Assessing microbial water quality, users' perceptions and system functionality following a combined water safety intervention in rural Nepal

Supplemental Materials

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1   Supplementary Data

Microbial quality of chlorinated water systems

System-chlorination improved microbial water quality at the point of consumption among households where chlorine was measured (see **Figure 4**). Amongst all treatment systems in which chlorination was intended but undetected, *E. coli* contamination was not significantly different from the treatment systems without planned chlorination. However, a significant difference in the *E. coli* concentration was observed from baseline to endline at the point of consumption amongst the households where free residual chlorine was measured. There, the *E. coli* concentration was significantly lower at endline than at baseline.

Chlorination improved microbial water quality significantly although in many systems where chlorination was intended, it was not carried out on a regular basis as indicated by a lack of detectable residual chlorine and stated through key informant interviews. In a total of 6 systems (minimum 1 per district), chlorination was planned regularly. However, only in 11% of the households in the systems where chlorination was intended there was actually measurable chlorine concentration at the point of consumption at the time of endline data collection. These 19 households belonged to two systems. The measured chlorine level varied between 0.1 and 1.5 mg Cl/L (M= 0.5, SD= 0.6). In 9 of these 19 water samples, we measured 0.1 mg Cl/L, the others ranged from 0.2 – 1.5 mg Cl/L within the recommended dosing range of 0.2 - 5.0 mg/L for disinfection efficacy (WHO, 2011). These 10 households had non-detectable *E. coli* concentrations except for one with 1.5 mg Cl/L, which showed 1 *E. coli* CFU/100 mL. Six of the households with 0.1 mg Cl/L had <1 *E. coli* CFU/100 mL at endline, one had 1 *E. coli* CFU/100 mL another had 15 *E. coli* CFU/100 mL, and for one the *E. coli* concentration was too numerous to count (TNTC).

Reference:

WHO, 2011. *Guidelines for Drinking-water Quality, 4th Edition*. World Health Organization, Geneva, Switzerland.

Associations between users' perceptions of their water service and system functionality metrics

There was a significant correlation between the functionality of the main drinking water source (functioning well, functioning not so well, not functioning) and the user's satisfaction (satisfied, dissatisfied, extremely dissatisfied). Better functioning sources were associated with the availability of the source when needed, and both were associated with higher users' satisfaction. Further, more hours of reported water availability were associated with higher rated source functionality at present and both were associated with higher confidence that the water system would be functional one year later.

The interruption in the water system within the last year during which no water was available for more than one week correlated negatively with the hours of water available per day at the tap, the current functionality and the confidence in a functional system one year later. So, more hours of water availability, better rated current functionality and higher confidence in the functionality after one year were associated with less interruptions. Further, interruptions correlated with lower user satisfaction with the water system. All Spearman's correlations presented were of moderate strength with p-values < .02. (More details on the correlation are in Table S8.)

Abbreviations

CFU	colony forming units
DPD	N,N-Diethyl-p-phenylendiamin
DWS	drinking water scheme
E. coli	*Escherichia coli*
Eawag	Swiss Federal Institute of Aquatic Science and Technology
FCHV	Female community health volunteer
FRC	free residual chlorine
HWTS	household water treatment and safe storage
IWRM	Integrated Water Resource Management
M	Mean
N	sample size
NGO	non-governmental organization
NPR	Nepalese Rupee
OR	odds ratio
SD	standard deviation
SDG	Sustainable Development Goal
TNTC	too numerous to count
USD	United States Dollar
VMW	village maintenance worker
WASH	water, sanitation and hygiene
WHO	World Health Organization
WSP	water safety plan
WUSC	water users' committee

Supplementary Figures and Tables

1.1 Supplementary Figures

Figure S1: 5-dot scale used for perception and ownership questions during the household and key informant interviews.
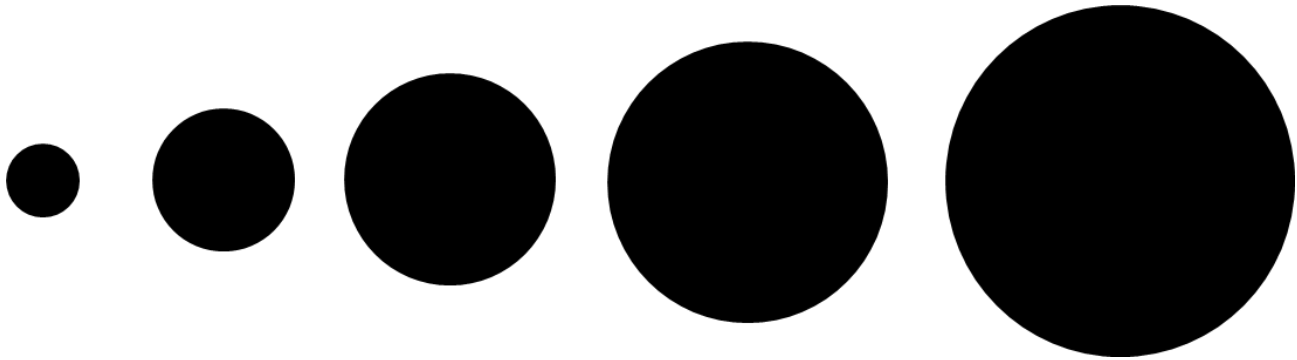
1.2 Supplementary tables

Table S1: Households' characteristics from all households reported at endline.

	N	Min.	Max.	Median	Mean	SD
Respondent age (years)	487	14	88	36	38.4	14.2
People in household	487	1	18	6	6.4	2.5
Children in household	487	0	10	3	2.7	1.6
School children	454	0	10	2	2.3	1.4
Children under 5 years	454	0	4	1	0.8	0.9
Household monthly expenditure (USD)	487	8.80	704.00	79.20	95.60	70.24
Household landownership (ropani)	471	0	50	5	6.1	5.8
Hours of water availability (h)	487	0	24	24	16.6	9.5

Table S2: Households' characteristics reported in percentage of all the households at baseline and endline.

	Baseline [%]	Endline [%]
Ethnicity of household		
Brahmin, Chhetri, Thakuri	67.7	69.6
Dalit	21.7	21.4
Janajati	9.9	8.8
Biggest concern for people living in village		
transportation and roads	16.4	23.4
water supply	33.5	20.5
electricity services	13.4	18.3
unemployment	5.9	10.1
support for agriculture	14.2	8.2
education	4.1	6.3
health and healthcare facilities	1.4	5.5
sanitation and hygiene	7.9	4.9
Highest education of respondent		
primary education	19.1	19.5
secondary education	16.6	16.6
college and higher	4.1	7.6
literate	32.9	40
illiterate	27.2	16.4
no education	0.2	1.2
Walls made of		
stone and mud	91.9	95.1
stone and cement	6.7	3.9
bricks and cement	0.8	0.6
wood planks	0.6	0.4

	Baseline [%]	Endline [%]
Floor made of		
earth	95.1	94.5
concrete	4.9	5.3
Roof made of		
stone slates	54	56
corrugated galvanized iron (CGI) sheet	24.5	29.2
straw	14.4	9.2
concrete	1.6	2.9
mud	5.5	2.5
Electricity		
electric grid	13.8	15.0
solar panel	77.5	83.0
no electricity (no grid, no panel)	12	6.4
Food production		
produce own food	97.2	96.3
don't produce food	2.8	3.7
Is anyone in this household involved in the water supply system in this community? (could mention multiple)		
no	71.0	71.0
water users' committee (WUSC) member	23.3	23.4
water safety plan task force member	2.4	1.6
village maintenance worker (VMW)	0.6	2.5
female community health volunteer (FCHV)	1	0.2
Water users committee meetings		
no answer	8.7	10.9
never	19.5	12.7
once a year	3	1.6
once every half a year	2	1.8
3 monthly	7.1	8.6
2 monthly	3.7	3.3
once a month	33.7	33.3

	Baseline [%]	Endline [%]
Main drinking water source		
piped village connections	71.2	71.3
piped household connections	27.0	26.1
open source	0.6	0.6
protected source	0.2	0.8
river	0.2	0.2
unmanaged piped water	0.8	0.8
rainwater		0.2

Table S3: Water system descriptions of all the systems at endline as mean, standard deviation (SD), and minimum and maximum values.

	Mean	SD	Min.	Max.
Households per scheme	67.4	44.0	29	250
Taps per scheme	30.8	43.1	5	250
Reservoirs per scheme	2.5	1.2	1	6
Sources per scheme	2.3	1.3	1	5
Households per tap	3.8	2.8	1	13

Table S4: Household characteristics of sanitary infrastructure and hygiene conditions, in percentage of households in the treatment and control systems at baseline and endline.

	Treatment		Control	
Toilets	Baseline [%]	Endline [%]	Baseline [%]	Endline [%]
open defecation	0.6	0.0	1.7	0.6
shared toilets	7.4	1.6	13.3	1.7
simple pit latrine	11.5	15.9	20.0	19.6
ventilated improved pit latrine	80.5	82.5	65.0	78.2
Handwashing facilities				
non existing	24.3	17.3	38.3	30.0
pour water out from bucket	16.3	11.8	14.4	17.2
drum with tap	59.4	51.8	47.2	36.1
private tap (no option at baseline)		17.6		16.1
Handwashing facilities with soap available	53.0	66.2	35.0	33.5
Clean and good handwashing facilities	69.0	79.6	51.7	48.0
Animal kept over night				
in same house as people living	54.5	51.9	54.5	50.3
in same house but separate floor (no option at baseline)		27.9		27.9
not in same house as people	45.5	20.1	45.5	21.8

Table S5: Risk categories of the *E. coli* concentration in the control and treatment systems and the samples of the treatment systems where chlorine was measured and the ones without measured chlorine.

E. coli	Treatment		Control		Treatment with measured chlorine		Treatment without measured chlorine	
	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline
N	313	308	179	180	19	19	296	289
<1 CFU/100 mL	10.9%	19.8%	10.1%	7.8%	5.3%	78.9%	11.2%	15.9%
1 - 10 CFU/100 mL	29.4%	22.7%	28.5%	19.4%	31.6%	10.5%	29.3%	23.5%
11 - 100 CFU/100 mL	36.4%	35.1%	29.6%	36.7%	42.1%	5.3%	36.1%	37.0%
> 100 CFU/100 mL	23.3%	22.4%	31.8%	36.1%	21.1%	5.3%	23.5%	23.5%

Table S6: Spearman's correlations of functionality and users' perception, reported as spearman's rho correlation coefficient in a 2-tailed test.

		Satisfaction	Availability when needed	Source functionality	Functioning in one year	Interruptions	Hours of water availability
Availability when needed	Correlation Coefficient	.261**	1.000	.461**	.221**	-.242**	.157**
	Sig. (2-tailed)	.000	.	.000	.000	.000	.001
Source functionality	Correlation Coefficient	.275**	.461**	1.000	.336**	-.266**	.108*
	Sig. (2-tailed)	.000	.000	.	.000	.000	.018
Functioning in one year	Correlation Coefficient	-.030	.221**	.336**	1.000	-.210**	.114*
	Sig. (2-tailed)	.511	.000	.000	.	.000	.012
Interruptions longer than a week	Correlation Coefficient	-.109*	-.242**	-.266**	-.210**	1.000	-.127**
	Sig. (2-tailed)	.017	.000	.000	.000	.	.005
Hours of water availability	Correlation Coefficient	.059	.157**	.108*	.114*	-.127**	1.000
	Sig. (2-tailed)	.196	.001	.018	.012	.005	.

**. Correlation is significant at the 0.01 level (2-tailed).   *. Correlation is significant at the 0.05 level (2-tailed).

Table S7: Condition of transportation and storage container, in percentage of households in the treatment and control systems at baseline and endline.

	Treatment		Control	
	Baseline [%]	Endline [%]	Baseline [%]	Endline [%]
Transport container clean	77.6	93.0	75.4	64.3
Transport container lid	60.7	79.0	54.1	54.8
Transport container broken	2.8	7.0	4.9	9.5
Storage container clean	79.4	94.0	75.4	59.5
Storage container broken	18.7	10.0	16.4	2.4
Storage container lid present	69.0	73.7	55.0	59.8

Table S8: Construct of the binary comparison of the independent variables with the *E. coli* concentration at endline as basis for the ordinal logistic regression model

IV Category	General Construct	Specific Indicator(s)		Variable type	Spearman's correlation		Mann Whitney	
					Correlation coefficient	p	Z	p
Independent variables of Interest	Received REACH broad intervention	Household enrolment group (1=treatment, 0=control)		Binary	-0.180	< .001	-3.982	0.000
	Received chlorination through REACH	Intended chlorination (1=yes, 0=no)					-5.952	0.000
		Measured chlorine at EL		Continuous	-0.247	< .001		
		Measured chlorine in categories 0 = no chlorine detected 1= chlorine concentration <0.2mg/L 2= chlorine concentration >0.2mg/L		Ordinal	-0.247	< .001		
	Received REACH WASH Promotion	- Info received (1=yes, 0=no)	64.9% yes	Binary	0.048	0.293	-1.053	0.292
		- Perception of water safety (1=safe, 5=very risky)		Ordinal	-0.007	0.886		
		- WASH Awareness: Knowledge of chance of getting sick when drinking untreated water		Ordinal	-0.036	0.428		
	Household water treatment	Practicing water treatment at household level (1=yes, 0=no)	54.8% yes	Binary	-0.030	0.503	-0.671	0.502
	Safe storage	Storage container lid present (1=yes, 0=no)	68.6% yes	Binary	-0.103	0.023	-2.274	0.023
	Hand hygiene practices	Hand washing facilities soap available (1=yes, 0=no)	69.7% yes	Binary	-0.133	0.010	-2.575	0.010
	Functionality of the water system	- Interruption longer than one week within the last 6 months (1=yes, 0=no)	16.2% yes	Binary	-0.051	0.261	-1.125	0.260
		- Interruption longer than one day within the last 6 months (1=yes, 0=no)	26.3% yes	Binary	-0.071	0.131	-1.512	0.130
		- Current functionality (1 = no, 2 = yes, but not so well, 3 = yes well)	88.7% yes well 10.5% yes not so well 0.8% no	Ordinal	-0.036	0.425		
		- Confidence that system will be functional in 1 year		Ordinal	-0.069	0.130		-
			1: 3.3% 2: 12.5% 3: 20.5%	Binary (1,2,3 =0;	-.086	0.059	-1.886	0.059

		(1 = not at all, 5 = very)	4: 39.4% 5: 24.2%	4,5=1) Binary (1,2 = 0; 3,4,5 = 1)	-.090	0.046	-1.994	0.046
	Maintenance and repair	- Confidence that problem is fixed within 1 week 0=no answer 1=not at all confident 2=somewhat confident 3=very confident	1.4% 13.8% 45.6% 39.2%	Ordinal	-0.031	0.502		
				Binary (1 = 0; 2,3 = 1)	-0.023	0.615	-0.504	0.614
				Binary (1,2 = 0; 3 = 1)	-0.033	0.472	-0.720	0.471
		- VMW exists (1=yes, 0=no).	78.6% yes	Binary	-0.051	0.260	-1.126	0.260
	Intermittent water supply	Hours of water available at the tap per day 0= intermittent (<=12h) 1= continuous (>12h)	Exact hours 62% continuous	Continuous	-0.087	0.055		
				Binary	-0.082	0.071	-1.807	0.071
Other independent variables	Household size	Number of HH members		Continuous	0.087	0.056		
	Children present in home	Children < 5 years living in the HH (1=yes, 0=no)	57.7% yes	Binary	0.082	0.071	-1.876	0.061
	Education level	Interviewees highest level of education: primary or higher (1=yes, 0=no)	42.3% yes	Binary	0.029	0.518	-0.647	0.518
	Wealth level	Amount of typical regular monthly expenditure		Continuous	-0.094	0.039		
	Housing type	Floor material earth used (1=yes, 0=no)	94.5% yes	Binary	0.049	0.282	-1.077	0.282
	Sanitation	Is toilet clean (1=yes, 0=no)	68.5% yes	Binary	-0.034	0.452	-0.754	0.451
	Animal faeces	Animal sleeping in house:	20.7% no, 51.3% yes but separate floor	Ordinal	0.086	0.058		
		0= no, 1 = yes and yes but on separate floor	27.9% yes 79.2% → 1	Binary	0.080	0.076	-1.775	0.076
	District	V1: Achham = y/n	24.3%	All binary	0.157	< .001	-3.466	0.001
		V2: Dailekh = y/n	18.3%		0.012	0.798	-0.256	0.798
		V3: Jajarkot = y/n	19.9%		-0.077	0.089	-1.701	0.089
		V4: Kalikot = y/n	21.1%		0.048	0.292	-1.054	0.292
		V5: Surkhet = y/n	15.2%		-0.174	0.000	-3.839	0.000

Table S9: Ordinal logistic regression model including upper and lower boundary of the log odds and the odds ratio. Endline E. coli risk categories are: 0 = <1 CFU/100 mL (non-detect); 1 = 1-10 CFU/100 mL; 2 = 11-100 CFU/100 mL; and 3 = >100 *E. coli* CFU/100 mL (reference category).

Variable	Estimate (log odds)	Std. Error	Wald	df	Sig.	95% CI Lower limit	95% CI Upper limit	Exp(B) (OR)	95% CI Lower limit	95% CI Upper limit
Endline *E. coli* risk category= 0	-2.460	0.543	20.548	1	0.000	-3.524	-1.397	0.085	0.029	0.247
Endline *E. coli* risk category= 1	-1.117	0.532	4.413	1	0.036	-2.159	-0.075	0.327	0.115	0.928
Endline *E. coli* risk category= 2	0.561	0.530	1.121	1	0.290	-0.477	1.598	1.752	0.620	4.945
Treatment scheme (yes = 1, no = 0)	-0.619	0.197	9.930	1	0.002	-1.004	-0.234	0.538	0.366	0.791
Measured chlorine concentration (mg/L)	-3.491	1.178	8.782	1	0.003	-5.800	-1.182	0.030	0.003	0.307
WASH information received (yes = 1, no = 0)	0.301	0.204	2.172	1	0.141	-0.099	0.702	1.351	0.905	2.017
Practicing household water treatment (yes = 1, no = 0)	0.275	0.229	1.439	1	0.230	-0.174	0.725	1.317	0.840	2.065
Presence of lid on storage container (yes = 1, no = 0)	-0.444	0.231	3.696	1	0.055	-0.897	0.009	0.641	0.408	1.009
Confidence of functionality in one year (5 = very confident, 1 = not confident at all)	-0.281	0.248	1.285	1	0.257	-0.767	0.205	0.755	0.464	1.227
Confidence of problem fixed in one week (5 = very confident, 1 = not confident at all)	0.077	0.184	0.174	1	0.676	-0.283	0.436	1.080	0.753	1.547
Hand washing facilities with soap available (yes = 1, no = 0)	-0.144	0.219	0.431	1	0.512	-0.574	0.286	0.866	0.563	1.331
Hours of water availability (hours)	-0.009	0.009	0.872	1	0.350	-0.027	0.010	0.991	0.973	1.010
Number of people in household	0.043	0.038	1.289	1	0.256	-0.031	0.118	1.044	0.969	1.125
Presence of children under 5 years (yes = 1, no = 0)	0.158	0.184	0.733	1	0.392	-0.203	0.519	1.171	0.816	1.681
Monthly expenditure (USD)	-0.001	0.001	0.218	1	0.641	-0.003	0.002	1.209	0.853	1.715
Respondent completed primary or higher education (yes = 1, no = 0)	0.190	0.178	1.138	1	0.286	-0.159	0.539	0.999	0.997	1.002
Toilet clean (yes = 1, no = 0)	-0.029	0.208	0.020	1	0.888	-0.436	0.378	0.971	0.647	1.459
Animal in same house overnight (yes = 1, no = 0)	0.286	0.249	1.326	1	0.250	-0.201	0.774	1.332	0.818	2.168
Achham_yes_no	0.210	0.280	0.563	1	0.453	-0.339	0.759	1.234	0.713	2.137
Jajarkot_yes_no	-0.642	0.325	3.915	1	0.048	-1.278	-0.006	0.526	0.279	0.994
Kalikot_yes_no	-0.397	0.313	1.602	1	0.206	-1.011	0.218	0.672	0.364	1.243
Surkhet_yes_no	-0.882	0.330	7.126	1	0.008	-1.529	-0.234	0.414	0.217	0.791