Impact of Wastewater-Irrigated Urban Agriculture on Diarrhea Incidence in Ahmedabad, India

Timo Falkenberg[1,2], Deepak Saxena[3]

[1]Center for Development Research, University Bonn, [2]GeoHealth Centre, Institute for Hygiene and Public Health, University Bonn, Bonn, Germany,
[3]Department of Epidemiology, Indian Institute of Public Health, Gandhinagar, Gujarat, India

Abstract

Background: Urbanization and water scarcity are placing pressure on urban food security. Globally, wastewater irrigation is a common feature of urban agriculture; however, high pathogen densities of wastewater pose disease risk for farming households. **Objectives:** (a) Compare *Escherichia coli* concentrations of groundwater, surface, and wastewater. (b) Estimate the household diarrheal disease risk between the irrigation sources. **Materials and Methods:** This 12-month case-cohort study was undertaken in 187 households from four communities, selected purposively based on the irrigation water type, in urban Ahmedabad. The study included two communities utilizing surface water and one each using groundwater and wastewater. Households were visited bimonthly during each visit self-report health information was collected by health diary method. Water samples were analyzed for *E. coli* using the most probable number method. **Results:** Average *E. coli* concentrations, per 100 mL, in all the three water sources, were exceeding the international irrigation water standard and measured 3.04×10^4, 9.28×10^5, and 4.02×10^9 for groundwater, surface, and wastewater, respectively. The incidence of diarrhea in the groundwater area was 7.92 episodes/1,000 person-weeks, while the wastewater and surface water group had incidences of 13.1 and 13.4 episodes/1,000 person-weeks. A positive correlation between irrigation water quality and incidence of diarrhea was documented. The average treatment effect of wastewater quality obtained was 2.73. **Conclusion:** Large proportions of Ahmedabad's farming population rely on water unsuitable for irrigation, inducing significant adverse health effects for farming households. This warrants an urgent need of introducing the concept of urban agriculture to the local civic authorities.

Keywords: Diarrhea, health, irrigation, Urban agriculture, Water, Sanitation, Hygiene (WASH), wastewater

INTRODUCTION

Rapid population growth coupled with high urbanization is placing increased pressure on urban food security.[1] Urban agriculture has emerged as a mechanism to improve food security, while also providing employment opportunities for urban populations. Increasing water scarcity hampers agricultural productivity and thus forms a key driver for the reuse of wastewater.[2] In consequence, wastewater irrigation is common among urban farmers worldwide.[3,4] The perennial supply of wastewater forms a key advantage, as it allows farmers to cultivate year-round.[2] In addition, the high nutrient content of wastewater reduces fertilization requirements and consequently reduces input costs.[5] However, wastewater also hosts a multitude of pathogens and potentially harmful chemicals, particularly when left untreated.[6-8] The focus of this study lies on the pathogenic disease risk of farming households.

The fecal–oral transmission route forms the key risk pathway for farmers. Fecal pathogens are transferred through water, soil, food, hands, and flies to be ultimately ingested by a susceptible host.[9] While the specific type of infection and consequent disease manifestation depends on the specific pathogen; a common symptom of gastrointestinal infection is diarrhea, which still remains the second leading cause of death in children.[10] The adverse effects of unsafe drinking water, lack of sanitation, and inadequate hygiene on the incidence of diarrhea are well established,[11-13] it is hypothesized that wastewater irrigation also forms an important risk factor.

Address for correspondence: Dr. Timo Falkenberg,
Center for Development Research, Genscherallee 3, 53113 Bonn, Germany.
E-mail: falkenberg@uni-bonn.de

Access this article online

Quick Response Code:

Website:
www.ijcm.org.in

DOI:
10.4103/ijcm.IJCM_192_17

Therefore, this study compares the irrigation water quality of various sources and estimates the risk of diarrhea from this exposure.

MATERIALS AND METHODS

This case-cohort study was conducted in urban Ahmedabad (Gujarat-India), where 187 households were followed up from September 2013 to September 2014. The adequacy of the sample size was confirmed with a power calculation. Communities were purposively selected according to the proportion of farming households, their irrigation water source (groundwater, surface water, and wastewater) and geographic location (to ensure that spatial distribution of households covered the entire area). Snowball sampling was further used to ensure the sample saturation of the selected respective community. Out of four selected communities, the groundwater group (area I) was comprised of communities primarily utilizing groundwater for irrigation, while the exposure groups were communities irrigating with surface water (area II and III) or wastewater (area IV).

Each household was followed at bi-monthly intervals and information on morbidity (specifically diarrhea) was gathered by use of "health diary." The households were requested to fill-out the predetermined diary on a daily basis, recording disease symptoms of each household member. During each visit, the diary was reviewed and in case of noncompliance, retrospectively completed. A secondary visit (after 7 days) was also proposed in case of noncompliance to reduce recall bias.

Four rounds of water sampling and testing were conducted to document the seasonal variability. Water samples were collected from the irrigation source of the households; each sample was collected using a 110 mL sterile sampling container and was transported to the laboratory on ice within 3 h. Surface and wastewater samples were collected from the waterbody at the place of irrigation water extraction. Groundwater samples were collected from the borewell, which was left running for 10 min before samples were collected. The samples were microbiologically analyzed for *Escherichia coli* using multiple tube fermentation. *E. coli* is the internationally accepted indicator organisms, reflecting recent fecal contamination, and the presence of other fecal pathogens.[14] The most probable number technique was used to calculate the bacterial density, after biochemical confirmation of *E. coli*.

Household hygiene behavior was assessed using a structured observational approach adapted from Webb *et al.*[15] The simple hygiene index was quantified using a spot-check method, which essentially forms a checklist of possible observations. These were divided into five categories: environment, water, food, sanitation, and personal. The overall hygiene score is the sum of scores of all categories. The hygiene index was completed during each of the bi-monthly visits to capture possible temporal variations in hygiene behavior.

In addition, three cross-sectional surveys were conducted: baseline, hygiene, and farm survey, to gain insights into household composition, hygiene behavior, and farming practices.

The data were analyzed descriptively, utilizing standard statistical tests (e.g., *t*-test). Further statistical analysis was by linear regression analysis with diarrhea incidence forming the depended variable. Ultimately, the average treatment effect (ATE) was calculated using propensity score matching. The propensity score was estimated with the same set of variables from the regression analysis; those subjects with similar propensity scores were matched and used for calculating the ATE.

Ethical approval was issued from the University Bonn (Germany) and the Indian Institute of Public Health– Gandhinagar (India). Before data collection, informed consent was obtained from the head-of-household.

RESULTS

Sample population

Table 1 summarizes key variables across the research groups. It was observed that the research groups were not homogeneous in regard to other exposure factors, namely sanitation, drinking water, hygiene, and household composition. About 45% of the exposure group had access to sanitation, while 57% of the groundwater group had access. The difference was more pronounced between the wastewater and surface water group, with 31% and 55% sanitation coverage, respectively. Overall, access to sanitation was not balanced among the exposure groups and hence was controlled in the further analysis. Similarly, 81% of the groundwater group receives drinking water through the local civic body, while only 57% of the exposure group receives piped water within their premises. The samples were also unbalanced in terms of hygiene, with the exposure group showing significantly lower hygiene index scores.

Irrigation water quality

The 2006 WHO water guideline define health-based targets in regard to wastewater use, indicating that $<10^{-6}$ disability-adjusted life years should be induced by the use of wastewater.[16] According to the report, this is equivalent to <1,000-10,000 *E. coli* per 100 mL. In the present study, *E. coli* concentrations of <1,000 *E. coli* per 100 mL were considered suitable for unrestricted irrigation, while *E. coli* concentrations in excess of 10,000 colony forming units (CFU) per 100 mL were classified as unsuitable for irrigation. Water with *E. coli* concentrations between 1,000 CFU and 10,000 CFU per 100 mL are considered suitable for restricted irrigation.

Based on the microbiological assessment, the average *E. coli* concentrations of the three study groups render all sources unsuitable for irrigation, with the average contamination of groundwater amounting to 3.04×10^4 *E. coli* per 100 mL and surface and wastewater to 9.28×10^5 and 4.02×10^9 *E. coli* per 100 mL, respectively. Figure 1 presents a box plot of irrigation

Table 1: Descriptive statistics of selected variables

Variable	Wastewater group	Surface water group	Exposure group#	Groundwater group	Total
Number of households	52	77	129	58	187
Number of individuals	366	506	872	340	1212
Average household size	7.0	6.6	6.8	5.9	6.5
Proportion with children (%)	69	73	71	52	65
Average number of children+	2.4	2.4	2.4	2.3	2.4
Literacy (HH) (%)	46	31	37	48	41
Literacy (highest educated) (%)	87	61	71	79	74
Piped water (%)	67	51	57	81	65
Hand pump (%)	32	45	39	19	32
RO filter (%)	2	14	9	10	10
Access to sanitation (%)	31	55	45	57	49
Hygiene index score	−0.12	1.99	1.14	1.66	1.30
HW-after defecation (%)	18	61	44	61	49
HW-before eating (%)	85	60	70	30	58
HW-before cooking (%)	26	67	51	46	49
HW-after work (%)	63	31	44	28	39

#Exposure group: Area II-IV (using predominantly surface or wastewater), with irrigation water quality ≥1,000 *E. coli*/100ml. Groundwater group: Farmers utilizing groundwater for irrigation. Wastewater group: Farmers utilizing wastewater for irrigation. Surface water group: Farmers utilizing river or canal water for irrigation. +Among households with children, HH: Head of household, Piped water: water connection on-plot, RO filter: Reverse osmosis filter, HW: Hand washing, *E. coli: Escherichia coli*. Hygiene Index Score (max. +5, min. -5)

water contamination stratified by the research groups. A clear gradient was observed, with the groundwater group showing the lowest contamination and the wastewater group showing the highest. The high *E. coli* concentrations of the surface water group indicate frequent mixing of untreated sewage into surface waterways.

On aggregating the groundwater samples from the groundwater group, the water was found suitable for unrestricted irrigation with an average *E. coli* concentration of 411 CFU per 100 mL. After applying the statistical test of association (a series of *t*-tests) as narrated in Table 2, significant differences in groundwater quality was documented; samples from the exposure areas showing higher contamination than those from the groundwater area. Groundwater samples from exposure groups were highly contaminated with an average *E. coli* concentration of 1.07×10^5 CFU per 100 mL, indicating that the use of contaminated irrigation water adversely affects the groundwater quality in the area.

Incidence of diarrhea

Overall the incidence of diarrhea in the study sample was 11.5 episodes/1,000 person-weeks. The groundwater group showed the lowest incidence rate (7.93 episodes/1,000 person-weeks), while the exposure groups showed similarly elevated incidence, with the wastewater and surface water group having 13.1–13.4 episodes/1,000 person-weeks, respectively. The bivariate analysis showed that the incidence of diarrhea is higher among the exposed population.

The regression analysis [Table 3] showed a significant correlation between irrigation water *E. coli* concentration and the disease outcome variable; thus, affirming a direct relationship between irrigation water quality and incidence
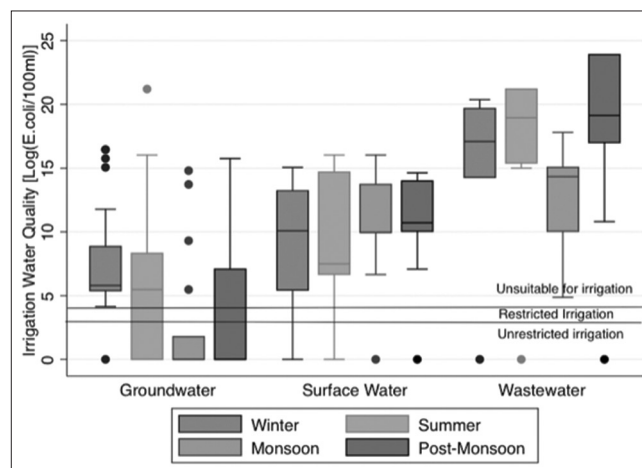

Figure 1: Irrigation Water Quality by Irrigation Water Source.n Lines = 3 Log (*Escherichia coli*/100 ml) (1,000 *Escherichia coli*/100 ml) and 4 Log (*Escherichia coli*/100 ml) (10,000 *Escherichia coli*/100 ml). Dots = outliers; top/bottom bars = max/min; box = quartile range (top = Q2; bottom = Q3); line = median

of diarrhea. An ATE of 2.73 was estimated, indicating 2.73 additional episodes of diarrhea per 1,000 person-weeks for each log-unit increase of *E. coli* per 100 ml.

DISCUSSION

The microbiological analysis has shown that both surface and wastewater are not suitable for irrigation in Ahmedabad and that reliance on contaminated irrigation water induces direct adverse effects on the health of those households engaged in the agriculture. The incidence of diarrhea was significantly higher among the exposed population, more so among

Table 2: Difference in groundwater quality between exposure groups

	Winter	Summer	Monsoon	Postmonsoon	Average
	(E. coli/100ml) (n=33)	(E. coli/100ml) (n=23)	(E. coli/100ml) (n=21)	(E. coli/100ml) (n=26)	(E. coli/100ml) (n=39)
Groundwater group	1.49×10^3 (n=25)	2.63×10^2 (n=15)	1.09×10^1 (n=18)	7.62×10^{-1} (n=21)	4.11×10^2 (n=28)
Exposure group[#]	6.59×10^4 (n=8)	2.28×10^5 (n=8)	1.23×10^2 (n=3)	2.14×10^3 (n=5)	1.07×10^5 (n=11)
t-test	−4.86***	−2.05**	−5.02***	−3.80***	−3.01***
Exposure group break-up					
Wastewater group	3.50×10^3 (n=2)	6.50×10^5 (n=2)	1.23×10^2 (n=3)	2.77×10^3 (n=3)	1.31×10^5 (n=5)
Surface water group	8.67×10^4 (n=6)	8.67×10^4 (n=6)	/	1.2×10^3 (n=2)	8.68×10^4 (n=6)

*P<0.1; **P<0.05; ***P<0.01. Groundwater group: Area I (using predominantly groundwater), #Exposure group: Area II-IV (using predominantly surface or wastewater). E. coli: Escherichia coli

Table 3: Regression analysis: Irrigation water quality and incidence of diarrhea

Irrigation water quality (n=12,912)	Linear regression (OLS)	
	Coefficient	95% CI
Exposure[#]		
Log E. coli/100mL	0.13**	0.01-0.26
POU water quality	0.01**	0.003-0.0021
Access to sanitation	4.33***	2.24-6.42
Proportion with sanitation	−2.39	−6.17-1.40
Hygiene index		
HI-environment	−1.62*	−3.18-−0.06
HI-water	−3.09***	−3.96-−2.23
HI-food	1.83**	0.13-3.54
HI-personal	−2.42***	−3.56-−1.28
HW		
HW-after defecation	−4.38***	−6.12-−2.63
HW-before eating	−5.55***	−7.12-−3.98
HW-before cooking	3.57***	2.08-5.06
HW-after work	1.17*	−0.21-−2.55
Soap shown	−1.83	−5.66-1.99
Demographic controls		
Eats own produce	3.00***	0.81-5.19
Landownership	−0.70	−2.89-1.49
Socioeconomic status	−1.28***	−2.10-−0.45
Proportion of children	21.67***	17.89-25.45
Maximum education level	0.07	−0.18-0.33
R^2	0.04	

*P <0.1; **P < 0.05; ***P < 0.01. Dependent variable: Continous irrigation water quality (Log[E. coli/100mL]); Independent variable: Incidence of diarrhea per person-week. n: Total person-weeks, HI: Hygiene index component, HW: Hand washing, POU: Point-of-use, CI: Confidence interval, E. coli: Escherichia coli

wastewater as compared to surface water group, indicating an adverse health impact of exposure to unsafe irrigation water. Therefore, measured E. coli density of irrigation water is directly and positively correlated with the disease outcome. The correlation remained robust when controlling for the effects of the established diarrhea risk factors (drinking water, sanitation, and hygiene), highlighting additional health risks induced by wastewater irrigation. Furthermore, irrigation with unsafe water can contribute to groundwater contamination, which forms the primary drinking water source of the sample population.

The results have shown that the unknowing reliance on diluted wastewater for irrigation is widespread in Ahmedabad and is practiced unplanned and unregulated. The presence of sewage outflow valves along the west bank of the river was observed during sample collection and was confirmed by the microbiological analysis of surface water. As suggested in the literature, large volumes of untreated sewage are released into the surface waterways on a daily basis.[17] As surface water forms the primary source of irrigation water in Ahmedabad,[18] large proportions of the farming population are exposed to diluted wastewater, which does not meet the international irrigation water standard.

Recommendations
Based on the observations of extent and unplanned nature of wastewater irrigation from the above study; there is an urgent need for introducing the concept of urban agriculture to the local civic authorities. Urban agriculture calls for the planned usage of the urban waste stream, thus requiring integration into the municipal waste management strategy with an underlying set of regulations, protecting human and environmental health without undermining the livelihood of urban farmers. Better urban water management, to identify hot spots for cross-contamination of groundwater with irrigation water are required, as well as better information, education, and communication to the communities engaged with wastewater irrigation, to sensitize them to the potential threats of wastewater irrigation.

Limitations
Due to nonavailability of population registries of research areas, randomized sampling could not be employed. Although the nonrandom sample with snowball sampling was applied, the entire spatial extent of the village was covered, and clustering of households were avoided.

Regular follow-ups were gathered by diary method, a possible reporting bias was minimized by use of trained field staff.

Acknowledgment

Financial support and sponsorship

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Korth M, Stewart R, Langer L, Madinga N, Rebelo Da Silva N, Zaranyika H, *et al*. What are the impacts of urban agriculture programs on food security in low and middle-income countries: A systematic review. Environ Evid 2014;3:21.
2. Hanjra MA, Blackwell J, Carr G, Zhang F, Jackson TM. Wastewater irrigation and environmental health: Implications for water governance and public policy. Int J Hyg Environ Health 2012;215:255-69.
3. Molden D. Water for Food, Water for Life: A Comprehensive Assessment of Water and Wastewater Microbiology. London: International Water Managemnet Institute/Earthscan; 2007.
4. Drechsel P, Evans AE. Wastewater use in irrigated agriculture. Irrigation Drainage Syst 2010;24:1-3.
5. De Zeeuw H, Van Veenhuizen R, Dubbeling M. The role of urban agriculture in building resilient cities in developing countries. J Agric Sci 2011;149:153-63.
6. Blumenthal UJ, Mara DD, Peasey A, Ruiz-Palacios G, Stott R. Reducing the health risks of using wastewater in agriculture: Recommdended changes to WHO guidelines. Urban Agric J 2008;1:26-9.
7. Hamilton AJ, Stagnitti F, Xiong X, Kreidl SL, Benke KK, Maher P. Wastewater irrigation. State Play Vadose Zone J 2007;6:823-40.
8. Lee-Smith D, Prain G. Understanding the links between agriculture and health. International Food Policy Research Institute, 2020. Vision Focus Brief 2006;13:1-2.
9. Morris R. Microorganisms and disease. In: Mara D, Horan N, editors. Handbook of Water and Wastewater Microbiology. London: Academic Press; 2003. p. 177-85.
10. UNICEF/WHO. Diarrhoea: Why Children Are Still Dying and What Can Be Done. New York: UNICEF/WHO; 2009.
11. Esrey SA, Habicht JP. Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. Epidemiol Rev 1986;8:117-28.
12. Clasen T, Schmidt WP, Rabie T, Roberts I, Cairncross S. Interventions to improve water quality for preventing diarrhoea: Systematic review and meta-analysis. BMJ 2007;334:782.
13. Cairncross S, Hunt C, Boisson S, Bostoen K, Curtis V, Fung IC, *et al*. Water, sanitation and hygiene for the prevention of diarrhoea. Int J Epidemiol 2010;39 Suppl 1:i193-205.
14. WHO, editor. Water Quality: Guidelines, Standards and Health. London: IWA Publishing; 2001.
15. Webb AL, Stein AD, Ramakrishnan U, Hertzberg VS, Urizar M, Martorell R, *et al*. A simple index to measure hygiene behaviours. Int J Epidemiol 2006;35:1469-77.
16. WHO, editor. Guidelines for the safe use of wastewater, excreta and greywater. Wastewater Use in Agriculture. Vol. 2. Geneva: World Health Organization; 2006.
17. UNESCO, UN, editor. Water for People, Water for Life. New York: Paris and Berghahn Books; 2003.
18. Palrecha A, Kapoor D, Malladi T. Wastewater Irrigation in Gujarat: An Exploratory Study. IWMI-Tata Water Policy Research Highlight; 2012. p. 30.