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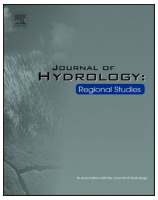

Physical and non-physical factors associated with water consumption at the household level in a region using multiple water sources

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ABSTRACT

Study region: Kathmandu Valley, Nepal.
Study focus: Water scarcity affects more than 40 % of the global population. Households in low- and middle-income countries typically use alternative water sources to piped water such as groundwater, tanker water and jar water and various coping strategies to deal with water scarcity. This study quantitatively examines the association between using multiple water sources and individual water consumption. In addition, we investigated the relationship between individual water consumption and physical (i.e. water source, supply time) and non-physical (wealth status, education for household head, house ownership, participation in local community, water treatment) factors before and after the 2015 Gorkha earthquake. A survey about socio-demographics, domestic water use behavior, and community involvement was conducted three times and the data collected from 992 households were used for analysis.
New hydrological insights for the region: It was confirmed that use of additional water sources is associated with greater individual water consumption. This was especially the case in households using both groundwater and tanker water. In addition, wealth status, education for household head, and house ownership were associated with increased individual water consumption but this association was not apparent after the earthquake. Participation in the local community was also associated with increased individual water consumption except for the period impacted by the earthquake. Households using treated water consumed less water across all periods surveyed.

1. Introduction

Water scarcity affects more than 40 % of the global population, and 30 % of people lack access to safely managed drinking water services (United Nations, Sustainable Development Goals, Goal 6, accessed 2021). According to definitions previously proposed, the

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“minimum level of service” is 20 L/capita/day (LPCD) (WELL, 1998), “total recommended basic water requirement” is 50 LPCD (Gleick, 1996) and “optimal access” for domestic hygiene is 100 LPCD (Howard and Bartram, 2003). However, there are regions where domestic water consumption does not reach 100 LPCD (Gleick, 1996; Shaban and Sharma, 2007). To deal with water scarcity, the use of multiple water sources is commonly practiced at households in Asia, Africa, and the Pacific (Cook et al., 2016; Elliott et al., 2017; Grace et al., 2013; Howard et al., 2002; Luetkemeier and Liehr, 2018; Özdemir et al., 2011; Shrestha et al., 2017). However, to our knowledge, no study has quantitatively investigated the association between using multiple water sources and water consumption at household level.

Recently, water insecurity has been defined at the household level as the inability to “access and benefit from affordable, adequate, reliable, and safe water for wellbeing and a healthy life” (Jepson et al., 2017). Achore et al. (2020) identified that nine key coping strategies are typically employed by households including construction of alternative source, water sharing and borrowing from social networks, and treatment to improve water quality to deal with water insecurity. According to previous reports, households with higher income had higher probability of digging a tube well (Grace et al., 2013; Zerah, 2000) the probability to treat water and larger water storage capacity (Zerah, 2000). In addition, it was indicated that more educated households have higher cost to behaviors: collecting, pumping, treating, storing, and purchasing, to deal with water scarcity (Pattanayak et al., 2005). As above, socioeconomic status such as household income and education level are associated with coping strategies. Venkataramanan et al. (2020) classified individual and households-level coping strategies related to access into three types: Physical, Economic and Social. Here, we assumed physical factors which depend on the external environment (e.g. water source and water supply system) and also non-physical factors (e.g. wealth status) are associated with access, i.e. water consumption. Though several reports confirm factors associated with household water consumption (Babel et al., 2007; Nauges and van den Berg, 2009; House-Peters and Chang, 2011; Coulibaly et al., 2014), many of them focused on factors that are not determined at the household level (e.g. economics and climate) and no reports considered the combined use of different sources of water. It remains unknown how physical and non-physical factors are associated with water consumption at household.

The Kathmandu Valley, Nepal, is a region with chronic water scarcity due to population growth and rapid urbanization that has occurred since 1990 (Thapa and Murayama, 2010). Like places with similar characteristics elsewhere in the world, households in Kathmandu habitually use multiple water sources to deal with water scarcity. Water demand is 370 million liters per day (MLD), while Kathmandu Upatyaka Khanepani Limited (KUKL), which is the only piped water supply company for the region, provides 144 MLD of piped water in the wet season and 86 MLD in the dry season (Tamrakar and Manandhar, 2016). These production volumes have remained almost constant from 2008 to 2014 despite population growth. The Nepal government is implementing Melamchi Water Supply Project, which aims to distribute 510 MLD of water supply from the Melamchi river in two phases: 170 MLD by September 2016 (delayed by two years because of the 2015 earthquake, shortage of fuel, and other project management issues) and an additional 340 MLD by 2023. However, only 60 MLD is being distributed around the Valley as of March 2021 (The Himalayan Times, 2021) and the progress of this project is behind the initial plan. Udmale et al. (2016) estimated supply deficit would be 124 MLD in 2021 after the first phase based on estimated population and the assumption that residents need 135 LPCD. Also, Thapa et al. (2018) showed there is some inequity in water distribution in the water service area, and the area with new reservoirs is expected to reach 317 LPCD while the area with existing reservoirs is expected to deteriorate to 52 LPCD in 2024 after the second phase. In addition, the average time of piped water supply was 4 h per week during the dry season in 2015. Due to insufficient water supply, households must use not only piped water but also alternative water sources (Shrestha et al., 2017). However, the main alternative water sources in the Kathmandu Valley, Nepal (i.e. groundwater, tanker water, and jar water) are likely to be microbiologically polluted (Haramoto, 2018; Pant, 2011; Warner et al., 2008; Maharjan et al., 2018; Malla et al., 2015) compared to piped water (Ito et al., 2020), particularly during wet season for groundwater (Shrestha et al., 2014). Groundwater recharge is larger during wet season (1.949 Million-Cubic Meters: MCM) than during dry season (1.052MCM) (Lamichhane and Shakya, 2020) and Pandey et al. (2013) reported “if the shallow aquifer could be managed properly (by regulation of groundwater development as well as augmentation of recharge), it has potential to meet most of the water demand in the Valley”. For household consumption the unit cost for using groundwater (0.18 USD /Cubic meters) is estimated to be much cheaper than that for tanker water (2.22 USD/ Cubic meters) (Ojha et al., 2018). According to previous reports (Pattanayak et al., 2005; Guragai et al., 2017), households practice choice of water sources, treatment and storage in this area, however, there was no information about the effect of “borrowing and sharing water from social networks”. In Nepal, the 7.6 magnitude Gorkha earthquake was occurred on April 25, 2015. The earthquake caused major (partial) damage to 1,570 (3,663) out of 11,288 water supply systems in the affected areas (NPC, 2015) which resulted in a ∼40 % reduction in piped water supply post-earthquake (Thapa et al., 2016). Those environmental factors, i.e. seasonality and earthquake, supposedly affect other physical factors such as well collapse and obstruction of vendor water distribution or non-physical factors.

The objective of this study was to quantify the association between using multiple water sources and individual water consumption. In addition, we investigated the relationship between water consumption and physical and non-physical factors before and after the Gorkha earthquake.

2. Methods

2.1. Study area

Kathmandu is the capital city of Nepal, a low-income country at the north of India in South Asia. Kathmandu Valley, located in the midland of the Himalayas between 27° 32′13″ and 27° 49′10″N and 85° 11′31″ and 85° 31′38″E has an area of 665 km^2 and consists of the entire Bhaktapur district, 85 % of Kathmandu district and 50 % of Lalitpur district (Pant and Dongol, 2009). The average annual

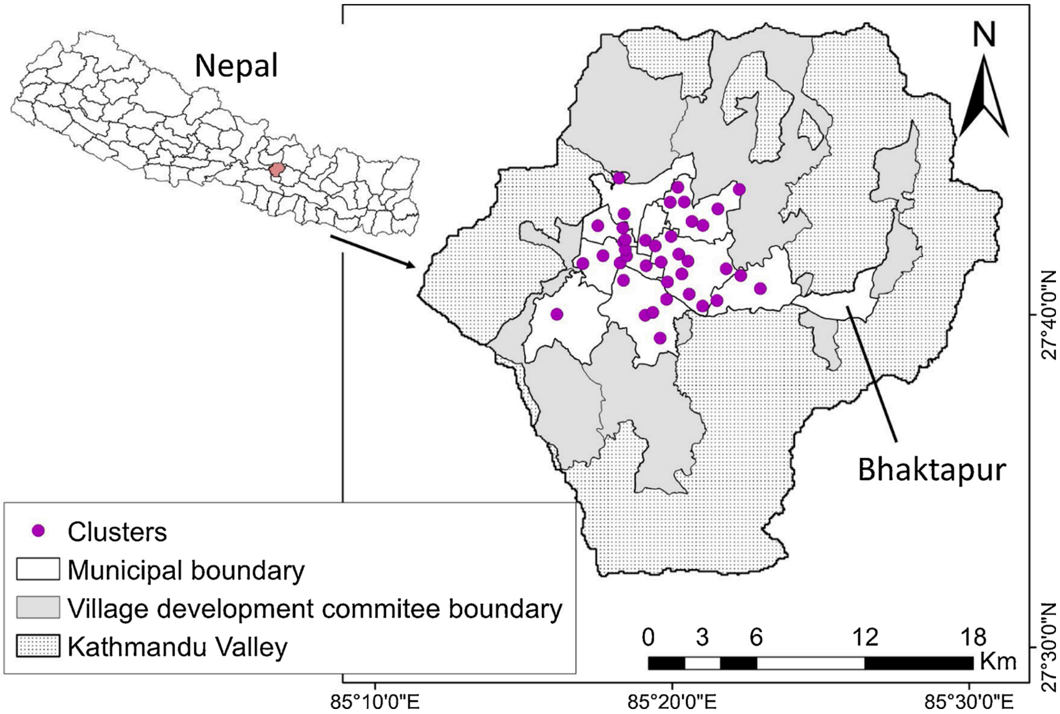

Fig. 1. Questionnaire survey locations (clusters) in the Kathmandu Valley.
White and gray areas are KUKL service areas. The central white areas refer to municipalities and the peripheral grey areas refer to Village Development Committees (VDC). These administrative divisions were current as of January 2017. The study was conducted in white areas shown in Fig. 1, except for Bhaktapur which did not have population data available at the time of study planning.

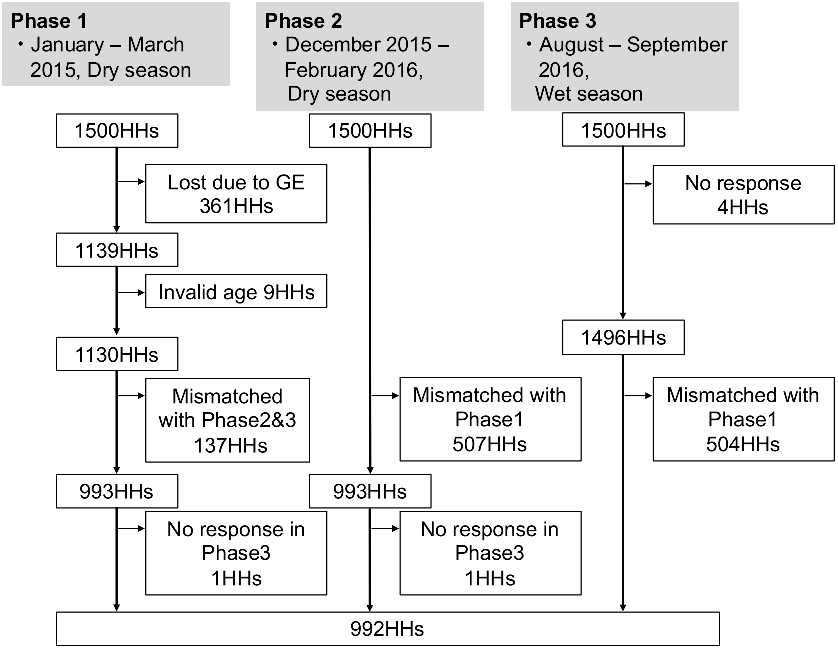

Fig. 2. Outline of three questionnaires and valid data for analysis.
HHs : Households, GE: Gorkha earthquake.

Table 1
Dependent and independent variables and their definitions for linear regression analysis.

Variable	Description	Types of variables	Definition
Dependent variable			
Consumption	Water consumption (Liter/caita/day)	Continuous	
Independent variable			
Physical			
Source[a]	Water source (PW, GW, and TK) used in the households	Nominal	Only PW : Reference group GW (and PW)[b] TK (and PW)[c] GW and TK (and PW)[d]
Supply time	Supply time of PW (hour/week)	Continuous	
Earthquake	Before and after earthquake	Nominal (Binary)	Before = 0, After = 1
Season	Dry or wet season	Nominal (Binary)	Dry season = 0, Wet season = 1
Non-physical			
Wealth status	Wealth status divided into 5 levels based on household asset possessions	Nominal	Lowest: Reference group Lower Medium Higher Highest
Head education	Educational attainment of household head	Nominal	No education: Reference group Primary/Secondary College/University
Ownership	House ownership	Nominal (Binary)	Tenant = 0, Owner = 1
Community	Participation in local community	Nominal (Binary)	No = 0, Yes = 1
Treatment	Water treatment at home	Nominal (Binary)	No = 0, Yes = 1

[a] PW = Piped water, GW = Groundwater, TK = Tanker water.
[b] Only GW / GW and PW.
[c] Only TK / TK and PW.
[d] GW and TK / GW, TK and PW.

rainfall is 1200 mm, and about 80 % of annual rainfall occurs during the June to September wet season (Prajapati et al., 2021). The population of Kathmandu Valley increased from 2.51 million in 2011–3.2 million in 2015, and the population growth rate was 4.3 % per year from 2006 to 2015 (Tamrakar and Manandhar, 2016). As of 2017, KUKL was distributing water to households through 10 branch offices in the Kathmandu Valley and provides services to 90 % of the population.

2.2. Questionnaire survey

This study used a questionnaire survey conducted in the densely populated areas of all KUKL water supply areas (i.e. the white areas shown in Fig. 1) but excluding Bhaktapur. The sampling unit was a household and there are more than 40,000 households in our target area. A two-stage cluster survey design was used for households sampling. In the first stage, total 50 clusters were extracted applying the probability proportional to size (PPS) sampling technique on the basis of household number and geographical locations of each cluster were randomly selected using geographic information system. Here, household numbers in wards of the municipalities were considered for selecting cluster. In the second step, the trained interviewers from local community randomly selected 30 households closest to each selected geographical location. They conducted face-to-face interviews with any one of the household members aged between 15 and 60 years, who were capable of understanding and answering the questions. The questionnaire was created in English and translated into Nepali. Answers were given in Nepali and translated back into English. The questionnaire included questions on socio-demographics characteristics, economic, domestic water use behavior (water storage, treatment, collecting, buying, etc.) and community involvement. The details of this questionnaire have been explained by Shrestha et al. (2017). The questionnaire was conducted in three phases as shown in Fig. 2.

Phase 1, baseline period, was conducted during the dry season from January to April 2015, but only in 39 clusters (1139 households) due to the Gorkha earthquake. Phase 2 was conducted in 50 clusters (1500 households) during the dry season from December 2015 to February 2016 (8 months after the earthquake), and Phase 3 was conducted in 50 clusters (1500 households) during the wet season from August to September 2016 (1 year and 4 months after the earthquake). After excluding households that were answered by family members of invalid age or that had missing answers in one or more of the study phases, the data from 992 households were included in this study.

2.3. Factors for analysis

Table 1 shows dependent and independent variables selected in this study for linear regression analysis.

Piped water, groundwater, tanker water, and jar water are the main water sources in Kathmandu Valley and are considered in this

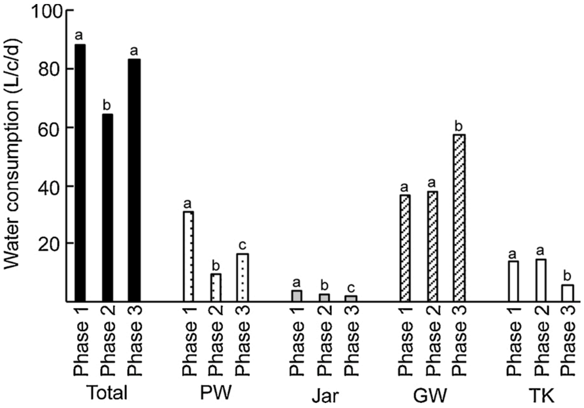

Fig. 3. Mean of water consumption (LPCD) for total and each source in three phases.
Different letters indicate that the mean difference between periods is significant at the 0.01 by post hoc comparisons using Games-Howell test in each source.

study. (Few households answered they use another type of waters such as stone spout, spring water, rainwater and community water source.) Piped water is defined as water supplied by the water utility, KUKL. Groundwater is defined as water extracted from underground through private dug wells and tube wells. Tanker water is market water sold by private vendors, and is delivered from a truck or tanker. Jar water is also a market water available in 20 L bottle. Households answered water consumption (in L) per day for each source separately and the water consumption amount divided by the family size is the water consumption liter per capita per day (LPCD) used in this study. The sum water consumption from different sources was considered as total water consumption, a dependent variable.

Seven independent variables (i.e. source, supply time, wealth status, education for household head (head education), ownership, community and treatment) were decided with respect to both physical and non-physical characteristics while referring to previous reports (Shrestha et al., 2013, 2018). “Source” consisted of 4 categories: households using only piped water, groundwater (and piped water), tanker water (and piped water), groundwater and tanker water (and piped water). “Supply time” was the hours per week that piped water is supplied. “Source” and “supply time” were identified as physical factors. “Wealth status” was determined by constructing a wealth index based on 16 household asset possessions (e.g. television, bicycle, car and refrigerator) (Cordova, 2009). The wealth index represented a household’s long-run economic status. The principal component analysis was used for identifying the weighting of each asset prior to constructing a wealth index. Based on the wealth index, households were categorized in to five quintiles: lowest/lower/medium/higher/highest (Shrestha et al., 2017). “Head education” consists of 3 categories based on attainment of education by household head: no education, primary or secondary school, and college or university. Since there is usually more than one household per house in this area, “Ownership”: house owner/tenant was also considered. Achore et al. (2020) has identified “water sharing and borrowing from social networks” as one of the coping strategies to deal with water insecurity. Being a member of a local community strengthen social network of a household and water is borrowed or shared to cope with water scarcity. Hence, whether or not a household is a member of local community was decided as an independent variable, “Community”. Though this study focused on water consumption, quality also should not be overlooked, and “treatment” was included as an independent variable. “Treatment” consists of 2 categories: with/without water treatment regardless of the method of treatment. “Wealth status”, “Head education”, “Ownership”, “Community” and “Treatment” were identified as non-physical factors that vary at the household level. The above seven factors were adjusted as covariates in multiple linear regression analysis.

First, a regression analysis was conducted using all data collected from Phase 1–3 and including “earthquake: before/after” and “season: dry/wet” as independent variables in addition to the above seven independent variables. Another regression analysis was then conducted in each of the three phases to enable comparison of the association between seven independent variables and water consumption under the different situations before and after the April 2015 Gorkha earthquake and across the wet and dry seasons.

2.4. *Statistical analysis*

A post hoc comparison using the Games-Howel test was used to examine the difference in water consumption of each source across the three phases, and the difference in water consumption for each water source and also for combinations of water sources. The correlation between continuous variables, and continuous and nominal variables was assessed using Pearson correlation coefficient, and the correlation between nominal variables was assessed using Cramer’s V. The correlation was considered strong when Pearson correlation coefficient exceeded 0.7 (Dancey and Reidy, 2007) and Cramer’s V exceeded 0.5. Multiple linear regression analysis was

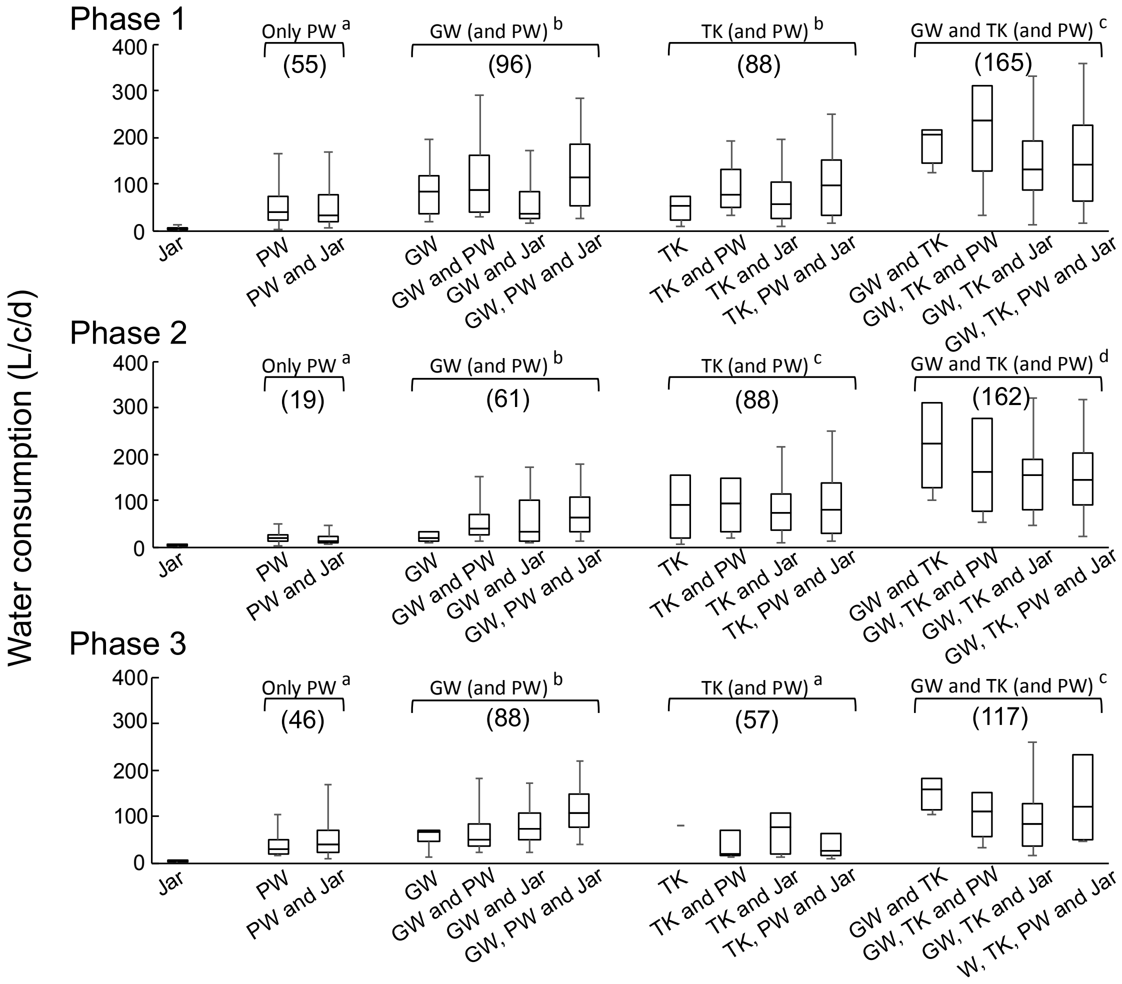

Fig. 4. Water consumption (LPCD) for each combination of using water sources in three phases and four groups decided based on these combinations.

The upper and lower bars represent the 95th and 5th percentile values of per capita water consumption, respectively. The upper and lower lines of these boxes represent 75 % and 25 %, respectively, and the middle lines represent the median values. Different letters indicate that the mean difference is significant at the 0.05 by post hoc comparisons using Games-Howell test. The number in parentheses were the mean of water consumption for each group.

used to indicate the impact of the selected factors on individual water consumption and correlation coefficient and significance levels were calculated. The significance level was set at <0.05 for all statistical analyses. All statistical analyses were conducted by using the IBM SPSS Statistics Version 26.0 (IBM Corporation, Armonk, NY, USA).

2.5. *Ethical considerations*

The ethical review board of the University of Yamanashi and the Nepal Health Research Council reviewed and approved the study protocol (Shrestha et al., 2017). The participants were informed about the objectives and procedures of the study and requested to participate voluntarily. The anonymity and confidentiality of the participants were assured. Those who agreed to the terms and conditions signed the informed consent form. Omitting questions and withdrawing from the study were permitted at any time during the interview.

Table 2
Number of households for each variable and its ratio in three phases.

	Phase 1		Phase 2		Phase 3	
	HHs	%	HHs	%	HHs	%
Consumption	832	–	884	–	913	–
Missing answer	160		108		79	
Source						
PW	157	20	178	20	113	13
GW (and PW)	346	45	533	61	681	76
TK (and PW)	165	22	83	10	29	3
GW and TK (and PW)	100	13	81	9	78	9
Missing answer	224		117		91	
Supply time	979	–	984	–	990	–
Missing answer	13		8		2	
Wealth status						
Lowest	164	20	167	19	169	19
Lower	163	20	169	19	175	19
Medium	182	22	175	20	187	21
Higher	152	18	184	21	188	21
Highest	167	20	185	21	189	21
Missing answer	164		112		84	
Head education						
No education	227	28	143	16	150	17
Primary/Secondary	307	38	578	66	592	65
College/University	269	34	158	18	167	18
Missing answer	189		113		83	
Ownership						
no	347	42	230	27	239	27
yes	485	58	636	73	656	73
Missing answer	160		126		97	
Community						
no	538	65	550	62	648	71
yes	294	35	334	38	265	29
Missing answer	160		108		79	
Treatment						
no	145	17	238	27	292	32
yes	687	83	646	73	621	68
Missing answer	160		108		79	
Complete data	735	–	853	–	878	–
Missing data	257		139		114	

3. Results

3.1. Water consumption for each source

In Phase 1, 2, and 3 appropriate responses relating to water consumption were received from 832, 884 and 913 out of 992 households, respectively. Fig. 3 shows the mean household consumption for each water source (and their total) in each of the three phases. Piped water consumption significantly decreased in Phase 2 and partially recovered in Phase 3. There were significant differences in piped water consumption between all phases ($p < 0.01$). Jar water consumption was relatively low for all three phases. Groundwater consumption was significantly higher ($p < 0.01$) in the wet season (Phase 3). Whereas tanker water consumption was significantly lower ($p < 0.01$) in wet season than in dry season (Phase 1 and Phase 2). The total water consumption significantly decreased after the earthquake ($p < 0.01$) and recovered in the wet season ($p < 0.01$).

3.2. Combination of using water sources

In Phase 1, 2 and 3 appropriate responses relating to water sources were received from 768, 875 and 901 out of 992 households,

Table 3
Relationship between different factors and water consumption (LPCD).

	All phases		Phase1		Phase2		Phase3	
	β [a] (95 % CI)	Adjusted β [b] (95 % CI)	β [a] (95 % CI)	Adjusted β [b] (95 % CI)	β [a] (95 % CI)	Adjusted β [b] (95 % CI)	β [a] (95 % CI)	Adjusted β [b] (95 % CI)
Intercept		59** (49, 70)		34** (14, 55)		37** (21, 54)		64** (46, 81)
Source								
Only PW	Ref.							
GW (and PW)	42** (36, 49)	38** (32, 45)	42** (28, 55)	42** (28, 55)	42** (33, 51)	39** (29, 49)	42** (31, 52)	26** (14, 38)
TK (and PW)	47** (37, 56)	29** (19, 38)	34** (18, 49)	18* (1.9, 34)	69** (55, 83)	57** (42, 72)	11 (−12, 33)	−2.6 (−25, 20)
GW and TK (and PW)	111** (102, 120)	101** (92, 111)	110** (92, 128)	98** (80, 116)	143** (129, 157)	136** (121, 151)	71** (55, 86)	55** (38, 72)
Supply time	−1.8** (−2.4, −1.3)	−0.57* (−1.1, −0.05)	−1.1** (−1.8, −0.42)	−0.43 (−1.1, 0.22)	−7.1** (−9.1, −5.1)	−0.59 (−2.6, 1.4)	−10** (−12, −7.9)	−4.1** (−6.6, −1.5)
Wealth status								
Lowest	Ref.							
Lower	14** (6.1, 23)	5.7 (−1.7, 13)	14 (−2.5, 31)	7.8 (−7.9, 24)	17* (3.1, 31)	6.3 (−5.2, 18)	12 (−0.28, 24)	4.4 (−6.8, 16)
Medium	21** (12, 29)	10** (3.0, 18)	39** (23, 55)	25** (8.8, 41)	19** (5.3, 33)	10 (−1.3, 22)	3.5 (−8.5, 16)	−2.1 (−13, 8.9)
Higher	9.2* (0.95, 17)	5.8 (−1.8, 13)	31** (14, 48)	18* (0.80, 34)	5.8 (−7.7, 19)	4.2 (−7.4, 16)	−5.3 (−17, 6.7)	−2.7 (−14, 8.7)
Highest	15** (6.7, 23)	4.5 (−3.1, 12)	29** (12, 45)	17 (−0.15, 34)	11 (−2.5, 24)	−0.43 (−12, 11)	6.4 (−5.5, 18)	1.3 (−10, 13)
Head education								
No education	Ref.							
Primary/ Secondary	−2.7 (−10, 4.0)	−0.35 (−6.5, 5.8)	3.0 (−10, 16)	12 (−0.87, 24)	−8.9 (−21, 2.9)	−11* (−21, −0.80)	2.3 (−8.0, 13)	−0.23 (−10, 10)
College/ University	−0.17 (−8.1, 7.8)	4.3 (−2.9, 12)	16* (1.7, 29)	18** (5.5, 31)	−16* (−31, −1.5)	−6.4 (−19, 6.1)	−11 (−23, 2.0)	−1.9 (−14, 10)
Ownership								
Tenant	Ref.		Ref.					
Owner	17** (12, 23)	14** (8.5, 19)	29** (19, 40)	19** (7.5, 30)	7.7 (−2.1, 17)	4.7 (−3.8, 13)	20** (12, 29)	14** (5.8, 23)
Community								
No	Ref.		Ref.					
Yes	24** (19, 30)	16** (11, 22)	29** (18, 40)	25** (14, 36)	16** (7.2, 25)	4.6 (−3.3, 13)	32** (24, 40)	17** (8.6, 26)
Treatment								
No	Ref.		Ref.					
Yes	−31** (−37, −25)	−24** (−29, −18)	−24** (−38, −11)	−21** (−34, −7.7)	−36** (−45, −26)	−20** (−28, −12)	−35** (−43, −28)	−20** (−29, −12)
Earthquake								
Before	Ref.							
After	−14** (−20, −8.8)	−34** (−40, −28)						
Season								
Dry	Ref.							
Wet	7.3** (1.9, 13)	16** (11, 22)						
Adjusted R^2		0.26		0.24		0.35		0.19

CI : Confidence interval for β.
The number in parentheses : Lower and upper bound of 95 % CI.

[*] p-value<0.05.

[**] p-value < 0.01.

[a] Regression coefficients were calculated by a simple regression analysis and show the relationship between water consumption and each factor, respectively.

[b] Regression coefficients were calculated by a multiple regression analysis and show the relationship between water consumption and each factor considering the impacts of the other factors.

respectively. There were 15 combinations of using water sources, and water consumption associated with each combination is shown in Fig. 4. We assumed that piped water is the most basic water source because of the quality and groundwater and tanker water are used for the shortage of piped water, and divided households into four groups: "only pipe", "only ground / ground and pipe", "only tanker / tanker and pipe" and "ground and tanker / ground, tanker and pipe". Here, households using only jar water were excluded since its consumption was very low. The number of households in each group was shown in Table 2.

The mean water consumption increased with the number of water sources throughout all phases, except for households using tanker water in Phase 3. In Phase 1, 2, 3, respectively, households using one alternative source consumed 1.6–1.8, 3.2–4.6, and 1.2–1.9 times the amount of water consumed by households using only piped water. In Phase 1, 2, 3, respectively, households using two alternative sources consumed 3, 8.4, and 2.5 times the amount of water consumed by households using only piped water. Between households using groundwater and those using tanker water, though there was no difference in Phase 1, those using tanker water consumed more water in Phase 2 ($p < 0.01$), while those using groundwater consumed more water in Phase 3 ($p < 0.01$). Water consumption in households using both alternative sources were significantly high throughout all phases and exceeded 100 LPCD which complied with optimal water access quantity as proposed by Howard and Bartram (2003).

3.3. Number of households for each factor

The number of households for all factors and their ratios are shown in Table 2 (more details of descriptive statistics are shown in Appendix, Table A1). In the Kathmandu Valley, 20 % (13 %) of households used only piped water in dry (wet) season. More than 28 % of households were members of one or more communities, and more than 67 % of households treated water. The data collected from 735, 853 and 878 households in Phase 1, 2 and 3, respectively, that answered all factor-related questions were included for multiple linear regression analysis.

Water storage is a coping strategy, however, we did not include the factor since it had a strong correlation with "source". There were no strong correlations between independent variables that avoided the problem of multicollinearity in multiple regression analysis (Appendix, Table A2).

3.4. Relationship between factors and water consumption

The results of the multiple linear regression analyses are shown in Table 3. The results using data from all phases indicated that water consumption decreased after the earthquake and increased during wet season, and these impacts appeared greater by being adjusted with other variables. After confirming the significant impacts from the two background variables, details of indirect or riffle associations with water consumption were examined in each phase by excluding the two variables.

Adjusted regression coefficient indicated that consumptions were high in households using multiple water sources except for households using tanker water in Phase 3 (wet season) compared to households using only piped water. In particular, the consumption of households using both alternative sources were more than double the consumption of households using one alternative source throughout the three phases. After being adjusted by the other factors, supply time was a statistically insignificant factor in the dry season (Phase 1: $p = 0.19$, Phase 2: $p = 0.56$, Phase 3: $p < 0.01$), however, unadjusted it tended to be associated with reduced consumption throughout the three phases. Households with higher wealth status and with higher education for household head consumed more water, however, these associations were not statistically significant after the earthquake. In Phase 2, though households with primary or secondary education for head significantly consumed less water than those with no education, education had negligible association with water consumption since households with highest education, college or University was not significant. In addition, households owning a house and participating in the local community consumed more water except in Phase 2. The direction of the relationship between the consumption and water treatment was negative in all phases. The models explained 19–35 % of the variability in individual water consumption.

4. Discussion

This study quantifies the association between using multiple water sources and individual water consumption in a region with limited access to water. Furthermore, the physical and non-physical factors that affect water consumption were assessed considering the effect of the earthquake. The key findings were: 1) use of additional water sources was associated with greater water consumption, especially in households using both groundwater and tanker water, 2) wealth status, education for household head (head education), house ownership were associated with increased water consumption in the baseline period but this association was not apparent after the earthquake, and 3) households using treated water consumed less water across all periods while participation in the local community increased water consumption except after the earthquake.

The regression models could explain 19–35 % of the variability in individual water consumption, which is above the sufficient criterion (10 %). The result of multiple regression analysis using data of all phases showed that water consumption decreased after the earthquake. In addition, water consumption was positively correlated to season when adjusting other variables while such increase was not detected by a descriptive analysis (Fig. 3). Piped water supply in wet season is usually high but the preliminary result indicated that piped water consumption in wet season (Phase 3) was lower than that in dry season (Phase 1). This indicated that the damage on piped water system from the earthquake persisted until Phase 3 which was not in ordinary wet season. Although the effect of season on water consumption was implied as mention above, there was another concern that the impacts of the earthquake on not only piped water but also several other variables continued until Phase 3 and, for this reason, the impact of seasonality was not further examined in this study.

Multiple regression analysis indicated households with shorter supply times tended to consume more water (Table 3). According to Pasakhala et al. (2013), households with shorter supply time tended to use a larger number of water sources. Groundwater and tanker water, which are common alternatives to piped water, are available in larger amounts at one time than piped water, and thus total water consumption increased in households with shorter supply times. Phase 2 and 3 results showed that households were able to achieve consumption of more than 80 LPCD by using tanker water and groundwater despite the decrease in water supply due to the earthquake (Fig. 4). While this value was above the recommended value for basic requirements (Gleick, 1996) it is below the recommended value for optimal access (Howard and Bartram, 2003) so is not sufficient from the perspective of domestic health and hygiene. As shown in Fig. 4, individual water consumption increased with the increase in the number of water sources even after the earthquake, except for households using tanker water in Phase 3. Particularly, water consumption synergistically increased in households using two alternative sources. Shrestha et al. (2020) concluded that the use of a greater number of water sources was one of the characteristics necessary for disaster resilience and water security. In addition, water deficit between supply and demand may continue even after 24 h-availability of electricity from December 2016 (Global Press Journal, 2017) and Melamchi Water Supply Project. Thus, the diversity of water sources would be essential in the future.

Our study indicated wealth status, education for household head, and ownership contributed to increased water consumption in the baseline period (Phase 1). Pasakhala et al. (2013) reported household income was the most influential factor in selection of coping strategies including purchase and use of alternative sources and found the households with low-income tend to consume less water similar to the result of this study. In addition, according to previous reports, households with highly educated head member have higher coping costs (Pattanayak et al., 2005) and owners pay more to get water from alternative sources though tenants compromise their water consumption (Guragai et al., 2017). Wealth status, education for household head and ownership may have helped improve coping strategies and then increase water consumption. Water treatment had a significant negative impact on the consumption throughout the three phases. Although households usually treat water only for drinking purpose, the practice of treating water might have affected total water consumption. Households using treated water may be able to implement strategies for coping with water scarcity, i.e. the gap between demand and supply, as well as pollution. In other words, they may have high awareness of conserving water, and as a result, total water consumption decreased. We also noticed the importance of membership in the local community that increased water consumption in the baseline period. According to a previous report (Bisung and Elliott, 2014), interactions among community members affected their ability to collectively craft and enforce rules for management of water and sanitation facilities. In the Valley, households supposedly enabled to actively cooperate on treatment, distribution and protection of water through participation in community (Shrestha et al., 2019). Though we indicated wealth status, education for household head, ownership and participation in the local community had a positive impact on individual water consumption, the relationships were insignificant after the earthquake and the mean consumption decreased to 64 LPCD. Given that the mean consumption in baseline period was 88 LPCD, the gap of these values may include a potential amount that can be increased by these factors.

In this study, individual water consumption (LPCD) was calculated by dividing household water consumption by the size of families. This was based on assumption that all household members use water equally. According to Achore et al. (2020) and Venkataramanan et al. (2020), water sharing with social networks was identified as a coping strategy. Our model could be improved and water saving effect can be better assessed by considering water sharing rates within households. In addition, a comparative study is needed to verify the impact of controlling variables on water consumption in regions using multiple water sources.

Regarding physical factors, we suggest to strengthen the diversity of water sources in both baseline and emergency periods. As Pandey et al. (2013) stated, regulation of groundwater development and augmentation of recharge are important. In addition, road maintenance and improvement can help make the distribution of tanker water more efficient, even in emergency periods. Regarding non-physical factors, we suggest that encouragement of participation in the local community is an immediate and effective strategy for residents to cope with scarcity in surface water and groundwater resources. In particular, introducing compact water treatment systems (Shrestha et al., 2019) that are decentralized and managed by residents may enhance relationship among residents and water security. As a result, it will be easier for residents to participate in the local community. Support for construction of new wells or systematic improvement for increasing supply time of piped water, especially focused on households with lower socioeconomic status, could also help reduce water scarcity. Our study contributes to understanding the local situation in Kathmandu Valley, Nepal but the same approach could be applied in similar regions around the world to assess the effectiveness of different strategies used to cope with water scarcity.

5. Conclusions

This study showed that individual water consumption increased with the increase in the number of water sources. Particularly, it synergistically increased in households using groundwater and tanker water. In addition, wealth status, education for household head, and house ownership were associated with significantly higher water consumption, however, these relationships disappeared after the earthquake. Participation in the local community, a factor of coping strategy, also increased individual water consumption. On the other hand, households using treated water consumed less water regardless of the survey periods, probably because people in these households have higher awareness of conserving water.

Author contributions

Yuri Ito: Conceptualization, Investigation, Data curation, Formal analysis, Writing-Original Draft, Funding acquisition. **Yuka Kobayashi:** Formal analysis, Writing-Review & Editing. **Hiroshi Yokomichi:** Formal analysis, Writing-Review & Editing. **Sadhana Shrestha Malla:** Investigation, Writing-Review & Editing. **Anthony S. Kiem:** Writing-Review & Editing. **Kei Nishida:** Conceptualization, Formal analysis, Writing-Review & Editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A

Table A1
Descriptive statistics of water consumption for each dependent variable.

	Phase 1		Phase 2		Phase 3	
	Mean	SD	Mean	SD	Mean	SD
Source						
PW	55	45	19	16	46	36
GW (and PW)	96	75	61	52	88	54
TK (and PW)	88	65	88	63	57	46
GW and TK (and PW)	165	93	162	87	117	83
Supply time	–	–	–	–	–	–
Wealth status						
Lowest	65	66	54	51	80	53
Lower	80	74	70	63	92	56
Medium	105	80	73	68	84	56
Higher	96	79	59	66	75	58
Highest	94	85	65	70	86	64
Head education						
No education	82	75	73	71	84	64
Primary/Secondary	85	77	64	64	86	58
College/University	97	82	57	58	73	50
Ownership						
no	71	69	59	62	69	54
yes	100	82	67	66	89	58
Community						
no	78	73	58	59	74	52
yes	107	84	74	72	106	65
Treatment						
no	108	84	90	69	107	54
yes	84	76	54	60	72	56

Noted: Mean and SD on supply time are blanks since it is continuous variable.

Table A2

Correlation matrix between eight factors.

	Consumption	Source	Supply time	Wealth status	Head education	Ownership	Community	Treatment	Earthquake	Season
All phases										
Consumption	1.00									
Source	0.40^{**a}	1.00								
Supply time	−0.12^{**a}	−0.21^{**a}	1.00							
Wealth status	0.05^{*a}	0.07**	−0.02^{a}	1.00						
Head education	0.00^{a}	0.06*	0.03^{a}	0.07**	1.00					
Ownership	0.12^{**a}	0.04	−0.12^{**a}	0.28**	0.04	1.00				
Community	0.17^{**a}	0.20**	−0.09^{**a}	0.11**	0.16**	0.24**	1.00			
Treatment	−0.20^{**a}	0.14**	0.14^{**a}	0.12**	0.10**	0.02	0.18**	1.00		
Earthquake	−0.10^{**a}	0.26**	−0.12^{**a}	0.02	0.25**	0.12**	0.05**	0.13**	1.00	
Season	0.05^{**a}	0.24**	−0.08^{**a}	0.01	0.12**	0.06**	0.10**	0.09**	0.50**	1.00
Phase 1										
Consumption	1.00									
Source	0.35^{**a}	1.00								
Supply time	−0.11^{**a}	−0.22^{**a}	1.00							
Wealth status	0.13^{**a}	0.10*	−0.03^{a}	1.00						
Head education	0.08^{*a}	0.06	0.01^{a}	0.11**	1.00					
Ownership	0.19^{**a}	0.13**	−0.10^{**a}	0.36**	0.08	1.00				
Community	0.18^{**a}	0.25**	−0.11^{**a}	0.12**	0.15**	0.28**	1.00			
Treatment	−0.12^{**a}	0.12**	0.09^{**a}	0.13**	0.06	0.01	0.11**	1.00		
Phase 2										
Consumption	1.00									
Source	0.57^{**a}	1.00								
Supply time	−0.23^{**a}	−0.36^{**a}	1.00							
Wealth status	0.02^{a}	0.09*	−0.02^{a}	1.00						
Head education	−0.07^{*a}	0.11**	0.00^{a}	0.07	1.00					
Ownership	0.05^{a}	0.06	−0.19^{**a}	0.24**	0.07	1.00				
Community	0.12^{**a}	0.25**	−0.09^{**a}	0.13**	0.18**	0.22**	1.00			
Treatment	−0.25^{**a}	0.24**	0.26^{**a}	0.19**	0.09*	0.04	0.13**	1.00		
Phase 3										
Consumption	1.00									
Source	0.24^{**a}	1.00								
Supply time	−0.30^{**a}	−0.35^{**a}	1.00							
Wealth status	−0.01^{a}	0.05	0.01^{a}	1.00						
Head education	−0.06^{a}	0.08	0.13^{**a}	0.07	1.00					
Ownership	0.15^{**a}	0.08	−0.13^{**a}	0.24**	0.07	1.00				
Community	0.25^{**a}	0.12**	−0.11^{**a}	0.08	0.15**	0.26**	1.00			
Treatment	−0.29^{**a}	0.22**	0.32^{**a}	0.14**	0.10**	0.03	0.32**	1.00		

Noted: **Correlation is significant at the 0.01 level.

*Correlation is significant at the 0.05 level.

a: Pearson correlation coefficient. A value of 0.1−0.3, 0.4−0.6 and 0.7−0.9 were considered to have weak, moderate and strong correlations, respectively.

Without a: Cramer’s V. A value of 0.1−0.25, 0.25−0.5 and 0.5< were considered to have weak, strong and very strong correlations, respectively.

Appendix B. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ejrh.2021.100928.

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