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The role of water use patterns and sewage pollution in incidence of water-borne/enteric diseases along the Ganges River in Varanasi, India

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Abstract
In Varanasi, India, an estimated 200 million liters daily or more of untreated human sewage is discharged into the Ganges River. River water monitoring over the past 12 years has demonstrated faecal coliform counts up to 10^8 MPN (most probable number) per 100 ml and biological oxygen demand levels averaging over 40 mg/l in the most polluted part of the river in Varanasi. A questionnaire-based survey was used to estimate water-borne and enteric disease incidence and study river use among resident users of the Ganges River in Varanasi. The overall rate of water-borne/enteric disease incidence, including acute gastrointestinal disease, cholera, dysentery, hepatitis-A, and typhoid, was estimated to be about 66% during the one-year period prior to the survey. Logistic regression analysis revealed significant associations between water-borne/enteric disease occurrence and the use of the river for bathing, laundry, washing eating utensils, and brushing teeth. Thirty-three cases of cholera were identified among families exposed to washing clothing or bathing in the Ganges while no cholera cases occurred in unexposed families. Other exposure factors such as lack of sewerage and toilets at residence, children defecating outdoors, poor sanitation, low income and low education levels also showed significant associations with enteric disease outcome. This study provides an estimate of water-borne/enteric disease incidence and identifies possible risk factors for residents who live by and use the Ganges River in Varanasi.

Keywords: *Sewage pollution, water-borne disease, enteric disease, Ganges River, Varanasi*

Introduction

Water-borne disease continues to pose a major threat to public health both in the developed and developing world (Ford 1999). Isolated outbreaks of diarrhoeal disease still occur in developed countries despite widespread employment of sewage collection and treatment facilities and water treatment practices designed to insure safe water supplies (Ford & Colwell

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1996). The situation is more serious in the developing world. The World Health Report 2002 notes: "About 1.7 million deaths a year worldwide are attributed to unsafe water, sanitation and hygiene, mainly through infectious diarrhoea. Nine out of ten such deaths are in children, and virtually all of the deaths are in developing countries" (WHO 2002).

Collection and treatment of human sewage is an issue closely tied to the safety of water supplies. When adequate sanitation is lacking, human faecal contamination of water transmits micro-organisms that cause both diarrhoeal disease, including cholera, and equally dangerous non-diarrhoeal diseases such as hepatitis A. Water-borne/enteric diseases can be spread among a human population not only through water-borne transmission but also by a variety of related means including the faecal-oral route and by direct human-to-human contact. The cycle of transmission of water-borne disease can be broken through effective collection, treatment, and disposal of sewage, and the provision of safe water supplies. According to WHO estimates in 2002, about 2.6 billion, or 42%, of the world's population lack improved sanitation, and over one billion, or 17%, lack improved water supplies (WHO/UNICEF 2004). The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation defines "improved" sanitation as household connection to a public sewer or septic system, a pour flush latrine, a simple pit latrine, or a ventilated improved pit latrine. The Joint Monitoring Programme defines an "improved" water supply as "one that is likely to supply safe water" not injurious to health, such as a household piped water connection, a borehole, a protected dug well, a protected spring, or rainwater collection.

Representative of other urban populations in the developing world, residents of Varanasi, a city of over one million people in north central India, still experience major public health problems associated with sewage pollution of the Ganges River and local water supplies. In 1986, the Government of India launched a Ganga Action Plan (GAP) to deal with sewage pollution of the Ganges River in Varanasi and a small number of other cities. What is now known as Phase 1 of the GAP program was officially completed in 1993. At this time, a non-governmental agency, the Sankat Mochan Foundation (SMF), established a testing facility to begin monitoring the efficacy of the GAP as implemented in Varanasi. Testing of such parameters as faecal coliform count (FCC) and biological oxygen demand (BOD) revealed that the river continued to have extremely high levels of faecal bacteria and organic waste. Visual observations indicated that untreated sewage continued to flow freely into the Ganges River from a variety of sewer outfalls, open drains, ditches, and other outlets, collectively referred to as point sources of pollution. Currently, there exist more than two dozen of these point sources releasing untreated sewage into the river in Varanasi.

In retrospect, many failures of the sewage collection and treatment program initiated under the GAP can be identified. In Varanasi, an activated sludge process was adopted in the sewage treatment plants built under the GAP. This process fails to directly control for faecal coliform or pathogenic micro-organisms. Post-treatment effluent from the main sewage treatment plant in Dinapur on the north (downstream) boundary of Varanasi has been passed on to nearby villages for agricultural use as fertilizer. Unfortunately, the quality of this treated effluent is such that the villagers receiving and using it have since seen their aquifers contaminated and rendered unfit for use. Related health problems such as an increased incidence of water-borne diseases now plague these village areas.

Under GAP, the Dinapur plant was designed with a sewage treatment capacity of 80 million liters daily (MLD). Two auxiliary plants located near Banaras Hindu University and the Diesel Locomotive Works were built with a combined capacity of an additional 20 MLD. In 1986, it was estimated that 130 MLD of sewage were being produced in Varanasi, leaving 30 MLD untreated under maximum operating capacity. According to a recent government statement (Uttar Pradesh Jal Nigam internet site 2005), the city's sewage production is now about 300 MLD, meaning that 200 MLD or more of raw untreated sewage currently enters the Ganges River.

Both the sewage treatment plants and the pump stations built under GAP to collect and divert sewage in Varanasi are dependent on electricity for their operation. Frequent power outages often lasting for 12 hours a day or longer force these operations to a halt, despite a contingency plan to use scarce fuel supplies to generate electricity at the plants and pump stations. During the monsoon season, sump wells are flooded and the pumping stations are shut down for 3–5 months of the year. The result is that no sewage is diverted by the pump stations during this period. During electrical outages and monsoon shutdown of pump stations, bypass vaults are opened to allow intercepted sewage to flow directly into the river. In addition to specific features of the sewage collection and treatment scheme implemented under GAP, leakage from aging and deteriorating sewer pipes is also of concern in Varanasi.

With recognition of the failure of the first phase of GAP, the Indian government has made a commitment to implement a second phase of GAP to effectively deal with industrial and urban pollution along the Ganges River. In the meantime, residents of Varanasi and other cities along the river continue to be exposed to unsafe water and associated health risks. This paper presents a summary and discussion of the SMF's water quality data collected from 1993–2004, and results and analysis of a health survey conducted during February and March 2004. The results of this study are presented with the hope that they will prove useful to public health and public policy planners in Varanasi.

Methods

Water quality testing

Water quality has been monitored by the SMF's Swatcha Ganga Research Laboratory (SGRL) at several sites along a 7-km waterfront of the Ganges River in Varanasi since 1993. Data for two locations, Tulsi Ghat located on the southern waterfront of the Ganges in Varanasi and the confluence of the Varuna and Ganges rivers at the northern boundary of the city (Figure 1), are presented. (Note: The word "Ghat" appears in several of the riverside place names and locales in Varanasi mentioned in this manuscript, and refers to the presence of "stairs" or "steps" that lead from nearby temples directly down to the Ganges River.) Among the monitoring sites, water testing has been performed most consistently at Tulsi Ghat. The SMF office and water testing laboratory are located at Tulsi Ghat, which has allowed for regular testing during adverse weather conditions such as the monsoon season, or when boat transportation to other test sites is otherwise unavailable. A total of 1642 measurements of BOD and 1577 measurements of FCC were made at Tulsi Ghat beginning January 1993 through March 2004. A total of 217 measurements of BOD and 219 measurements of FCC were completed at the Varuna-Ganges confluence site beginning May 1995 through March 2004. Although the data set is less complete, the data for the Varuna-Ganges site is noteworthy due to the Varuna River's location on the northern downstream boundary of Varanasi. The Varuna River serves as a major receptacle for the city's sewage and the confluence of the two rivers has the highest recorded FCC and BOD levels and lowest dissolved oxygen levels of any other test sites during the period that the Ganges has been monitored by the SMF.

Parameters measured by SGRL staff included temperature, pH, total dissolved solids (TDS), turbidity, dissolved oxygen (DO), biological oxygen demand (BOD) and faecal coliform count (FCC). Water was generally sampled at the same time each morning at about

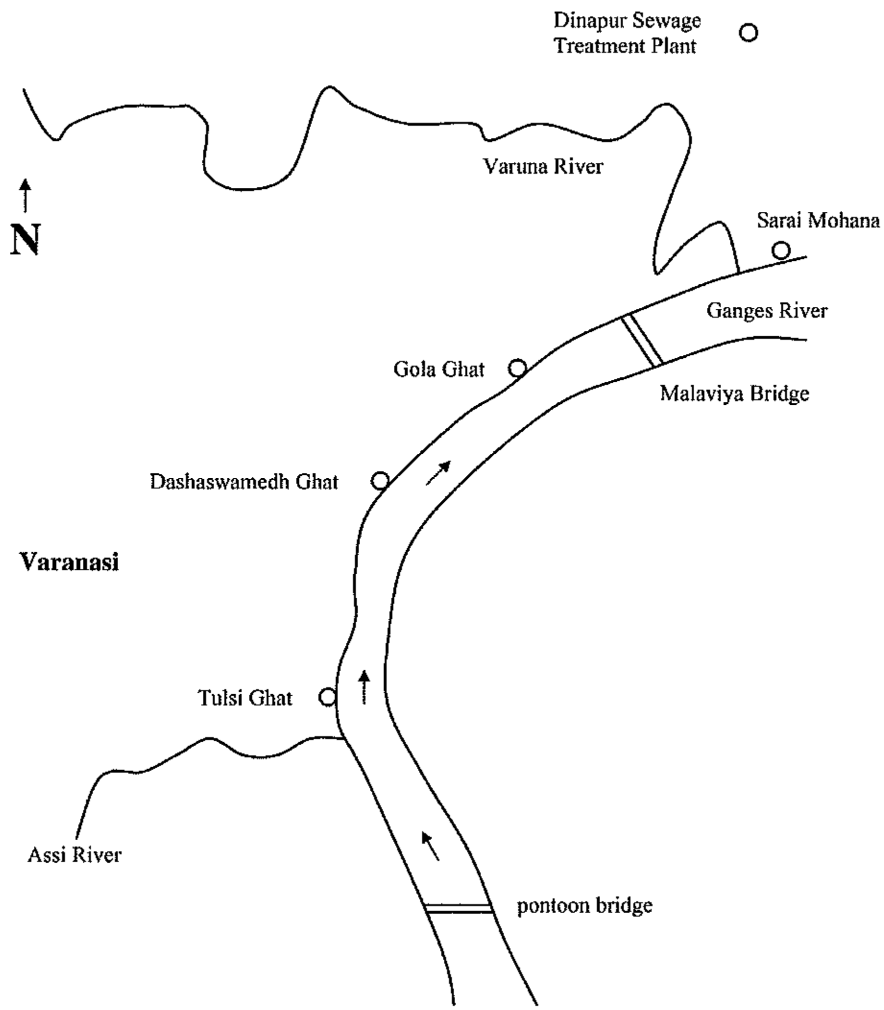

Figure 1. Map of Varanasi, showing the locations of the health survey sites of Tulsi Ghat, Dashaswamedh Ghat, Gola Ghat, and Sarai Mohana. The distance between Tulsi Ghat and Sarai Mohana is about 7 km.

8 am. Procedures described in Standard Methods for the Examination of Water and Wastewater (APHA 1992) were followed for collection and analysis of water samples. Data was entered into a spreadsheet program (Microsoft Excel 2004 for Mac) for graph preparation and analysis.

In addition to sampling and testing at sites normally monitored by the SMF, water samples were collected at locations along the Ganges River close to the health survey sites of Gola Ghat and Sarai Mohana on April 16, 2004. Testing at these additional sites was performed to provide water quality data for sites where cases of cholera were detected in the course of conducting the health survey. Water quality testing of these samples was performed by the SGRL in Varanasi.

Health survey

A survey of resident users of the Ganges River in Varanasi was conducted from February 25 to March 24, 2004. Many of the questions asked in the present study were taken from a questionnaire used in a previously published study of enteric disease risks in Hyderabad City, India in 1996 (Mohanty et al. 2002). The questionnaire was refined to address specific issues of interest in Varanasi such as sewage pollution of the Ganges River and local residents' regular use of the river for religious bathing, drinking, regular bathing, laundry, recreation and other activities. The questionnaire was also designed to reflect a cultural sensitivity for local residents' view of the river as a sacred entity with great significance to followers of the Hindu religion. The questionnaire was reviewed and approved by the Institutional Review Board at Montana State University. Informed consent was obtained with each respondent signing a Subject Consent Form. The head of a family was interviewed and asked to provide information for all members of the household. Four sites were chosen for the survey (Figure 1). Two of these sites are major areas of religious bathing activity (Tulsi Ghat and Dashaswamedh Ghat) and have been routinely monitored for water quality testing by the SGRL. Because of the relatively small number of religious bathers directly at Tulsi Ghat, other bathers and regular users of the river (e.g., laundrymen and fishermen) within a few hundred yards upstream and downstream of Tulsi Ghat were also interviewed. All family heads surveyed at Tulsi Ghat or Dashaswamedh Ghat were confirmed to be residents of those locales. A third survey site (Gola Ghat) is a few hundred meters downstream of another major religious bathing site (Panch Ganga Ghat) monitored by the SGRL. The neighborhood surveyed at Gola Ghat is adjacent to a major pump station for the collection and diversion of sewage. A fourth survey site (Sarai Mohana) lies directly downstream of the Varuna-Ganges confluence that is also monitored by the SGRL. For the two religious bathing sites of Tulsi Ghat and Dashaswamedh Ghat, religious bathers or other users of the river were approached and questioned directly on the river bank. For the neighborhood of Gola Ghat, residents were interviewed at their home sites. In Sarai Mohana, residents were interviewed in a small neighborhood office. At least 25 surveys were conducted for each of these four sites for a total of 104 interviews.

The survey questionnaire was designed to collect information as follows:

(1) To obtain an estimate of the occurrence of water-borne/enteric diseases including acute gastrointestinal infections (AGI), cholera, dysentery, hepatitis A, and typhoid. Details of occurrence of medically diagnosed and undiagnosed AGI for the previous 12-month period were obtained. Details of occurrence of medically diagnosed cases of cholera, dysentery, hepatitis A, and typhoid for the previous 12 months were also gathered. It was established during the first three interviews at Gola Ghat that several child and infant deaths due to cholera had occurred; therefore, all details of occurrence of medically diagnosed cholera and deaths from cholera were collected regardless of timeframe in order to learn more about the long-term incidence of cholera in the community. Information on hospitals, clinics, or physicians visited was recorded. A copy of the full questionnaire can be obtained from the authors.

(2) Exposure risk factors, including: availability of toilet facilities and use practices, bathing practices, source of household water, water treatment and storage practices in the home, household connection to a sewage collection line or septic tank, laundry practices, kitchen utensil cleaning practices and cleaning agents used, children's play areas, conditions of the sewer and sewerage structures surrounding the household, condition of the water used in the household, personal use of the Ganges River, eating habits, and food storage practices.

(3) Socio-economic indicators such as education, occupation, and monthly income.

Survey data was compiled into an Excel spreadsheet and logistic regression analysis performed using the Minitab Statistical Software program (version 14). The dependent variable of disease outcome was expressed as the number of members in a family affected by any water-borne disease out of total members in each family, or by number in a family afflicted by a given disease such as AGI, dysentery or cholera out of total number in the family. Independent variables tested included household sewer connection, household water quality, socio-economic indicators such as literacy and income levels, and various behavioral practices.

Relative disease risk for an exposure factor is calculated using the formula:

$$\rho = p_e / p_u$$

where p_e = number of exposed people with disease/total number exposed and p_u = number of unexposed people with disease/total number unexposed (Collett 1992).

Logistic regression analysis provides a calculation of the odds ratio (OR), which is the odds of disease in exposed people divided by the odds of disease in unexposed people. Closely related to relative risk, OR provides another measure of the association between disease outcome and an exposure factor. OR is calculated by the formula:

$$\psi = \frac{p_e/(1-p_e)}{p_u/(1-p_u)}$$

OR is also represented by the formula:

$$\psi = \frac{n_{11}/n_{12}}{n_{21}/n_{22}}$$

where n_{11} = number of exposed people with disease, n_{12} = number of exposed people without disease, n_{21} = number of unexposed people with disease, and n_{22} = number of unexposed people without disease.

Where the denominator is equal to zero because of no cases of disease existing among unexposed people, an estimate of OR is made possible by adding 0.5 to each number or cell of a 2 × 2 contingency table (Fleiss 1986). The formula for OR is modified as follows:

$$\psi = \frac{(n_{11}+0.5)/(n_{12}+0.5)}{(n_{21}+0.5)/(n_{22}+0.5)}$$

Results

Ganges river water quality in Varanasi

Scatter plots of water parameter test data for the years 1993–2004 were plotted for the Tulsi Ghat monitoring site (BOD and FCC data are shown in Figures 2 and 3, respectively; other graphs are not shown due to limited relevance to the water-borne disease study). One feature readily identified in these graphs is a periodicity in the data. For example, an annual cycle is noted for water temperature values that coincides with seasonal weather cycles, with water temperatures peaking in the summer months and reaching their lowest values during winter months. For the BOD in Figure 2, and FCC in Figure 3 (and for the pH, TDS, and DO–data not shown), a common periodicity is revealed with low values for all these parameter measurements generally occurring during late July through mid-September after the monsoon rains and associated flooding have commenced.

As can be seen in Figures 4 and 5, and in the summary data in Table I, average BOD and FCC values are much higher at the confluence of the Varuna and Ganges Rivers, with average

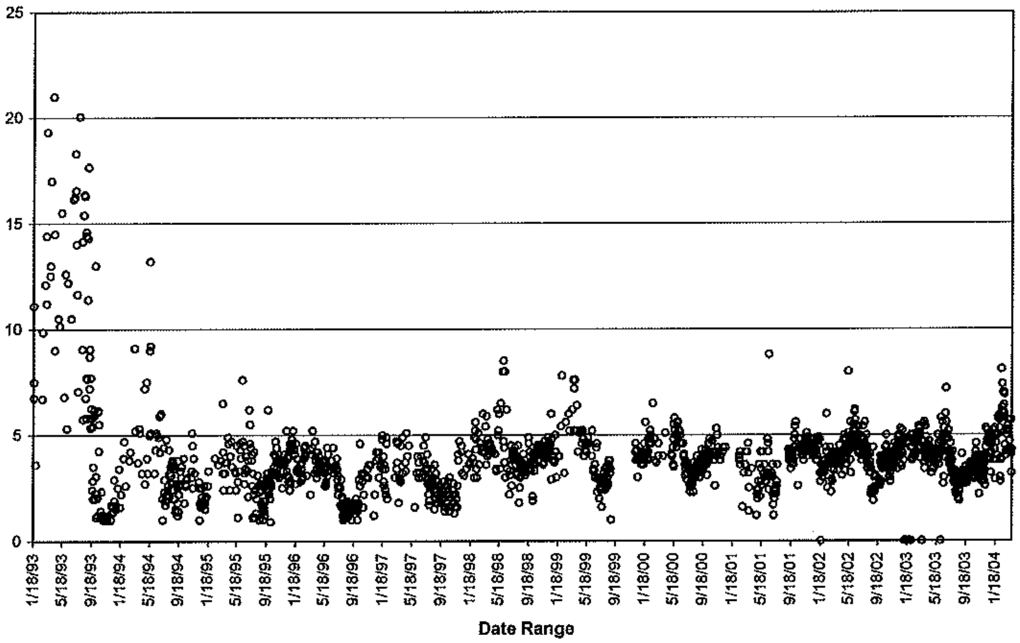

Figure 2. Biological oxygen demand measurements, Tulsi Ghat, 1993–2004.

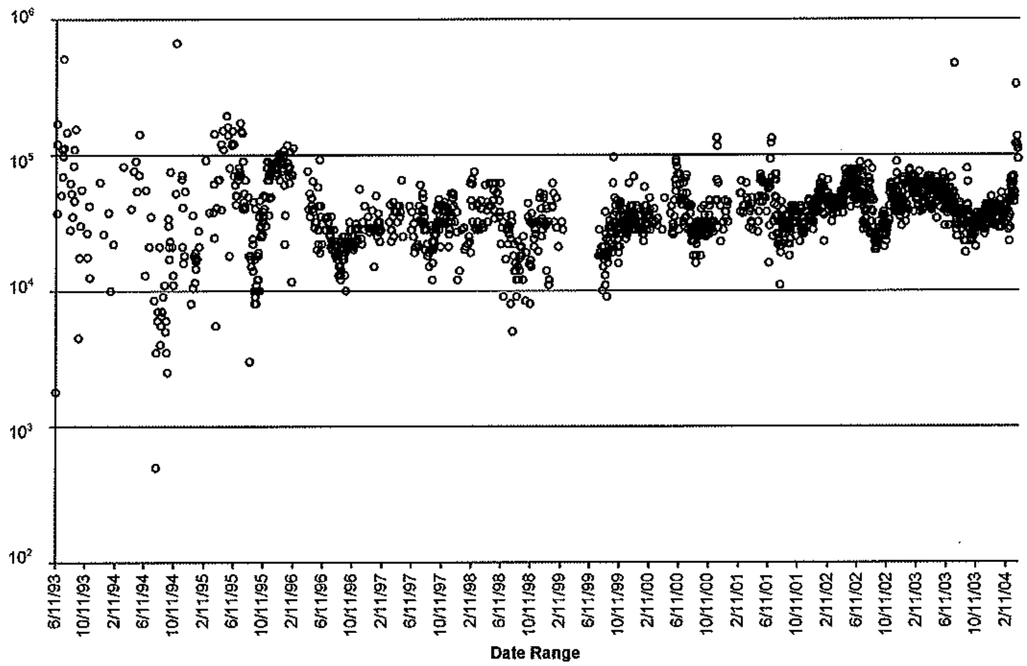

Figure 3. Faecal coliform count measurements, Tulsi Ghat, 1993–2004.

BOD for the Varuna-Ganges site (41.6 mg/l) being 10 times higher than at Tulsi Ghat (3.9 mg/l), and the average FCC at the Varuna-Ganges site (2.0×10^7 MPN per 100 ml) being three orders of magnitude greater than at Tulsi Ghat (4.2×10^4 MPN per 100 ml). Results of water testing for all health survey sites performed on April 16, 2004 (Table II) also indicated a generally high level of sewage pollution of the Ganges River in Varanasi.

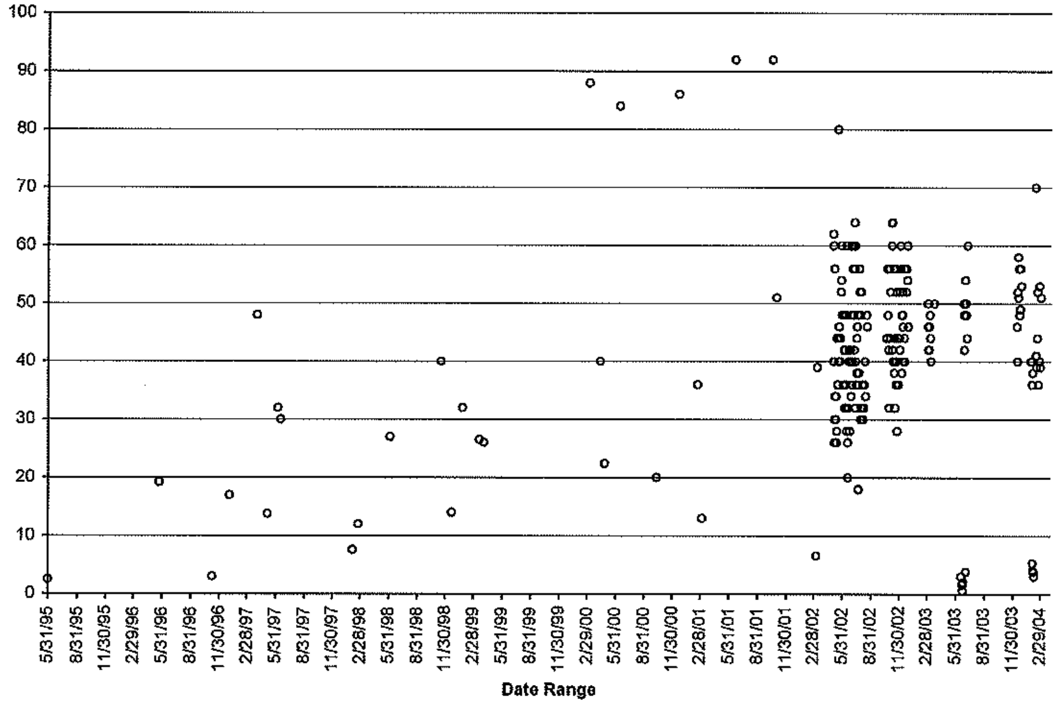

Figure 4. Biological oxygen demand measurements, Varuna-Ganges confluence, 1995–2004.

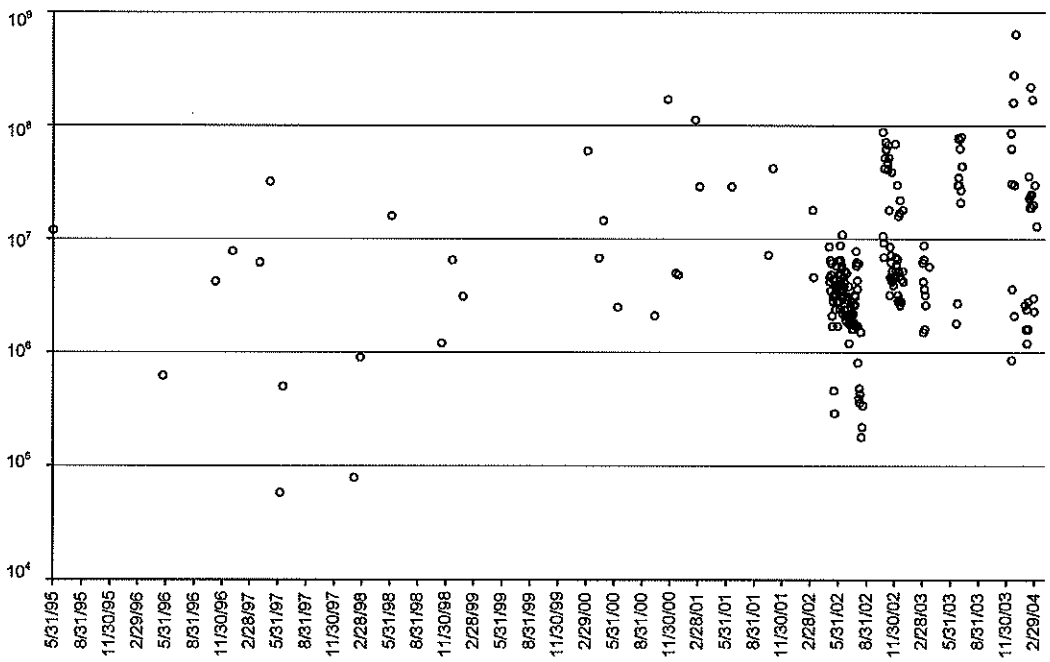

Figure 5. Faecal coliform count measurements, Varuna-Ganges confluence, 1995–2004.

Health survey results

Data for the 104 family heads interviewed, representing a total of 636 family members, and numbers reported to be affected with various water-borne/enteric diseases are summarized in

Table I. Water quality parameter measurements for the Ganges River sampled at Tulsi Ghat and the Varuna-Ganges confluence (values given are the arithmetic means with standard deviations in parentheses for all data gathered 1993–2004 at Tulsi Ghat and for 1995–2004 for the Varuna-Ganges confluence).

Parameter	Tulsi Ghat	Varuna-Ganges confluence
Water temperature (°C)	25.3 (3.8)	25.3 (4.3)
Total dissolved solids (mg/l)	200 (75)	358 (74)
pH	7.9 (0.4)	8.0 (0.2)
Turbidity (NTU)	318 (421)	105 (123)
Dissolved oxygen (mg/l)	6.8 (1.4)	5.1 (1.4)
Biological oxygen demand (mg/l)	3.9 (2.0)	41.6 (16.0)
Faecal coliform count (per 100 ml)	4.2×10^4 (3.2×10^4)	2.0×10^7 (5.5×10^7)

Table II. Water quality parameter measurements for Ganges River sites, April 16, 2004; sampling and testing for the river sites of Gola Ghat and Sarai Mohana were performed on this date after several cases of cholera were identified at these residential areas.

Parameter	Tulsi Ghat	Dashaswamedh Ghat (Rajendra Prasad)	Gola Ghat	Varuna-Ganges Confluence	Sarai Mohana
Water temperature (°C)	30	30	30.5	30.5	30.5
Total dissolved solids (mg/l)	350	380	350	350	360
pH	8.1	8.0	8.0	7.8	8.0
Turbidity (NTU)	48	29	19	38	89
Dissolved oxygen (mg/l)	5.3	4.9	5.6	4.3	3.4
Biological oxygen demand (mg/l)	9.0	6.4	4.3	64	32
Faecal coliform count (per 100 ml)	6.2×10^5	1.2×10^6	4.2×10^4	6.4×10^8	6.2×10^5

Table III and Figure 6. Residents of both Gola Ghat and Sarai Mohana had more than double the incidence of total water-borne/enteric disease and of AGI and about double the incidence of dysentery during the previous 12 months before the interviews were conducted than did local residents using the Ganges River at Tulsi and Dashaswamedh Ghats. Several cases of cholera and deaths from cholera (Table III) were reported in both Gola Ghat and Sarai Mohana, but not among resident users at the other two ghats. In Table III, cholera cases in which the patient survived are reported for the 12-month period preceding the interview as is reported for the other diseases. All cholera deaths reported during the interviews are included in a separate row in Table III. Cholera deaths were reported to have occurred as recently as two months before and as long ago as seven years before the survey, indicating the long-term persistence of this disease in these neighborhoods. No deaths from any of the other water-borne or enteric diseases being screened for were reported.

Survey data that showed strong associations with disease outcome when later tested by logistic regression analysis are summarized by survey site in Tables IV to VII. Summaries of monthly salary figures (Table IV) and education levels for all families interviewed (Table V) are suggestive of a lower standard of living for the residents of Gola Ghat and Sarai Mohana compared to resident users of the other two ghat areas. United Nations (http://www.un.org/millenniumgoals/) and World Bank (http://ddp-ext.worldbank.org/ext/MDG/gdmis.do) documents define "extreme poverty" as an individual subsisting on less than $1 US per day. A study specific to India (Dhongde 2003) cites a poverty line figure of 454 rupees per month below which an individual would be considered to live in poverty. Based on either of

Table III. Water-borne disease incidence at four locations on the Ganges River in Varanasi – survey conducted March to April 2004.

Number	Tulsi Ghat	Dashaswamedh Ghat	Gola Ghat	Sarai Mohana
Total families	25	25	29	25
Living family members	178	136	174	148
Any water-borne/enteric disease	68 (38%)	50 (37%)	147 (84%)	137 (93%)
AGI cases	68 (38%)	41 (30%)	140 (80%)	134 (91%)
Cholera cases	0	0	14 (8%)	19 (13%)
Cholera deaths	0	0	7	6
Dysentery cases	28 (16%)	31 (23%)	97 (56%)	50 (34%)
Hepatitis A cases	0	3 (2%)	4 (2%)	2 (1%)
Typhoid cases	0	1 (1%)	2 (1%)	0

Percentage values represent number of people afflicted with a given disease during the previous 12 months out of total living family members. Cholera deaths occurred as recently as 2 months before the survey up to 7 years before the survey. Data for cholera deaths is included to highlight the importance and long-term impact of this disease. No deaths were reported due to any of the other diseases surveyed for. AGI was defined as any occurrence of the following symptoms, either diagnosed medically or undiagnosed: Diarrhoea, liquid stools with mucus and/or blood, intestinal or stomach pain and cramps, or any combination of such symptoms, which lasted for at least one day after being symptom-free for at least two weeks. Cases of cholera, dysentery, hepatitis A, and typhoid were only counted if medically diagnosed.

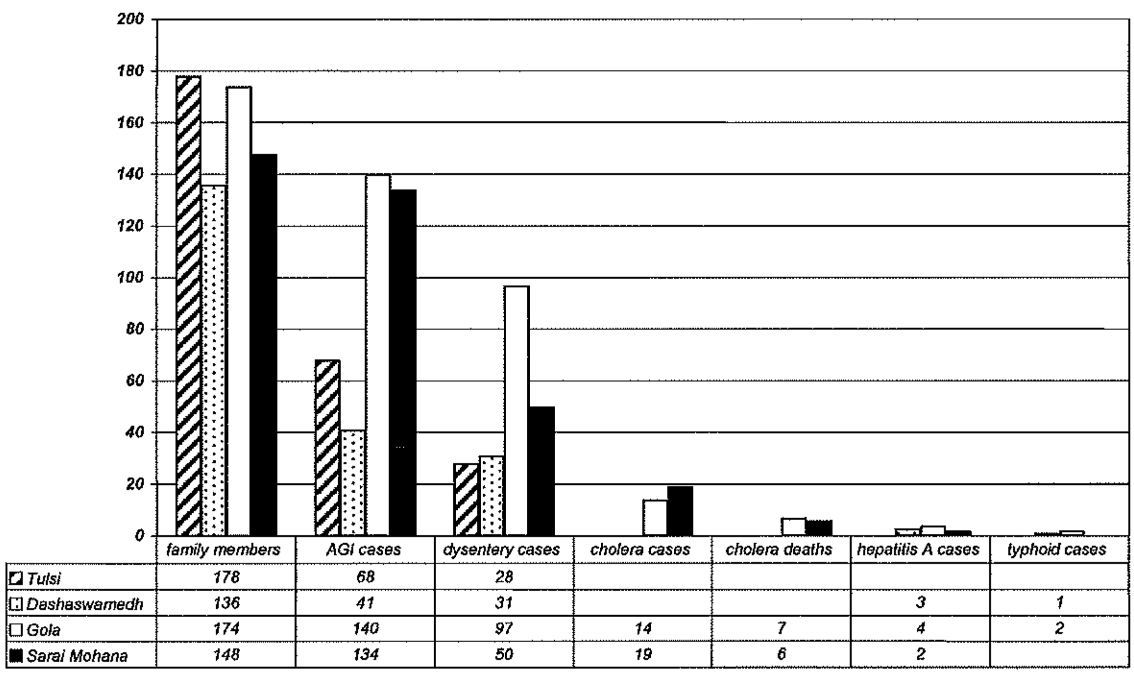

Figure 6. Water-borne disease incidence reported in the Varanasi neighborhoods of Tulsi Ghat, Dashaswamedh Ghat, Gola Ghat, and Sarai Mohana.

these figures, most of the families of Gola Ghat and Sarai Mohana are considered to be living in poverty.

Selected behavioral practices of respondents that might adversely affect personal or family health are summarized in Table VI. Table VII summarizes residential status regarding sewerage and water quality for each neighborhood. Water quality was scored as "bad" based

Table IV. Monthly income levels of families at four locations on the Ganges River in Varanasi. ($1 US = 47 Rupees in February 2004.)

Monthly income in Rupees	Tulsi Ghat	Dashaswamedh Ghat	Gola Ghat	Sarai Mohana
<1000	1	0	7	13
1001–3000	10	1	18	9
3001–5000	4	5	3	0
5001–7000	2	7	0	0
7001–9000	2	3	0	0
>9000	6	7	0	0
No response	0	2	1	3
Total families	25	25	29	25

United Nations/World Bank documents generally define anyone subsisting on less than $1 US per day as living in extreme poverty. A study by Dhongde (2003) cites a poverty line of 454 rupees per month for individuals living in urban areas of India such as Varanasi, a figure that is about one-third the United Nations value. By either of these definitions, families with two or more members with total income of less than 1000 rupees per month are considered to be living in poverty.

Table V. Education levels of families at four locations on the Ganges River in Varanasi.

Highest education level attained by household head(s)	Tulsi Ghat	Dashaswamedh Ghat	Gola Ghat	Sarai Mohana
Illiterate/no formal education	7	3	14	21
Primary	7	4	7	3
Matric (high school)	5	7	8	1
College graduate	4	5	0	0
Postgraduate	2	6	0	0
Total families	25	25	29	25

Table VI. Some behavioral practices of respondents which might affect health outcome of other family members.

Number of respondents who	Tulsi Ghat	Dashaswamedh Ghat	Gola Ghat	Sarai Mohana
Wash family clothing in Ganges River	10	0	28	24
Wash eating utensils in Ganges River	1	0	7	9
Clean eating utensils using mud	2	6	11	20
Total families	25	25	29	25

Table VII. Residential conditions which might directly affect health of all family members. Water quality was scored as "bad" based on responses that residential water was colored, smelled bad, tasted bad, or contained particle matter such as silt. In the Gola Ghat neighborhood, residents also noted that water obtained from a community well contained threadlike worms.

Residential conditions	Tulsi Ghat	Dashaswamedh Ghat	Gola Ghat	Sarai Mohana
No sewerage	0	0	9	25
Water quality is bad	14	12	27	20
Total residences	25	25	29	25

on responses that residential water was colored, smelled bad, tasted bad, contained particle matter such as silt, and in the Gola Ghat neighborhood, contained threadlike worms (not collected for speciation).

Logistic regression analysis

Binary logistic regression analysis was carried out to determine which independent variables were associated with disease outcome. Since data for exposure or risk factors was gathered from family heads and not from each member of a family individually, each member of a given family was deemed to share the same exposures as all other members of the family. Accordingly, in setting up logistic regression, the dependent variable of disease occurrence was expressed as the ratio of successes out of trials representing the occurrence of a given disease among members of each family. The results of binary logistic regression analysis are presented in Tables VIII to XI.

Only risk factors and their ORs with a lower limit of the 95% confidence interval (CI) greater than 2.0 are listed. Exposure factors associated with disease outcome included use of the Ganges River and its water for personal bathing, brushing teeth, washing of personal and family clothing, and washing dishes and kitchen utensils. OR values in the range of 3–5 were calculated for these exposure factors related to activity in the Ganges River. In the case of cholera incidence and its association with washing laundry or bathing in the Ganges River, an OR could not be calculated due to there having been no cases of cholera among families who did not wash laundry or bathe in the river (the formula for calculating OR would have a denominator value of zero in these cases). The 33 cases of cholera occurring in the previous year were exclusively in families who did wash laundry in the river or who bathed in the river, indicating a very strong association (see Tables XI, XII and XIII). Adding 0.5 to each cell in the 2 × 2 tables shown in Tables XII and XIII allows for calculations of ORs for these scenarios. The estimated ORs of 31 and 26 indicate strong associations between cholera and the exposure risks of washing laundry and bathing in the river.

Table VIII. Odds ratio calculations from binary logistic regression analysis for the outcome "any water-borne/enteric disease, family total".

Predictor	Odds Ratio	*p* value	95% CI lower–upper
No sewerage/no septic tank	13.37	<0.001	7.39–24.20
Children defecate outside home	12.75	<0.001	7.67–21.20
No bathroom or WC in home	9.46	<0.001	6.05–14.78
Worms in well water	7.92	<0.001	4.05–15.50
Monthly income <1000 Rupees	7.32	<0.001	3.31–16.17
Wash dishes/utensils in Ganges	5.05	<0.001	2.95–8.66
Monthly income <3000 Rupees	4.94	<0.001	3.48–7.01
Regular bathing in Ganges	4.72	<0.001	3.24–6.88
Children bathed outside home	4.66	<0.001	3.30–6.60
Utensils cleaned out on road	4.38	<0.001	2.05–9.38
Teeth brushed using Ganges water	4.21	<0.001	2.94–6.03
Utensils cleaned in front of home	3.13	<0.001	2.20–4.65
Utensils cleaned using mud	3.12	<0.001	2.14–4.55
Laundry washed in Ganges	3.02	<0.001	2.13–4.28
Wash hands using mud after using WC	2.93	<0.001	2.01–4.28
Illiterate head(s) of household	2.91	<0.001	2.05–4.13

Table IX. Odds ratio calculations from binary logistic regression analysis for the outcome "AGI, family total".

Predictor	Odds Ratio	p value	95% CI lower–upper
Children defecate outside home	10.68	<0.001	6.70–17.01
No sewerage/no septic tank	8.81	<0.001	5.35–14.51
No bathroom or WC in home	7.74	<0.001	5.12–11.70
Worms in well water	6.40	<0.001	3.50–11.69
Utensils cleaned out on road	4.82	<0.001	2.25–10.31
Children bathed outside home	4.72	<0.001	3.34–6.67
Monthly income <1000 Rupees	4.71	<0.001	2.44–9.09
Monthly income <3000 Rupees	4.59	<0.001	3.26–6.47
Regular bathing in Ganges	4.27	<0.001	2.94–6.22
Teeth brushed using Ganges water	3.76	<0.001	2.66–5.33
Wash dishes/utensils in Ganges	3.74	<0.001	2.31–6.07
Utensils cleaned using mud	3.06	<0.001	2.11–4.43
Utensils cleaned in front of home	2.99	<0.001	2.12–4.22
Laundry washed in Ganges	2.88	<0.001	2.04–4.07
Illiterate head(s) of household	2.87	<0.001	2.04–4.05

Table X. Odds ratio calculations from binary logistic regression analysis for the outcome "dysentery, family total".

Predictor	Odds Ratio	p value	95% CI lower–upper
Worms in well water	9.47	<0.001	5.96–15.05
Utensils cleaned out on road	8.25	<0.001	4.49–15.17
Residential water not always clean	4.45	<0.001	2.86–3.92
Regular bathing in Ganges	3.31	<0.001	2.09–5.24
Monthly income <3000 Rupees	2.91	<0.001	2.04–4.15

Table XI. Odds ratio calculations from binary logistic regression analysis for the outcome "cholera, family total".

Predictor	Odds Ratio	p value	95% CI lower–upper
Laundry washed in Ganges	31*	*	*
Regular bathing in Ganges	26*	*	*
No bathroom or WC in home	12.62	<0.001	4.38–36.37
No sewerage/no septic tank	8.30	<0.001	3.67–18.76
Monthly income <3000 Rupees	6.94	<0.001	2.41–19.99
Wash dishes/utensils in Ganges	4.56	<0.001	2.24–9.29
Monthly income <1000 Rupees	4.42	<0.001	2.08–9.38
Children defecate outside home	4.34	<0.001	2.03–9.28

*Odds ratio calculations for the exposure factors of washing laundry in the Ganges or bathing in the Ganges are not readily possible since no cases of cholera were identified in families not exposed to either of these factors. Since 33 cases of cholera were identified among family members who wash laundry in the Ganges or bathe in the river, the association between occurrence of cholera and these exposure risks is high. See Tables XII and XIII for additional information about these two risk factors and how OR calculations were made possible.

Other predictors directly related to lack of residential sewerage were also identified, including: lack of a sewer system or sewage disposal for the residence, lack of residential toilet, or children being sent outdoors to defecate due to lack of a residential toilet. OR values ranging from 8–14 were calculated for occurrence of all water-borne/enteric disease, AGI and cholera for exposure to these related risk indicators. Socio-economic indicators such as

Table XII. 2 × 2 contingency table showing incidence of cholera for those exposed and unexposed to washing laundry in the Ganges.

	Cases of cholera	Not diseased
Exposed to washing laundry in Ganges	33	412
Unexposed	0	191

An odds ratio cannot be calculated for this case due to the value of zero for cases of cholera in the unexposed population. If 0.5 is added to each cell in the table to allow for computation, an odds ratio of 31 is obtained.

Table XIII. 2 × 2 contingency table showing incidence of cholera for those exposed and unexposed to bathing in the Ganges.

	Cases of cholera	Not diseased
Exposed to regular bathing in Ganges	33	433
Unexposed	0	170

An odds ratio cannot be calculated for this case due to the value of zero for cases of cholera in the unexposed population. If 0.5 is added to each cell in the table to allow for computation, an odds ratio of 26 is obtained.

low monthly income and illiteracy among household heads also showed association with disease outcome.

As a follow-up to logistic regression analysis, relative disease risks for cholera, AGI, and all water-borne/enteric diseases were calculated for people lacking residential sewerage (Table XIV). For cholera, a relative risk value of 7.35 was calculated for exposure risk of "no sewerage" which is in close accord with the OR value of 8.30 obtained by binary logistic regression analysis. Relative risk values of 1.87 and 1.85 were calculated for AGI and all water-borne/enteric disease respectively for exposure risk of "no sewerage."

Discussion

According to a government report (Ministry of Environment and Forest, Government of India, Annual Report 2002–2003), the goals of GAP phase 1 were to improve the water quality of the Ganges River so that BOD would not exceed 3 mg/l and FCC would not exceed 2,500 MPN per 100 ml. According to this same report, the National River Conservation Directorate (NRDC) of the Government of India adopted standards in the year 2000 for "river water quality bathing class" rivers such as the Ganges of a maximum permissible FCC level of 2500 MPN per 100 ml, but a "desirable" level of no more than 500 MPN per 100 ml. The NRDC standards adopted in 2000 also include a maximum permissible level of BOD in treated wastewater of 30 mg/l.

Sargaonkar and Deshpande (2003) have reviewed water quality criteria and standards adopted by various international agencies, including the European Community (EC) and the WHO, and compared them with standards adopted by the Central Pollution Control Board in India in an attempt to create a general classification scheme for surface water quality in India. Under their proposed classification, BOD levels greater than 24 mg/l or total coliform count greater than 10,000 MPN/100 ml are indicative of heavily polluted water. The EC standards include a maximum admissible level of BOD of 6 mg/l for recreational use and a maximum admissible level total coliform count of 10,000 MPN/100 ml (or 2,000 MPN/100 ml for faecal coliform) for bathing waters.

Table XIV. Calculations of relative disease risk for cholera, AGI, or any water-borne/enteric disease surveyed for with exposure to "no sewerage" at residence.

25 people with cholera, exposed to "no sewerage" 190 people total, exposed to "no sewerage"	$25/190 = 0.1316 = p_e$ (incidence rate of cholera for those exposed to "no sewerage")	$\rho = p_e/p_u = 7.35$ (relative disease risk for cholera with exposure to "no sewerage")
8 people with cholera, unexposed 446 people total, unexposed	$8/446 = 0.0179 = p_u$ (incidence rate of cholera for those unexposed)	
170 people with AGI, exposed to "no sewerage" 190 people total, exposed to "no sewerage"	$170/190 = 0.8947 = p_e$ (incidence rate of AGI for those exposed to "no sewerage")	$\rho = p_e/p_u = 1.87$ (relative disease risk for AGI with exposure to "no sewerage")
213 people with AGI, unexposed 446 people total, unexposed	$211/446 = 0.4776 = p_u$ (incidence rate of AGI for those unexposed)	
177 people with water-borne/enteric disease, exposed to "no sewerage" 190 people total, exposed to "no sewerage"	$177/190 = 0.9316 = p_e$ (incidence rate of water-borne/enteric disease for those exposed to "no sewerage")	$\rho = p_e/p_u = 1.85$ (relative disease risk for all water-borne/enteric diseases surveyed for with exposure to "no sewerage")
225 people with water-borne/enteric disease, unexposed 446 people total, unexposed	$225/446 = 0.5045 = p_u$ (incidence rate of water-borne/enteric disease for those unexposed)	

Water quality testing performed by the SGRL over the past 12 years has shown that the Ganges River in Varanasi is seriously polluted. Average BOD levels in excess of 40 mg/l and average FCC levels in excess of 10^7 MPN/100 ml for the most polluted parts of the Ganges River, and especially around its confluence with the Varuna River, greatly exceed water quality standards adopted by either international or Indian government agencies. Untreated human waste continues to flow into the river at more than 2 dozen discharge points despite a great expenditure of money and resources by the Indian government under its Ganga Action Plan to collect and divert sewage from entering the river.

A seasonal decrease in FCC levels for the Ganges River in Varanasi was noted to occur during the monsoon rains. Minimum flow rates of about 120 meters per second occur during the dry season. During the monsoon season, flow rates increase to about 40,000 cubic meters per second. Monsoon flooding greatly increases the volume of water flowing in the Ganges River, diluting the amount of sewage and the number of sewage-associated faecal coliform bacteria present in the river. Unfortunately, as noted earlier, the annual monsoon floods cause problems with the sewage treatment system in Varanasi. Flooding of sump pumps forces the sewage pump system, including the pump station at Gola Ghat, to be closed down. Several residents of Gola Ghat also noted that the sewers present in their neighborhood become flooded during monsoon and release raw sewage directly into the footpaths and walkways surrounding their homes.

Sewage pollution of the Ganges River in Varanasi is not an isolated case; cities both large and small lying along the entire length of the river face similar sewage pollution issues. For example, Bilgrami and Kumar (1998) tested Ganges River water at multiple sites in Bhagalpur, a city of about 400,000 residents in north-east India where untreated waste is also released into the river. They found high concentrations of faecal streptococci (up to 4,450 MPN/100 ml), *E. coli* (up to 3.15×10^5 MPN/100 ml) and *Clostridium perfringens* (up to 3.5×10^4 MPN/100 ml) in the river. Other microbes identified in their study and posing a significant health risk included species of *Salmonella* and *Shigella*.

This pilot study demonstrates a very high incidence of water-borne disease among residents of Varanasi who rely on the Ganges River for a variety of daily needs and activities. Depending on the survey site, total water-borne disease incidence over the past year was determined to range from almost 40% upwards to over 90%, with an overall incidence of 66% (Table III). The high incidence of disease identified in Varanasi is similar to that established during a study in Hyderabad in 1996 (Mohanty et al. 2002) where community incidence rates for water-borne enteric disease were found to be some 200-fold higher than estimates calculated from hospital surveillance data. Even these high incidence rates established through survey are likely to underestimate the true incidence of disease due to recall bias.

A consideration of population immunity and susceptibility is relevant to the incidence of water-borne disease seen in Varanasi or Hyderabad, or to any population in the developing world. Residents of Varanasi are likely to be exposed to a greater variety of water-borne bacterial and viral pathogens than are people in more economically developed countries. As a result, they might be expected to develop a relatively strong immunity to water-borne disease agents. However, residents of Varanasi or Hyderabad still show a relatively high incidence of water-borne disease, presumably due to persistent exposure to a greater variety of water-borne disease agents, and because of exposure to a number of other factors including environmental pollutants and malnutrition which would render them more susceptible to disease (Ford & Colwell 1996).

Logistic regression analysis indicates that personal use of the Ganges River including washing laundry and kitchen utensils, brushing teeth, and bathing in the river have strong associations with disease outcome. Activity in the river can be expected to expose users directly to bacteria and infectious agents present due to the regular and widespread discharge of untreated sewage into the river. Users in turn carry home washed clothing and utensils which are an exposure risk for other family members. Users of the Ganges may become sick with water-borne disease and in turn transmit the disease to other family members living in close quarters.

Logistic regression analysis also indicated that variables such as lack of residential sewerage and toilets, children having to defecate outside due to lack of residential sewerage and toilets, well water visibly contaminated with worms (in Gola Ghat), socio-economic indicators such as very low wages and lack of education, and poor residential water quality are predictors for water-borne disease.

Relative disease risk was also calculated for the exposure risk of "no sewerage" as a predictor for cholera, AGI, and all water-borne/enteric disease. Since the incidence of cholera was low among residents having access to sewerage, the calculated values for relative disease risk (7.35) and OR (8.30) would be expected to be close, which was found to be the case. The relative disease risk values calculated for AGI (1.87) and all water-borne/enteric disease (1.85) are much lower than their related OR values of 8.81 and 13.37, respectively. This is to be expected since the background incidence rates were already high among those who did have access to sewerage (48% for AGI and 50% for all water-borne/enteric disease) and could only double at most. Accordingly, the relative risk values for AGI and all water-borne/enteric disease are quite significant for disease outcome among residents lacking sewerage.

It should be noted that the results of logistic regression analysis or calculation of relative risk for a given exposure factor do not establish a cause-and-effect relationship between risk factors and disease, but do identify an association between the dependent variable (health outcome) and the predictors (exposure or risk factors) such as activity in the Ganges River or lack of sewerage.

In describing the statistical associations between various risk factors and disease outcome, and in identifying specific risk factors such as personal use of the Ganges River, lack of sewer connections or septic tanks, lack of toilet facilities, and behavioral practices related to lack of bathrooms and toilets in the home, it cannot be stressed too highly how closely related all of these factors are to each other and to the overriding theme of sewage contamination. To conclude that one of these factors is a stronger predictor than another risks ignoring the interrelatedness of all of these factors.

The original aim of the health survey was to focus on how residents of Varanasi use the Ganges River and to estimate the incidence of specific enteric diseases that could be transmitted by river water. These goals were formulated in recognition of the highly polluted status of the Ganges River and the important role that the river plays in the daily life of many residents of the city. In carrying out the survey, data was also gathered on the sanitation status of residents' home living conditions. The data collected clearly indicate that lack of sewerage and toilet facilities and resultant behavioral practices such as children defecating outdoors contribute to the occurrence of enteric disease. It is readily acknowledged that the water-borne diseases surveyed for are not generally specific to water (Ford 1999). Clearly, a faecal-oral mode of disease transmission and person-to-person transmission are contributing to the occurrence of disease identified in this study. Reflecting the primary goals with which the study was undertaken, "water-borne/enteric disease" is referred to with the understanding that other modes of transmission are contributing to disease occurrence.

Behavioral practices related to use of the Ganges River such as cleaning laundry in, bathing in and drinking from the river are all factors that may account for the high background incidence of water-borne/enteric disease even among those residents who do have sewage connections in their homes and who enjoy a relatively high standard of living in Varanasi.

Resident users of the river interviewed at Tulsi Ghat and Dashaswamedh Ghat were better educated, better off in terms of average monthly income and typically reported having sewer connections at their homes. These residents still had an overall incidence of water-borne disease of 37–38%. This rate of disease more than doubled among residents of the Gola Ghat and Sarai Mohana neighborhoods where in addition to regular use of the river, residents were also likely to lack sewerage and toilet facilities in their homes.

In the two very poor neighborhoods of Gola Ghat and Sarai Mohana, additional risks could be identified. The neighborhood of Gola Ghat has a well that was constructed in early 2002, operated by hand pump, which is a primary water supply for many of the residents interviewed. Nineteen out of 29 family heads interviewed reported that water from this well regularly contained threadlike worms. This exposure factor showed a strong association with occurrence of water-borne disease and more specifically AGI and dysentery. Residents continue to use this well water since their only alternative would be to collect water from the nearby Ganges River or to obtain and carry water from a piped source further away from their residential area. In addition to having limited access to piped water treated at the city's water treatment plant, residents of Gola Ghat live close to a major sewage pump station that is reported to have leaking sewer pipe connections and that is currently the site of major construction and renovation of sewer lines.

Residents of Sarai Mohana lack both sewerage and any piped (treated) water supply. Residents generally reported using water from hand pump-operated bore wells drilled in their neighborhood. Water from these pumps was reported to be of poor quality; that is, the water smelled bad and was often colored. It is quite possible that these wells draw from a water table that is itself contaminated by the section of the Ganges River having the highest level of sewage-related pollution. In speaking with a local social worker about simple measures that could be taken to improve water safety for local residents, the principal author was told that residents of Sarai Mohana are too poor to be able to use wood, a scarce and expensive commodity, for boiling water, and are too overwhelmed with a sense of hopelessness from living in extreme poverty that they cannot even think of filtering water through inexpensive sari cloth. This simple and inexpensive practice of filtering water through cloth is used by many in India to remove aggregates of plankton harboring cholera bacteria from river water before the water is used for drinking or for cooking. A recent study (Colwell et al. 2003) has shown that incidence of cholera can be reduced by about one-half through using such a simple filtration procedure.

If the neighborhoods of Gola Ghat and Sarai Mohana are representative of other poorer sections of the city, the residents of Varanasi neighborhoods characterized by lack of sewerage, limited or no access to municipal water supply, low income level, and low education level appear to be most at risk for water-borne disease. In this study, the overall rates of water-borne disease were 84% and 93% in Gola Ghat and Sarai Mohana, respectively, compared to overall rates of 37–38% among the relatively more affluent residents interviewed at Tulsi Ghat and Dashaswamedh Ghat, whose homes had toilets and access to sewerage. Due to the relative lack of bathrooms, toilets, and sewerage compared to residents of Tulsi and Dashaswamedh Ghats, the poorer residents of Gola Ghat and Sarai Mohana depend on the polluted Ganges River itself as a source of water for routine bathing and personal hygiene, and the washing of laundry and utensils.

Conclusion

This study's compilation of over 10 years' worth of water quality data collected by the SGRL reveals the high level of sewage pollution of the Ganges River in Varanasi. The health survey demonstrates strong association between personal use of the Ganges River in Varanasi with water-borne disease incidence. A number of factors closely related to river pollution and linked to the problem of sewage contamination are also shown to be strong predictors for water-borne disease. Identification of these interrelated factors provides the basis for a more comprehensive study of risk factors related to water-borne disease and water quality in Varanasi.

This study should suggest to public health and government planners the crucial importance of alleviating pollution of the Ganges River by providing adequate collection and treatment of sewage for all residents of Varanasi to break the cycle of sewage contamination and water-borne diseases. Interim measures that might be considered for reduction of river-related disease occurrence include the banning of bathing or washing laundry. Such measures are unlikely to be popular or enforceable due to the important role of the Ganges River in the religious life of India (many residents and pilgrims perform religious bathing and wash personal clothing at the same time), and due to there being no readily available alternative sources of water for many of the poorest residents of Varanasi living near the river who depend on river water for daily needs. In the very poorest neighborhoods of Varanasi, the interim provision of community toilets might prove effective in reducing faecal-oral transmission of enteric disease provided that residents could be persuaded to use such facilities and that the waste could be treated on-site or transported for treatment.

In Varanasi, if the cycle of water-borne disease is to be prevented and if the Ganges River is to be restored to an unpolluted condition, effective city-wide collection and treatment of sewage is essential.

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