Desalination and Water Treatment
www.deswater.com

51 (2013) 2121–2129
February

doi: 10.1080/19443994.2013.734677

Impairment in water quality of Ganges River and consequential health risks on account of mass ritualistic bathing

Vinay Kumar Tyagi[a,*], Akanksha Bhatia[b], Rubia Zahid Gaur[b], Abid Ali Khan[b], Muntajir Ali[b], Anwar Khursheed[b], Absar Ahmad Kazmi[b], Shang-Lien Lo[a]

[a]*Graduate Institute of Environmental Engineering, National Taiwan University, Taipei 106, Taiwan (ROC)*
Tel. +886 (02) 3366 4377 (Office), +886 0972 837498 (Cell); Fax: +886 2 2392 8821; email: kazmifce@iitr.ernet.in
[b]*Department of Civil Engineering, Indian Institute of Technology, Roorkee 247667, India*

Received 12 September 2011; Accepted 21 August 2012

ABSTRACT

Effect of mass ritualistic bathing was studied on the water quality of Ganges River during Maha Kumbh festival in India. Significantly higher values of biochemical oxygen demand (BOD) (14 mg/L), chemical oxygen demand (67 mg/L), total suspended solids (55 mg/L), and ammonia nitrogen (2.15 mg/L) were observed during mass ritualistic bathing. The BOD values were observed to surpass the standard BOD criteria ($\leq$3 mg/L) of outdoor bathing. Similarly, higher number of total coliforms (792 most probable numbers [MPN]/100 mL) and fecal coliforms (482 MPN/100 mL) were observed in water samples, which show the alarming level of fecal contamination according to Indian and European (100 MPN/100 mL) standards of outdoor bathing. Furthermore, total 5,368 cases of water borne infections were observed during the epidemiological survey. In order to protect the public health and water quality of river, it is recommended to strictly regulate the bathing practices with continuous disinfection at upstream of bathing spot. Moreover, a comprehensive health-based investigation should be performed to facilitate the development of a suitable model.

Keywords: Maha Kumbh festival; Ganges River; Water pollution; Water borne diseases

1. Introduction

Himalayan rivers have an important place in Indian culture and tradition. They are the lifeline of majority of population in cities, towns, and villages. During festival periods, people take holy dip in these rivers [1]. Mass ritualistic bathing in rivers specifically in Ganges River occupies the most revered place in highly spiritual Hindu society of India. It is believed that a holy dip in Ganges River washes away all the sins. Hence, millions of people take bath in specific stretches of river during certain religious occasions like Kumbh festival. This time Kumbh festival was celebrated in Haridwar city of Northern India, which is a Hindu pilgrimage center and lies along the Ganges River at the boundaries between Indo-gangetic plain (South) and Himalayan foothills (North).

While in the earlier days, the ritual of bathing in Ganges River meant physical and spiritual cleanliness, however, millions of people bath at one spot nowadays with very little concern about water environment of river. They use soaps and shampoos, throw garbage, floral offerings, discarded clothes, plastics, etc. and sometimes even urinate/defecate in the sacred river water. Therefore, industrial effluents and sewage are not to be blamed alone for the water quality degradation of rivers; rather it is religion and present day ritualistic practices that have their own sizeable share. Sood et al. [2] reported that the lower regions of

*Corresponding author.

Gangetic river and its tributaries were heavily polluted due to severe anthropological activities, mostly due to religious believes. The biochemical oxygen demand (BOD) and fecal coliforms (FC) counts get usually elevated during such rituals, posing health hazards not only to the people taking the dip but also to the downstream habitat. Some pilgrims may also carry skin and other gastrointestinal diseases, so there is always a possible risk of outbreaks of communicable diseases [3].

Since, the mass ritualistic bathing is a worldwide phenomenon, which also occurs many times a year in different parts of India and millions of peoples gather on such occasions. Therefore, the present study was conducted to investigate the effects of mass ritualistic bathing on the water quality of Ganges River and subsequent health effect on bather population, with the intention that a comprehensive health-based policy may be framed to initiate necessary preventions and to stipulate the future actions.

2. Material and methods

2.1. Sampling site (Har Ki Pauri) and study schedule

Grab samples were collected during the peak bathing period (Fig. 1) from the three locations starting from 500 m upstream (Bhim Goda barrage: N29.95841, E078.17760, and Elev. 242 m), where no bathing took place (SITE I); midstream (Har ki Pauri: Holy bathing place: N29.95661, E078.17126, and Elev. 270 m), where mass ritualistic bathing took place (SITE II); and 1,000 m downstream of Har ki Pauri (N29.94670, E078.16235, and Elev. 271 m) (SITE III). Thus, a total river length of 1,500 m was covered for this study. However, the mass bathing was performed through a river length of approximate 500 m. The average flow rate of Ganges River was 11,845 m^3/s (SD: ±1,718; maximum: 13,708 m^3/s; and minimum: 8,070 m^3/s) during the entire study period (from 14 January 2010 to 28 April 2011). All the samples were collected before, during, and after the mass ritualistic bathing event (Table 1).

There were 11 particular days (from 14 January to 28 April 2010) considered important for bathing (Table 1).

The total numbers of samples
= 11 bathing occasions × 3 samples (pre, during, and post bath)
×3 sampling spots (up, mid, and downstream)
= *99 Samples.*

2.2. Samples analysis

The samples were collected in 1 L plastic containers (for physicochemical parameters) and 250 mL sterilized glass bottles (for microbiological parameters) on the days preceding and succeeding bathing events, and on the days of main bathing. The samples were preserved in an ice container at 4˚C prior to the analysis and processed within 2 h of collection. The samples were analyzed for the physicochemical parameters i.e. pH, temperature (water and ambient), dissolved oxygen (DO), BOD, chemical oxygen demand (COD), ammonia nitrogen (NH_4–N), nitrate (NO_3–N), phosphate (PO_4), acidity, alkalinity, total dissolved solids (TDS), total suspended solids (TSS), turbidity, conductivity, and bacteriological parameters (total coliforms (TC) and FC) as per Standard Methods [4].

2.3. Statistical analysis

Effects of mass ritualistic bathing on the physicochemical and bacteriological quality of river water were examined using the Pearson correlation analysis ($P \leq 0.05$) among the above said variables. In order to determine whether the observed correlations among the bathers population and physicochemical and microbiological variables were significant or not, data were subjected to paired two sample mean *t*-test using Microsoft Excel.

3. Results and discussion

3.1. Effect of mass ritualistic bathing on physicochemical quality of river water

Table 2 summarizes the physicochemical and bacteriological water quality data of 11 bathing occasions.

The temperature of river water was measured from 14 to 24˚C during the study period. Generally, the average water temperature was observed below 20˚C during January to March, which rose to 24˚C from the month of April onwards. The values of DO were also registered reasonably higher (up to 11 mg/L) in the month of January and decreased up to 8.3 mg/L in the successive months. However, mass ritualistic bathing had no significant effect on DO values and all the values were noted within the permissible limit (≥5 mg/L) of outdoor bathing standards [7].

The pH values were also found to be unchanged (mean pH value, 8) during the entire study period, which may be due to the strong buffering CO_3^{2-}–HCO_3^- capacity of water. All the pH values (7.6–8.5) were observed within the permissible criteria (pH, 6.5–8.5) of outdoor bathing ([7], Central Pollution Control Board). The values of alkalinity were sometimes higher (120 mg/L), which may be due to the practice of cloth washing by the bathers. A significant

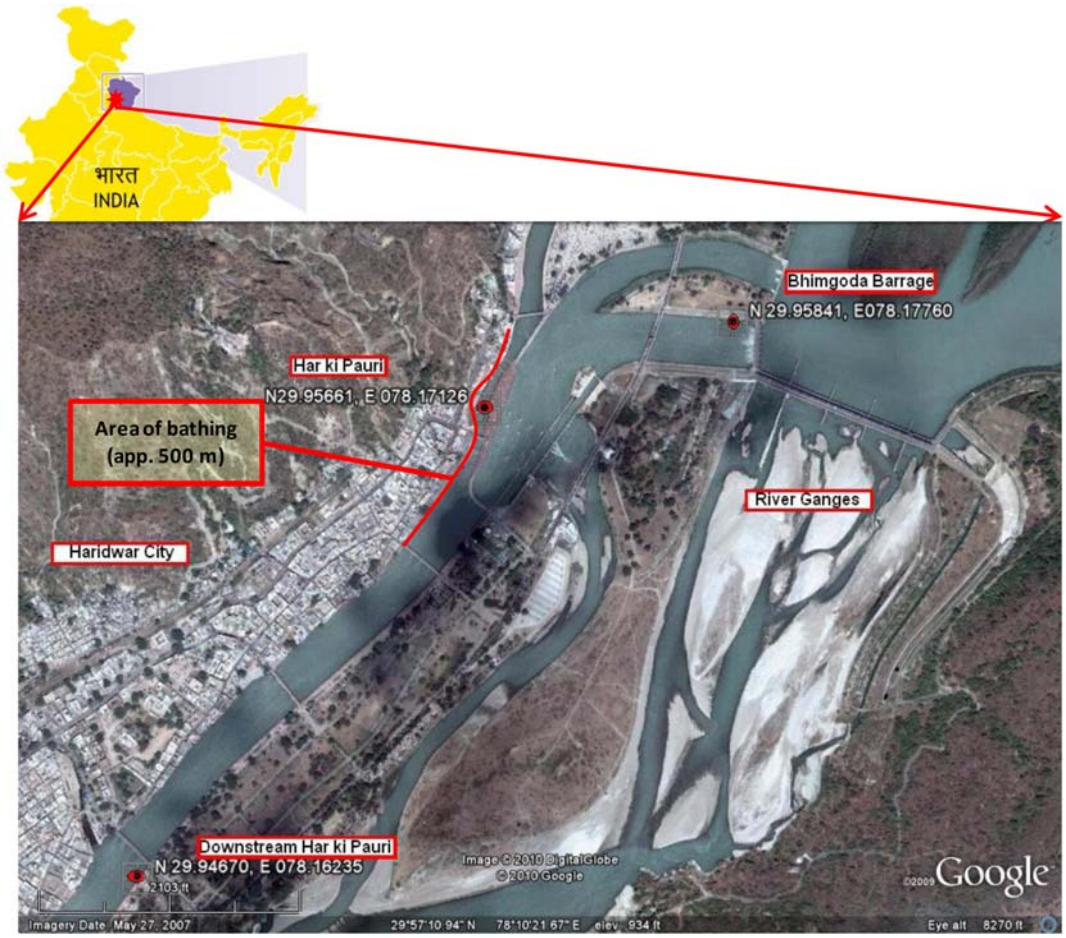

Fig. 1. Google map of Ganges River at Haridwar region showing sampling sites (in Red circle).

Table 1
Bathing events during Maha Kumbh festival

Date	Bathing occasion	Numbers of bathing population (in millions)
14/01/2010	Makar Sakaranti	0.9
15/01/2010	Mauni Amavashya–Suryagrahan Snan	1.0
20/01/2010	Basant Panchami	0.4
30/01/2010	Maagh Purnima	1.5
12/02/2010	Maha Shivaratri–Shahi Snan	4.5
15/03/2010	Somawati Amavasaya–Shahi Snan	7.0
16/03/2010	Navsamvatarambh Snan	3.5
24/03/2010	Ramnavami Snan	0.7
30/03/2010	Chaitra Purnima–Vasihanav Akhara Snan	2.5
14/04/2010	Mesha Sankranti–Shahi Snan Parv	18.0
28/04/2010	Vaisakh Aadhi Maas–Purnima Snan	1.6
No. of occasions = 11	Total number of bathers	41.6

increase was observed in turbidity values (6.3 NTU [nephelometric turbidity units]) during the mass ritualistic bathing, which is two-fold higher as compared to that of non-bathing days (3.5 NTU).

Table 2
Water quality of Ganges River during mass ritualistic bathing

Parameters	Before bathing ($n = 11$)		During bathing ($n = 11$)		After bathing ($n = 11$)		Bathing standards		
	Range	Mean (σ)	Range	Mean (σ)	Range	Mean (σ)	Indian[a]	USEPA[b]	European[c]
Temperature (°C)	14–24	18 (3.5)	14–24	18 (3.4)	15–24	18.4 (3.5)	–	–	–
DO (mg/L)	8.4–11	9.6 (1)	8.3–11.5	9.6 (1)	8.5–10.3	9.4 (0.7)	$\geq$5	–	–
pH	7.6–8.5	8.1 (0.3)	7.6–8.3	8.0 (0.2)	7.8–8.3	8.0 (0.2)	6.5–8.5	–	–
Alkalinity(mg/L as $CaCO_3$)	55–82	74 (8.1)	60–120	84 (19)	60–120	79 (21)	–	–	
TDS (mg/L)	93–101	98 (2.6)	84–102	96 (4.7)	92–100	96 (4.1)	–	–	–
Conductivity (µs/cm)	127–143	134 (5.9)	127–137	133 (2.7)	128–143	134 (5.1)	–	–	–
Acidity (mg/L)	15–30	20.4 (4.1)	16–35	23 (6.4)	15–29	21 (5.1)	–	–	–
Turbidity (NTU)	2.5–5.2	3.5 (0.7)	4.6–13.3	6.3 (2.5)	3.1–4.9	3.6 (0.6)	–	–	–
TSS (mg/L)	11–23	17 (3.7)	22–55	30 (9.7)	16–22	19 (1.9)	–	–	–
BOD (mg/L)	1.3–2.2	2 (0.4)	4–14	6 (2.9)	1.8–3.1	2 (0.4)	$\leq$3	–	–
COD (mg/L)	14–19	17 (1.8)	22–67	32 (13)	15–22	19 (2.3)	–	–	–
NH_4–N (mg/L)	0.14–0.7	0.45 (0.17)	0.84–2.15	1.11 (0.42)	0.16–0.76	0.49 (0.19)	–	–	–
NO_3–N (mg/L)	0.24–0.65	0.49 (0.14)	0.81–1.32	0.94 (0.14)	0.25–0.64	0.44 (0.11)	–	–	–
PO_4 (mg/L)	0.011–0.047	0.020 (0.012)	0.094–0.81	0.18 (0.227)	0.010–0.04	0.03 (0.01)	–	–	–
TC (most probable numbers [MPN]/100 mL)	80–220	137 (40)	250–2,100	791 (559)	84–220	149 (48)	$\geq$500	–	500
FC (MPN/100 mL)	40–160	83 (36)	170–1,500	482 (410)	22–130	72 (28)	100[b]	200	100

[a]Central Pollution Control Board (CPCB) Standards for outdoor bathing.
[b]Indian Standard limits for bathing waters ([7,21]).
[c]USEPA [8].

This is evident from Fig. 2, that turbidity increased proportionally on increasing the bathers load. The highest value of turbidity (13.3 NTU) was observed during the peak number of bathers. The change in turbidity was due to the disturbance of sediment particles on river bed during bathing and offering of prayer material (rich in colloids) like milk, wheat flour, sugar, etc. On the other hand, mass ritualistic bathing had no significant effect on conductivity, acidity, and dissolved solids concentration.

3.2. *Effect of mass ritualistic bathing on organic pollutants (BOD, COD, TSS, and nutrients)*

The BOD values were observed three-fold higher (6 mg/L) during the mass ritualistic bathing as compare to that of non-bathing days (2 mg/L) and surpassed the values (BOD$\leq$3 mg/L) of outdoor bathing standard [5]. Similarly, TSS (30 mg/L) and COD (32 mg/L) were also found higher during mass ritualistic bathing, when compared to that of non-bathing period (17 mg/L for both). Furthermore, exceptionally higher values of BOD (14 mg/L), COD (67 mg/L), and TSS (55 mg/L) were recorded during the peak loading of bathers (Fig. 3).

The BOD/COD ratio expresses the biodegradability fraction of organic pollutants, which increased from 11.8 to 18.8% during bathing days. The most probable reasons of higher values of BOD, COD, and TSS may be due to the offering of milk, curd, ghee, flowers, sugar, flour, idols, ashes of departed ones, body hairs, and other religious materials into the river water during mass ritualistic bathing events.

Fig. 4 shows the significant increase in NH_4–N concentrations (from 0.45 to 2.15 mg/L) due to the increase in number of bathers.

The high concentration of NH_4–N may be attributed to the sweat and urinal discharge by bathers.

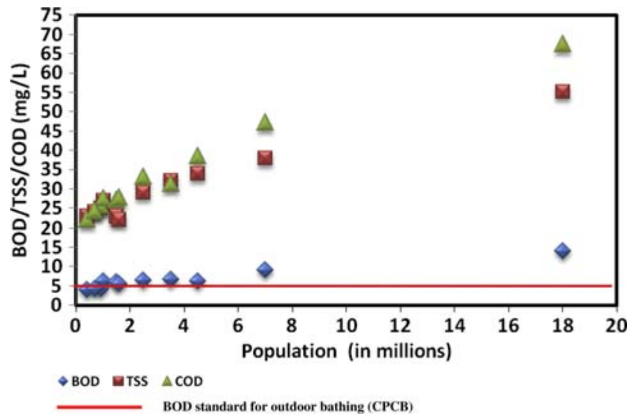

Fig. 3. Effect of number of bathers on the BOD, COD, and TSS concentration in river water.

The human urine contains > 90% NH_4–N, with ammonium bicarbonate being the dominant compound. Similarly, high PO_4 concentrations were observed during mass ritualistic bathing (from 0.2 to 1.32 mg/L), which is attributed to the use of soaps and detergents by the bathers.

3.3. *Effect of mass ritualistic bathing on microbiological quality of river water*

Table 2 shows the presence of TC (137 MPN/100 mL) and FC (83 MPN/100 mL) in water samples during non-bathing days too, which may be contributed through soil leaching and surface runoff [6].

Significantly higher numbers of TC (792 MPN/100 mL) and FC (482 MPN/100 mL) were observed in 55% samples ($n = 11$) collected during the bathing days. The numbers of TC and FC were even higher than the outdoor bathing standard (TC$\leq$500 MPN/100 mL; FC 100 MPN/100 mL) of Bureau of Indian Standards [7], US Environmental Protection Agency

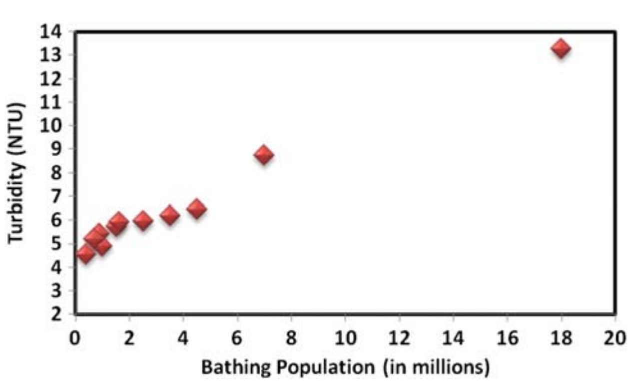

Fig. 2. Effect of number of bathers on the turbidity of river water.

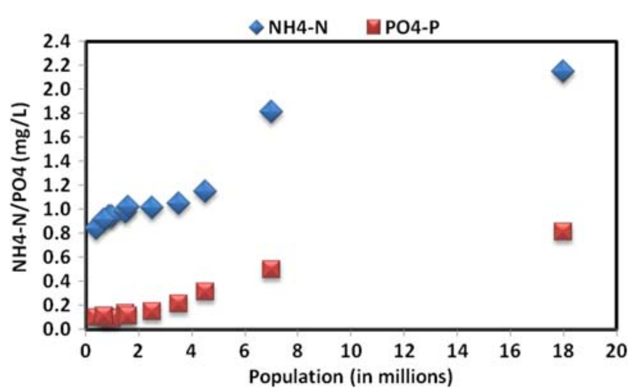

Fig. 4. Effect of bathers' density on the NH_4–N and PO_4 concentration in river water.

(USEPA) [8], and European Economic Community [9]. Currently, the bathers themselves are considered to be a nonpoint source of FC, as they transport a significant amount of fecal indicator bacterial loads to the water and resulting in negative impacts on human health [10]. Resuspension of bottom sediments by bathers increases the turbidity values and microbial load from both sediments and bathers to the recreational water, which may also be considered as nonpoint sources of contamination [11]. The mean amount of fecal material shed per bather was estimated at 0.14 g [12].

The number of coliforms bacteria in water samples expressed a significant correlation with the number of bathers (Fig. 5). The highest number of TC (2,100 MPN/100 mL) and FC (1,500 MPN/100 mL) were observed during the peak number of bathers (18 million).

The number of pathogens shed into the water can be determined with any bather load. The range of FC contributed by each bather was observed between 10^5 and 10^6 [13,14]. The majority of enteric microorganisms are released within the first 15 min of body contact [13]. This is assumed that this degree of exposure will occur with anyone coming in contact with the water during any contact water-related activity. Generally, all water contact activities resulted in at least 15 min exposure to the water and about 10–30% of the population is infected with an enteric pathogen (30% is worst case). Thus, at least 10% of the population will be excreting at least one enteric pathogen in water.

Furthermore, the findings show the presence of coliform bacteria in the water samples collected from 1,000 m downstream from the bathing spot (Har-ki-pauri region). However, the number of TC (231 MPN/100 mL) and FC (137 MPN/100 mL) were observed towards the lower side at downstream when compared to that of bathing spot (TC-791 MPN/100 mL; FC-482 MPN/100 mL) (Fig. 6).

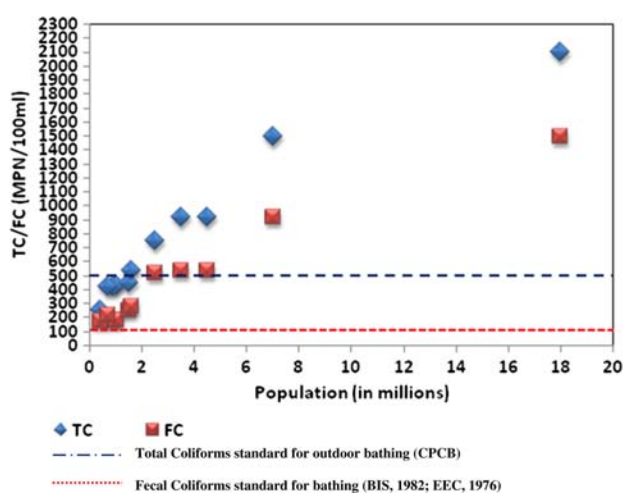

Fig. 5. Effect of number of bathers on the fecal indicators values in river water.

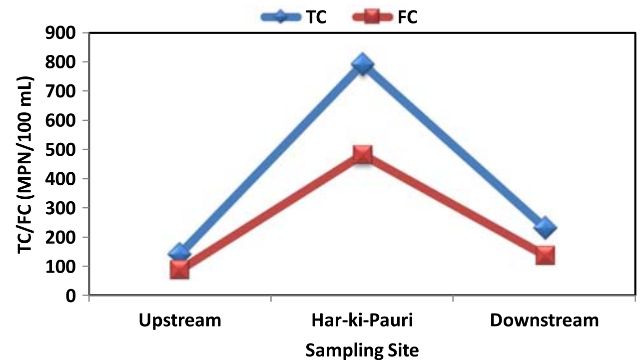

Fig. 6. Effect of distance on the density of coliform bacteria.

The decrease in the numbers of coliform bacteria could be resulted from the combined actions of various biological (grazing by protozoa, virus-induced cell lysis, loss of cultivability induced by stress conditions and autolysis) and physicochemical parameters (stress due to osmotic shock caused by salinity gradient, nutrients depletion, sunlight intensity, and temperature decrease) and possible deposition onto sediments. The phenomenon of the disappearance of fecal bacteria in natural aquatic environments has been studied by sanitary engineers concerned with the process of "self purification" of wastewater after release into natural waters [15,16]. Various researchers observed the coliforms mortality rate of 30×10^3/h in river during different periods of the year [6,17]. Fecal bacteria die in aquatic system much more rapidly i.e. two times higher than autochthonous bacteria. It could also be envisioned that under limiting substrate conditions, the organisms reverted to endogenous metabolism and then die off.

4. Incidence of sickness due to water borne infections

Table 3 shows the number of bathers infected with water borne diseases during the entire bathing occasions.

The epidemiological data were collected from 50 medical camps and hospitals near and within Kumbh Mela region during the entire study period. The finding shows a significant increase in the incidence of water borne infections during bathing events. The

Table 3
Total incidence of infection observed for the whole bathing population due to water borne pathogens

Population (millions)	Number of individuals infected with water borne diseases					Mean of coliforms bacteria (MPN/100 mL)	
	Severe diarrhea	Skin diseases	Abdominal pain	Vomiting with abdominal pain	High grade fever	TC	FC
416	1,616	102	1,992	1,257	401	791	482
	Total cases: 5368						

highest number (1,992 individuals) of patients were diagnosed to be affected with abdominal pain, followed by the patients who suffered with severe diarrhea (1,616 individuals), and nausea (vomiting with abdominal pain; 1,257 individuals). Furthermore, 401 and 102 individuals were also accounted to be suffering from high-grade fever and skin problems (rashes and itching), respectively. All the patients reported to the medical camps and nearby hospitals were recorded to be felt uncomfortable after bathing.

This is expected that a considerable percentage of bathing population carry skin and other communicable diseases. Furthermore, the bathers also used the river water for drinking as a part of ritual, due to its divine consideration, irrespective of its water quality. Previous studies [18–20] reported that bathers shed appreciable amounts of microbes into the water through their skin, and swimming-related illnesses appears to be associated with the microbial water quality, even in the absence of point sources of fecal contamination. Generally, a median of 1.4×10^4 protozoa (*Giardia* and *Cryptosporidia*) and 1.4×10^7 enteric viruses (enteroviruses, adenoviruses, and rotavirus) are shed into the water per person (based on average of all persons in the water both shedding and not shedding). A significant impact on the concentration of pathogens in the water is expected even in case of occurrence of accidental fecal release at a frequency of one per 1,000 persons.

However, the main problem with the present epidemiological study was to cope up with large number of variables, which affect the real observations. One of the major constraints of the epidemiological study was the quick departure of the bathers, which affects the consistency of data. Short stay of bathing population (only 1–2 days) at the place of bathing event as well as no stay of local population (from nearby cities) at the place of bathing event, which accounts for the approximate 35% of total bathing population is also not included in this study.

5. Statistical validation of the effect of mass ritualistic bathing on the river water quality

The effects of mass ritualistic bathing on the physicochemical (turbidity, BOD, COD, TSS, NH_4–N, and PO_4) and bacteriological (TC and FC) quality of river water were investigated statistically using the correlation analysis of the data (Table 4).

Significant correlations were observed among the bathers population and physicochemical and microbiological variables, which show that bathing population had a greater effect (from 94 to 99%) on the physicochemical and bacteriological quality of river water.

In order to determine whether the observed correlations among the bathers population and physicochemical and microbiological variables were significant or not, data were subjected to paired two sample mean *t*-test. Results obtained from the statistical analysis of data are summarized in Table 5.

The results obtained from paired *t*-test between the mass of bathing population and different physicochemical and microbiological variables indicate that the critical values of t (2.2) obtained from the *t*-distribution table at 5% (P=<0.05) probability level is lower than the observed values of *t*-stat (2.5) in each case. It shows that the chances of error in drawing out conclusions are less than 5%. Hence, null hypothesis is rejected. Thus, it can be concluded that the real and significant correlation exists between the obtained experimental data for mass of bathing population and physicochemical and microbiological variables in the analyzed water samples. Therefore, it is concluded that the correlations that exist among the observed sets of experimental data are quite obviously significant and not obtained by chance. These interrelationships can be helpful in routine monitoring as well as in future studies.

Table 4
Correlation matrix of the variables: population load and physicochemical and microbiological parameters ($n = 11$)

	Bathers population	Turbidity	BOD	COD	TSS	NH_4–N	PO_4–P	NO_3–N	TC	FC
Bathers population	1									
Turbidity	0.99	1								
BOD	0.97	0.97	1							
COD	0.98	0.98	0.97	1						
TSS	0.97	0.95	0.95	0.98	1					
NH_4–N	0.94	0.97	0.94	0.97	0.93	1				
PO_4–P	0.98	0.98	0.95	0.99	0.97	0.98	1			
NO_3–N	0.96	0.94	0.95	0.93	0.91	0.90	0.93	1		
TC	0.96	0.96	0.96	0.98	0.97	0.97	0.98	0.91	1	
FC	0.97	0.97	0.96	0.99	0.97	0.96	0.98	0.90	0.99	1

Table 5
Results of paired t-test: two sample for means between the numbers of bathing population, physicochemical and microbiological variables

Variables		Turbidity	BOD	COD	TSS	NH_4–N	PO_4–P	TC	FC
	Data paired								
Population	r^2	0.99	0.97	0.98	0.97	0.94	0.98	0.96	0.97
	t-statistic	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	t-critical	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	P	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

6. Future recommendations

Several controlling and management options are suggested herewith in order to protect the public health and river water quality. Each option involves an expected reduction in health hazard to the bathers. The flux of bathers can be regulated by introducing limited number of bathers at bathing place. The people who are suffering from gastroenteritis can be advised to avoid bathing, otherwise it can result in cross-infection. Peoples should be advised to take the dip for small time i.e. ≤ 5 min (avoid longer bathing time) in order to minimize the exposure to the pathogens and possible release of pathogens by infected individuals in water. The offering of prayer material at the bathing place can be prohibited. The use of shower prior to bathing should be recommended as well as diapered children should not be allowed to enter in the water. Continuous chlorine disinfection should be applied at the upstream of bathing place.

7. Water quality modeling

The purpose of the water quality modeling is to provide temporally and spatially varying pathogen concentration data to the disease transmission model. These temporally and spatially varying concentration data are used in the disease transmission model in conjunction with site-specific patterns of beneficial use during these large gatherings to define exposure from contact during mass bathing. A second goal of the water quality modeling is to evaluate alternative control strategies that may affect viral loading. Specific details about the water quality model and the application of the model to have not been attempted so far may be due to the absence of any synchronized long-term study on national basis with specific targets.

This experience is only successful in revealing upstream and downstream sporadic exceedances of water quality parameters only during surge of bathers and quick recovery later. Nevertheless, public health evaluation particularly during peak times needs careful considerations to develop a model so as to simulate risk in future events and possible deployment of facilities for risk mitigation or health aid/epidemiological measures. In the absence of any specific funding, the present study was almost a scientific adventure of authors to evaluate the river environment in view of a tremendous flux of on a particular period, however, the data are localized and it lack quantity. Moreover, in the absence of results on account of application of series of management options, no simulation-based methodology can be decided. It should, however, be understood that, during any mass bathing event, an individual may be exposed to a number of different pathogens derived from various different sources. Although it is not practical to estimate the cumulative risk from mass bathing via a simulation study, it is nevertheless feasible to frame an investigation in a manner such that practical risk management decisions may be considered. It is with this perspective that this investigation will pave the way for future policy formulation and implementation.

8. Conclusion

Mass ritualistic bathing causes the significant changes in the physicochemical and microbiological quality of river water. The values of BOD, TC, and FC were observed to surpass the standard outdoor bathing criteria during bathing events. The water quality was found unfit for both drinking and bathing purposes during 55% occasions of mass ritualistic bathing. Total 5,368 cases of water borne infections including, severe diarrhea, high-grade fever, skin infections, vomiting with abdominal pain were diagnosed among the bathers. Proper legislative efforts including chlorination of river water and to educate the bathers can improve the bathing conditions, reduce the pollution load on river water, and minimize the health risks. Nonattainment of health implications during periodic mass ritualistic bathing leads to severe impairment in water quality that could be controlled possibly by developing a model to simulate the risks in future events and by deployment of facilities for risk mitigation or epidemiological measures. Therefore, a massive exercise is needed for data collection under different sets of conditions at large scale.

Acknowledgments

The authors wish to express their appreciation to Kumbh Mela authorities, Central Water Commission (CWC), and concerned Chief Medical Officers (CMO's) for necessary permissions and procurement of information/data and our field assistants M/s Sushil, Vipin, and Arshad for continuous sampling, monitoring, and data collection despite all kind of administrative restrictions and stresses.

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