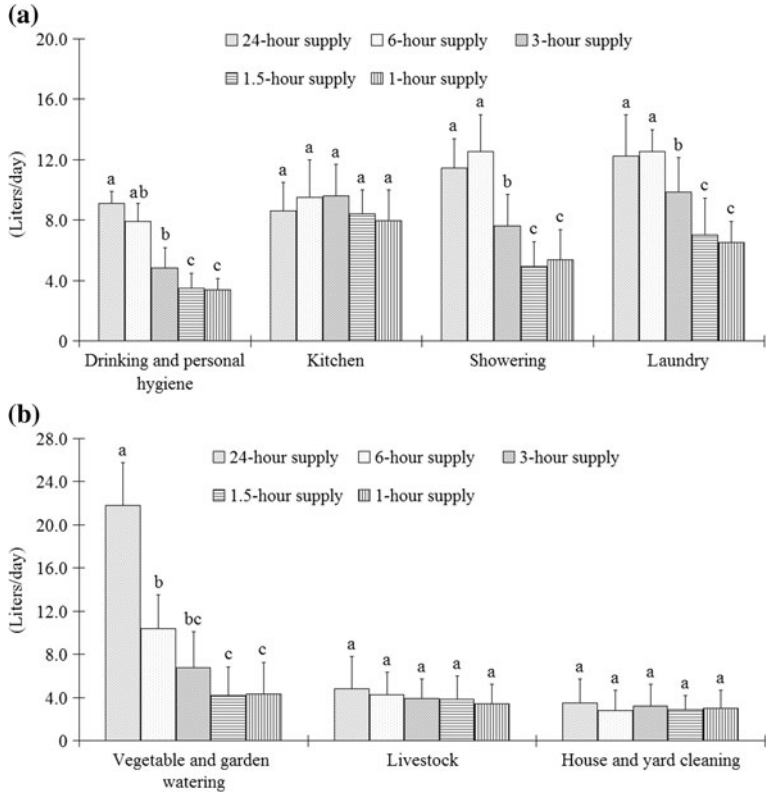

Fig. 3 Water use patterns (liters per capita per day) (means and SD) (L c^{-1} d^{-1})/under different water supply restriction (n=225). Note: **a** and **b** represent the indoor and outdoor water consumption of the sampled households, respectively. Mean scores that share a common letter in each column are not sign. differences (p<0.05) a>b>c

washing hands, feet, and face is significantly lower (0.18) in villages with a 24-h daily supply than in villages with 1.5- and 1-h daily supplies (0.56 and 0.59, respectively; Table 5).

Outdoor water consumption for domestic use mainly consists of vegetable and garden watering, livestock, and house and yard cleaning. Water supply time restrictions strongly affect vegetable and garden watering, with the water consumption for this activity dropping to 10.4 l (6 h d^{-1}), 6.8 l (3 h d^{-1}), 4.3 l (1.5 h d^{-1}), and 4.4 l (1 h d^{-1}) from the significantly higher 21.8 l d^{-1} used with a 24-h supply pattern (Fig. 3b). Furthermore, vegetable and garden watering as well as yard cleaning frequency is significantly lower in villages with less than 6 h supply than in those with 24 h supply (Table 6).

3.4 Water Appliances and Devices

Compared with solar water heaters of high utilization, the utilization of bathrooms and washing machines is lower and is highly affected with supply time restrictions. In the villages of Jiadao and Liujiatai, less than 21 % of respondents report using bathrooms for showering because of the limited water supply. In Jiangjiazhai, a 24-h supply village, 47 % of body cleaning takes place in the bathroom (Table 7). The remaining 53 % of body cleaning does not take place in bathroom for a variety of reasons, including nonworking equipment, lack of hot

Table 5 Indoor water use activities per family (frequency per week) (n=225) (Mean±SD)

Indoor water activities	Village and duration of water supply (h d^{-1})				
	A-24 h	B-6 h	C-3 h	D-1.5 h	E-1.0 h
Doing laundry/household	3.9±0.66^{a}	3.7±0.44^{a}	3.4±0.53^{a}	3.6±0.39^{a}	3.0±0.40^{a}
Showering/person	2.8±0.35^{a}	2.4±0.32^{a}	2.6±0.28^{a}	2.7±0.36^{a}	2.5±0.32^{a}
Face, hands and feet washing/person	36.3±5.61^{a}	29.8±5.05^{b}	27.0±4.66^{b}	19.8±5.24^{c}	22.1±5.36^{c}
Using of shared water while washing face, hands and feet/person (ratio: frequency of using of shared water while washing face, hands and feet/total frequency of face, hands and feet washing)	0.18±0.06^{c}	0.30±0.08^{b}	0.33±0.05^{b}	0.56±0.08^{a}	0.59±0.08^{a}

Means with different superscripts within each row differ significantly (P<0.05) a>b>c; A, B, C, D and E represent the villages of Jiangjiazhai, Yanghou, Xixiaozhai, Jiadao and Liujiatai respectively

water or heating facilities, and persistent habits among the elderly (approximately 86 % of elders report that they scrub their bodies with a basin of water in the bedroom instead of showering).

Washing machines are very common among households in the Wei River basin, and nearly every family has one. However, utilization of washing machines for doing the household laundry is very low because of lack of knowledge, exorbitant electric costs, and old habits, as reported by 13 %, 54 %, and 33 % of respondents, respectively. In villages with 24-h supply patterns, only 21 % reported using washing machines at all.

4 Discussion

Despite disadvantages such as inconvenient supply times, anxiety due to insufficient water supply and extra costs related to household water storage systems (McIntosh 2003), intermittent water supply patterns are prevalent in many developing countries because of low tariffs, investments, and effectiveness for controlling water demand (Vairavamoorthy et al. 2008; Faure and Pandit 2010). In rural regions of China, although the water supply has been highly improved in the last decade, the whole supply system remains weak, consisting of thousands of small-scale water utilities run by village user associations. Lack of funds and technical support (64 %), water shortages (42 %), easy management (26 %), and other reasons (20 %) account for 90 % of the villages adopting intermittent water supply. Consequently, intermittent water supply is likely to exist for a long time.

Table 6 Outdoor water use activities per family (frequency per week) (n=225) (Mean±SD)

Outdoor water activities	Village and duration of water supply (h d^{-1})				
	A-24 h	B-6 h	C-3 h	D-1.5 h	E-1.0 h
Vegetable and garden watering/household	2.3±0.66^{a}	1.3±0.43^{b}	1.0±0.44^{b}	1.2±0.47^{b}	1.3±0.41^{b}
House and yard cleaning/household	3.9±0.47^{a}	2.3±0.64^{b}	2.0±0.59^{b}	1.8±0.48^{b}	1.9±0.43^{b}

Means with different superscripts within each row differ significantly (P<0.05) a>b>c; A, B, C, D and E represent the villages of Jiangjiazhai, Yanghou, Xixiaozhai, Jiadao and Liujiatai respectively

Table 7 Utilization of water consuming appliances and apparatus per family (n=225) (Mean±SD)

Appliances and apparatus	Village and duration of water supply/day				
	A-24 h	B-6 h	C-3 h	D-1.5 h	E-1.0 h
Washing machine utilization (ratio: wash using machine/total washing)	0.21 ± 0.04^{a}	0.17 ± 0.04^{ab}	0.12 ± 0.04^{b}	0.13 ± 0.06^{b}	0.10 ± 0.06^{b}
Bathroom utilization (ratio: bath inside bathroom/total bath)	0.47 ± 0.07^{a}	0.32 ± 0.05^{ab}	0.35 ± 0.08^{ab}	0.18 ± 0.04^{c}	0.21 ± 0.04^{bc}
Solar water heater utilization of family with solar water heater (ratio: bath with solar water heater/total bath)	0.94 ± 0.06^{a}	0.90 ± 0.10^{a}	0.97 ± 0.05^{a}	0.85 ± 0.12^{a}	0.89 ± 0.07^{a}

Means with different superscripts within each row differ significantly (P<0.05) a>b>c; A, B, C, D and E represent the villages of Jiangjiazhai, Yanghou, Xixiaozhai, Jiadao and Liujiatai respectively

Our results reveal that intermittent water supply of 1–6 h results in lower water use (33.6–59.7 L c^{-1} d^{-1}) than continuous water supply of 24 h d^{-1}, where 71.4 L c^{-1} d^{-1} was consumed. This finding is inconsistent with studies in Kathmandu, India, reporting that consumers without access to 24-h supply tend to use more water than those with 24-h supply because they throw away "old" water to be replaced with a fresh supply every day (McIntosh 2003). This inconsistency is due to the large quantity of water consumed for vegetable and garden watering in the Wei River basin. Rather than throwing away "old" water, it is consumed for additional outdoor irrigation. Furthermore, households reduce outdoor water use activities (vegetable and garden planting, frequency of vegetable and garden watering, and frequency of house and yard cleaning) when water demand is not completely satisfied. Additional reductions in water consumption under intermittent water supply patterns are derived from indoor activities such as personal hygiene (reduced frequency of face, hands, and feet washing as well as high ratios of water sharing among family members) and limited use of water use appliances (low ratios of washing machine and solar water heater ownership) and of bathrooms.

The utilization of washing machines and bathrooms significantly affects indoor water consumption (Lyons et al. 2010). Present utilization rates are low, even in villages with a 24-h water supply because (1) washing machines and bathrooms are fairly new developments; thus, they are usually used by young people (over 85 % of the younger members of the population go to cities for work and only return during important festivals); (2) washing machines cause exorbitant electric bills (approximately US$ 0.05 d^{-1}); (3) traditional habits and lack of knowledge of elders induce unwillingness to change their behavior. Solar water heaters and flush toilets, introduced in the last 5 years, are not yet popular among the local people. However, once households have solar water heaters, their utilization rate is high. The convenience of solar water heaters and hot water is attractive to locals, and they increase the bathroom utilization rate as well as the duration of use. In the next several years, the use of solar water heaters and washing machines and the popularization of flush toilets are expected to be prime reasons for an increase in the household water consumption in the Wei River basin.

Determining an appropriate daily duration of water delivery for intermittent water supply for domestic use relies heavily on understanding the effect of water delivery time restrictions on water consumption and use activities—especially for hygiene purposes. Our study shows that compared with continuous water supply, intermittent water supply has the potential for greater hygiene risks not only from waterborne disease because of stored water (Mintz et al. 1995) but also through influencing water use behaviors for hygiene purposes. This effect was

observed even in villages with a water supply time of 6 h d^{-1}. Further, regarding the required quantity of water for domestic water consumption, our results indicate that the 6 h d^{-1} supply regime (approximately 60 L c^{-1} d^{-1}) is regarded as adequate for indoor water use (Howard and Bartram 2003), but inadequate for outdoor water use. This is consistent with our finding that indoor domestic water consumption is not significantly different when water supply times are 6 or more hours a day, whereas outdoor water consumption decreases when the supply is reduced to 6 h d^{-1}. In addition, we find no statistically significant differences in water consumption or water use activities among the villages with water supply times of 1 and 1.5 h, indicating that 33.6–34.7 L c^{-1} d^{-1} is the minimum required amount for domestic water use activities for households in the Wei River basin.

The World Health Organization (WHO) published guidelines stating that the minimum amount of water needed for metabolic, hygienic, and domestic purposes is 20 L c^{-1} d^{-1} (WHO 1997). Gleick and Iwra (1996) and Roberts et al. (2001) calculated the value as 50 L c^{-1} d^{-1} and 30 L c^{-1} d^{-1}, respectively. However, these standards have been questioned because water use habits, cultures, and economies vary between populations. For example, US residents consume about 410 L c^{-1} d^{-1} of municipal water, whereas UK residents consume 105 L c^{-1} d^{-1} (Rosen and Vincent 1999; Zehnder et al. 2003). Our study shows that the current basic water consumption in the Wei River basin is heavily dependent on the preference for having a vegetable garden, traditional habits (sharing water among family members), utilization of water use appliances, and types of water supply. In addition, this study shows that households may, now or in the future, employ a large number of water appliances, choose to use their domestic water supply to irrigate kitchen gardens or support livestock, and will require far more than the 50 L c^{-1} d^{-1} suggested by Gleick and Iwra (1996).

Therefore, in addition to the earlier discussed potential hygiene risks (waterborne disease and water use behaviors) from intermittent water supply, the present research indicates that (1) water providers adopting an intermittent supply of 6 h d^{-1} will most heavily affect outdoor water consumption, (2) a supply of 1.5–6 h d^{-1} will also heavily affect indoor water consumption, and (3) a supply of 1.5 h d^{-1} is the minimum water delivery time that should be provided considering the future of the changes of water use habits and improvements in living standards.

5 Conclusions

Adopting an intermittent water supply can reduce domestic water consumption; however, it may also result in increased hygiene risks from reduced frequency of face, hands, and feet washing and increased frequency of water sharing among family members. In the villages of the Wei River basin, water supply restrictions greatly affect outdoor water consumption when the supply drops to 6 h d^{-1}, and indoor water consumption begins to be affected in villages with water supplies between 1.5 and 6 h d^{-1}. The water supply in villages is adequate for the quantities of water consumed for indoor and some outdoor use when water is provided for 6 or more hours a day. However, the availability of 1.5 and 1 h water supplies meets only the current minimum need for domestic use, 33.6–34.7 L c^{-1} d^{-1}. This minimum need is expected to increase with the popularization of solar water heaters and flush toilets as well as the full utilization of washing machines. The results of this study provide useful information and a practical method for determining the appropriate daily water supply where intermittent water delivery is practiced in rural regions of developing countries.

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