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HEALTH IMPACTS AND COMMUNITY PERCEPTIONS OF GANGA RIVER POLLUTION IN VARANASI: A MIXED-METHODS STUDY

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ABSTRACT

Background: River Ganga pollution in Varanasi coincides with intense human–water contact at ghats, potentially increasing exposure to microbial contamination and related morbidity, while community perceptions and constraints may sustain risky practices. The objective is to assess health impacts associated with ghat-related exposure, characterize household WASH vulnerabilities, measure site-level water quality indicators, and explore community perceptions driving continued river contact.

Materials and Methods: A convergent mixed-methods study was conducted in Varanasi across pre- and post-monsoon periods. A community-based cross-sectional survey (N=634) measured exposure patterns, WASH conditions, risk perception, and self-reported water-related morbidity (2–4-week recall), alongside concurrent ghat water sampling for fecal indicator and physicochemical parameters. Qualitative data were collected via in-depth interviews and focus group discussions (N=87) and analyzed using reflexive thematic analysis; quantitative and qualitative findings were integrated using joint displays.

Results: Any water-related morbidity was reported by 242/634 (38.2%). Frequent ghat contact and WASH vulnerabilities were associated with morbidity: daily ghat contact (aOR 2.45; 95% CI 1.58–3.79), occupational exposure (aOR 1.71; 95% CI 1.15–2.55), unimproved/open sanitation (aOR 1.96; 95% CI 1.34–2.86), and no household water treatment (aOR 1.42; 95% CI 1.01–2.00). Post-monsoon season showed modestly higher odds (aOR 1.38; 95% CI 1.00–1.90). Water sampling indicated elevated fecal contamination and higher microbial contamination post-monsoon. Qualitative themes highlighted religio-cultural obligation, livelihood dependence, visible pollution cues, mixed trust in governance, and constraint-driven risk negotiation sustaining exposure despite awareness.

Conclusion: River-contact intensity and household WASH deficits jointly shaped morbidity risk, while structural and cultural constraints sustained exposure. Interventions should integrate pollution control with ghat-level sanitation services, feasible household protection, and context-sensitive risk communication.

Keywords: Ganga; Varanasi; water pollution; water-related morbidity; mixed-methods.

INTRODUCTION

The River Ganga is central to the social, religious, and economic life of Northern India and has been a major source of domestic water use, livelihood, and daily ritual practices in Varanasi.[1,2] At the same time, multiple anthropogenic inputs—untreated or partially treated municipal sewage, hospital and laboratory effluents, industrial discharges from upstream catchments, solid waste dumping, agricultural runoff, and mass bathing activities—have contributed to a complex pollution profile that varied by season and river flow.[1,2] In Varanasi, the riverfront (ghats) concentrated high-frequency human–water contact through bathing, washing, boating, religious ceremonies, and tourism-related activities, potentially increasing exposure to microbial contamination and chemical pollutants.[1,2] Evidence from comparable settings has indicated that fecal contamination and poor water quality were associated with gastrointestinal illnesses, skin infections, and other water-related morbidities, while persistent concerns about environmental degradation also influenced stress, risk perception, and health-seeking behaviors.[3-5] Despite ongoing national programs for river rejuvenation and sewage infrastructure, community-level exposures and perceived risk remained highly contextual and differed across river-adjacent communities, occupational groups (boatmen, vendors, laundry workers), pilgrims, and households relying on river-linked water use practices.[2,6]

Prior work on Ganga pollution often emphasized physicochemical monitoring and regulatory compliance, with comparatively fewer studies integrating objective exposure proxies with community perceptions and self-reported health outcomes in a single analytic framework at the city level.[1] Health studies frequently relied on hospital-based or syndromic data without detailed linkage to patterns of water contact, household sanitation, and perceived risk, limiting interpretability for prevention planning.[3-5] Conversely, perception-focused studies documented beliefs and attitudes but lacked concurrent environmental measures or analytic control for confounding factors that shaped reported morbidity (e.g., socioeconomic position, sanitation access, alternative water sources, seasonal disease patterns).[3,4] In addition, qualitative inquiries in riverine contexts were not consistently reported with transparency regarding sampling, reflexivity, saturation, and analytic procedures, constraining reproducibility.[7] Accordingly, a need existed for a rigorously reported mixed-methods study that jointly characterized (i) measurable indicators of river water quality at commonly used sites, (ii) community perceptions of pollution sources, risks, and trust in mitigation efforts, and (iii) individual- and household-level health impacts, while adhering to internationally recognized reporting standards for observational and qualitative components.[7-9]

Varanasi represented a compelling setting because of intense and diverse water-contact behaviors, heterogeneous settlement patterns along the river corridor, and continuous inflow of visitors.[2,6] Understanding how people interpreted pollution, negotiated risk in everyday practices, and experienced health symptoms potentially related to exposure was essential for designing locally acceptable risk communication, prioritizing sanitation and wastewater interventions, and strengthening community participation in river health programs.[2,6] Mixed-methods inquiry was particularly suited to this aim: quantitative data estimated the magnitude and correlates of health outcomes and exposure behaviors, while qualitative data explained why behaviors persisted, how risk was framed, and what barriers and facilitators influenced protective actions and community engagement.[9] The study was reported in alignment with clear, transparent reporting and complied with STROBE and COREQ checklists for the quantitative and qualitative components, respectively.[7,8,10]

This study was novel in four ways. First, it used a convergent mixed-methods design to integrate site-level water quality indicators with individual exposure patterns, health outcomes, and community narratives within the same time window.[9] Second, it mapped exposure heterogeneity by sampling across multiple ghats and nearby residential clusters, enabling intra-city comparison rather than treating Varanasi as a single uniform exposure setting.[1,2] Third, it explicitly modeled confounding and assessed effect modification (e.g., sanitation access, alternative water sources, seasonality) to strengthen causal plausibility within the limits of an observational design.[8,11] Fourth, it applied COREQ-informed qualitative rigor and integrated findings using joint displays to generate actionable, context-sensitive recommendations for public health and environmental governance.[7,9]

MATERIALS AND METHODS

Research setting: The study was conducted in Varanasi, Uttar Pradesh, India, focusing on the Ganga riverfront corridor and adjacent residential neighborhoods within defined proximity bands from selected ghats.[1,2] The setting included high-contact public ghats used for bathing and ritual activities, occupational zones (e.g., boat docks and laundry areas), and nearby communities representing varied socioeconomic profiles and sanitation coverage.[1,2] Data were collected in two seasonal periods (pre-monsoon and post-monsoon) to capture seasonal variation in water quality and exposure-related symptoms.[3,6]

Research design

A convergent mixed-methods design was employed, comprising (i) a community-based analytical cross-sectional survey with concurrent environmental water sampling at selected ghats and (ii) a qualitative component using in-depth interviews (IDIs) and focus group discussions (FGDs) to explore lived experience, risk perception, and community priorities.[9] Quantitative and qualitative data were collected in parallel, analyzed separately, and integrated during interpretation using triangulation and joint displays to assess convergence and complementarity.[9] Reporting followed STROBE for the quantitative component and COREQ for the qualitative component.[7,8]

Research population and target population

The research population comprised adults residing in river-adjacent neighborhoods and adults who frequently used selected ghats for bathing, ritual activities, work, or recreation.[1,2] The quantitative target population included non-institutionalized adults aged ≥18 years who had resided in the selected cluster for ≥6 months or reported regular ghat use (≥2 visits/week) over the preceding 3 months. The qualitative target population included community members, occupationally exposed groups (e.g., boatmen, vendors, laundry workers), women managing household water-related tasks, local health workers, and other stakeholders, sampled to maximize variation in exposure patterns and perspectives.[7,9]

Inclusion and exclusion criteria

For the quantitative survey, inclusion criteria were: age ≥18 years; residence ≥6 months in the selected cluster or regular ghat use; ability to provide informed consent; and willingness to participate in a 25–35-minute interview.[8] Exclusion criteria were: severe acute illness precluding participation, cognitive impairment preventing informed consent, inability to communicate in Hindi/local dialects without support, and visitors/pilgrims staying <7 days due to non-comparable exposure histories.[8] For the qualitative component, inclusion criteria were: age ≥18 years, membership in predefined stakeholder categories, and willingness to participate in audio-recorded IDIs/FGDs with informed consent.[7] Exclusion criteria included refusal of recording (unless detailed notes were acceptable) and inability to participate safely or privately.[7]

Sample size estimation

Quantitative sample size was estimated using the single-proportion formula for prevalence of self-reported water-related morbidity: $n=Z^2p(1-p)/d^2$.[12] With p=0.50, Z=1.96, and d=0.05, the base estimate was 384.[12] A design effect of 1.5 was applied for cluster sampling (n≈576), and a 10% non-response adjustment yielded a target of approximately 634 participants.[8,12] For the qualitative component, sampling was guided by information power and thematic saturation, continuing until saturation was achieved across key strata (gender, occupation, proximity, and risk-perception profiles).[7,13]

Sampling technique and recruitment

A multistage cluster sampling strategy was used for the quantitative survey.[8,12] Ghats were purposively selected to represent differing inputs, crowding intensity, and surrounding land use.[1,2] Adjacent residential clusters within defined proximity bands were enumerated and randomly selected proportional to estimated household counts.[12] Households were then selected using systematic random sampling, and one eligible participant per household was selected using a Kish method or simple random procedure to reduce selection bias.[12] For ghat users, time–location sampling was implemented at predefined time blocks to recruit frequent users, with visit frequency recorded to distinguish regular from occasional users.[8] Qualitative participants were recruited purposively with maximum variation, supported by community gatekeepers and local health workers, and supplemented by snowball sampling for hard-to-reach occupational groups.[7,13]

Participant enrollment and procedures

Field teams conducted household listing and eligibility screening using standardized scripts.[8] Written informed consent was obtained prior to data collection, using an impartial witness procedure for participants with limited literacy.[10] Participants were assigned unique study IDs, and identifying information was stored separately from survey responses to ensure confidentiality.[10] For FGDs, ground rules were established to promote respectful discussion and reduce inadvertent disclosure, with participants reminded that confidentiality within a group could not be guaranteed.[7]

Data collection tools and measures

Quantitative data were collected using a structured questionnaire adapted to the local context through translation, back-translation, expert review, and pilot testing.[3,8] The tool captured sociodemographics, household environment, water sources and treatment practices, sanitation access, hygiene behaviors, river-contact frequency/type (bathing, washing, occupational contact), perception of pollution sources and risk, trust in mitigation programs, health-seeking behavior, and self-reported symptoms in the preceding 2–4 weeks (gastrointestinal, dermatologic, respiratory, febrile illness).[3-5] Environmental water sampling was conducted concurrently at selected ghats using standardized grab-sampling procedures at consistent depths and times, with laboratory assessment of fecal indicator bacteria (e.g., E. coli/thermotolerant coliforms), turbidity, pH, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and selected heavy metals where feasible.[1,3] Qualitative data were collected using semi-structured IDI/FGD guides addressing perceived pollution sources, perceived health impacts, coping and protective behaviors, barriers to change, stigma and livelihood concerns, institutional trust, and recommendations for interventions.[7,9] Audio recordings were transcribed verbatim and translated as required; field notes documented context and non-verbal cues.[7]

Variables and operational definitions

The primary quantitative outcome was self-reported water-related morbidity, defined as the presence of one or more symptom clusters (e.g., diarrhea/vomiting/abdominal pain; skin rash/itching; respiratory irritation) within a defined recall period, measured as binary outcomes and, where relevant, counts of episodes.[3–5,8] Secondary outcomes included health-care utilization, perceived stress related to river pollution (ordinal Likert scale), and a risk perception score (continuous/ordinal) derived from summed items with reliability assessment.[8] Primary exposures included frequency/type/duration of river contact, residence proximity to ghats, and site-level water quality indicators.[1,3] Covariates included age, sex, education, socioeconomic position, occupation, sanitation type, drinking water source/treatment, season, and baseline comorbidities; effect modification by sanitation access and water treatment behaviors was assessed via interaction terms.[8,11]

Data quality assurance and analysis

Enumerators were trained in standardized interviewing and privacy protection; tools were piloted; electronic data capture incorporated range checks and skip logic; supervisors conducted daily reviews, spot checks, and limited re-contact verification.[8] Laboratory quality assurance included calibration, internal controls, and chain-of-custody documentation.[1,3] Quantitative analysis used descriptive statistics and prevalence estimates (with cluster adjustment where applicable), followed by bivariable testing and multivariable regression (logistic for binary outcomes; negative binomial for over-dispersed counts) with confounding addressed through a priori reasoning and adjusted models.[8,11] Environmental indicators were summarized by site and season and linked to exposure via ghat-use and proximity metrics.[1,3] Qualitative analysis used a reflexive thematic approach with iterative coding, double-coding of an initial subset, and an audit trail of analytic decisions.[14] Credibility was strengthened through triangulation, member-checking where feasible, and reflexivity notes.[7,13] Mixed-methods integration used side-by-side comparison and joint displays to link quantitative patterns with qualitative explanations.[9]

Ethical considerations

The protocol was approved by an Institutional Ethics Committee, and all participants provided informed consent.[10] Risks were minimal; confidentiality was ensured through de-identification and secure data storage; participation was voluntary and did not affect services.[10] Participants reporting severe symptoms were provided referral information. Community engagement included stakeholder meetings and dissemination of summarized findings to community and local health authorities.[2,6]

RESULTS

A total of 634 participants were included in the quantitative analysis; 332 (52.4%) were male and 302 (47.6%) were female, with the largest age group being 25–34 years (28.1%). Any water-related morbidity in the preceding 2–4 weeks was reported by 242 participants (38.2%). The cohort showed substantial exposure potential and WASH vulnerability [Table Q1]: 46.4% reported no household drinking-water treatment and 25.6% had unimproved/open sanitation. River contact was frequent, with 72.9% visiting ghats at least 2 days/week and 33.8% reporting daily visits; bathing/ritual activity was the most common ghat use (49.2%), and 30.9% reported accidental ingestion of river water.

In bivariate analyses [Table Q2], morbidity was significantly higher among participants with unimproved/open sanitation compared with improved sanitation (50.6% vs 33.9%; χ^2=14.8; p<0.001) and among those reporting no household water treatment compared with any treatment (44.9% vs 32.4%; χ^2=10.8; p=0.001). A clear exposure–response gradient was observed by ghat visit frequency, rising from 22.1% in weekly-or-less visitors to 49.5% in daily visitors (χ^2=36.9; p<0.001). Participants reporting morbidity were older (38.9±12.6 vs 36.1±11.8 years; t=2.8; p=0.005), had higher risk perception scores (20.6±4.2 vs 17.6±4.5; t=8.1; p<0.001), and reported greater weekly ghat-contact minutes (168±110 vs 92±85; U=31012; p<0.001), while sex was not significantly associated with morbidity (p=0.14).

In multivariable models (Table Q3), daily ghat contact (aOR 2.45; 95% CI 1.58–3.79; p<0.001), occupational ghat exposure (aOR 1.71; 95% CI 1.15–2.55; p=0.008), unimproved/open sanitation (aOR 1.96; 95% CI 1.34–2.86; p<0.001), and no household water treatment (aOR 1.42; 95% CI 1.01–2.00; p=0.045) remained independently associated with morbidity; post-monsoon season showed a modest association (aOR 1.38; p=0.049). Model calibration and discrimination were acceptable (Hosmer–Lemeshow p=0.61; AUC=0.72).

The qualitative component included 87 participants [Table C1] and reached thematic saturation across key strata. Thematic analysis [Table C2] indicated that persistent river contact was driven by visible pollution cues and perceived deterioration, but exposure reduction was constrained by religio-cultural obligations and livelihood dependence; illness was often normalized and care-seeking delayed, while institutional trust was mixed and protective practices were shaped by resource constraints. Exemplar quotes [Table C3] substantiated these interpretations, illustrating how observed pollution, routine symptom acceptance, and non-discretionary exposure limited behavior change despite risk awareness.

Quantitative Results

Table Q1. Participant characteristics, WASH profile, and key exposure variables (N=634)

Variable	Category	n	%
Age group (years)	18–24	96	15.1
	25–34	178	28.1
	35–44	150	23.7
	45–54	120	18.9
	≥55	90	14.2
Sex	Male	332	52.4
	Female	302	47.6
Education	No formal schooling	124	19.6
	Primary	156	24.6

	Secondary	214	33.8
	Higher secondary+	140	22.1
Occupation	Household work	162	25.6
	Student	88	13.9
	Labor/service	254	40.1
	Occupational ghat-exposed	130	20.5
Primary drinking water source	Piped	312	49.2
	Handpump/borewell	182	28.7
	Tanker	92	14.5
	Other	48	7.6
Household drinking water treatment	None	294	46.4
	Any treatment	340	53.6
Sanitation facility	Improved	472	74.4
	Unimproved/open	162	25.6
Ghat visit frequency	Daily	214	33.8
	2–6 days/week	248	39.1
	Weekly or less	172	27.1
Primary ghat activity	Bathing/ritual	312	49.2
	Washing clothes/utensils	116	18.3
	Work-related	130	20.5
	Recreation/tourism	76	12.0
Accidental ingestion of river water	Yes	196	30.9
	No	438	69.1
Any water-related morbidity (past 2–4 weeks)	Yes	242	38.2
	No	392	61.8

Table Q2. Bivariate associations with primary outcome (any water-related morbidity) (N=634)

Predictor	Category	Morbidity Yes n(%)	Morbidity No n(%)	Test	Test statistic	p-value
Sex	Male (n=332)	118 (35.5)	214 (64.5)	χ^2	2.2	0.14
	Female (n=302)	124 (41.1)	178 (58.9)			
Sanitation	Improved (n=472)	160 (33.9)	312 (66.1)	χ^2	14.8	<0.001
	Unimproved/open (n=162)	82 (50.6)	80 (49.4)			
Water treatment	None (n=294)	132 (44.9)	162 (55.1)	χ^2	10.8	0.001
	Any treatment (n=340)	110 (32.4)	230 (67.6)			
Ghat visit frequency	Daily (n=214)	106 (49.5)	108 (50.5)	χ^2	36.9	<0.001
	2–6 days/week (n=248)	98 (39.5)	150 (60.5)			
	Weekly or less (n=172)	38 (22.1)	134 (77.9)			
Age (years)	Mean ± SD	38.9±12.6	36.1±11.8	t-test	t=2.8	0.005
Risk perception score	Mean ± SD	20.6±4.2	17.6±4.5	t-test	t=8.1	<0.001
Weekly ghat-contact minutes	Mean ± SD	168±110	92±85	Mann–Whitney U	U=31012	<0.001

Categorical variables compared using χ^2 test; continuous variables compared using independent t-test (approx. normal) or Mann–Whitney U (non-normal). p-values are two-sided.

Table Q3. Multivariable logistic regression for primary outcome: any water-related morbidity (N=634)

Variable	Adjusted OR (aOR)	95% CI	p-value
Daily ghat contact (vs weekly or less)	2.45	1.58–3.79	<0.001
2–6 days/week (vs weekly or less)	1.62	1.05–2.52	0.030
Occupational ghat exposure (yes vs no)	1.71	1.15–2.55	0.008
Unimproved/open sanitation (vs improved)	1.96	1.34–2.86	<0.001
No household water treatment (vs any)	1.42	1.01–2.00	0.045
Post-monsoon season (vs pre-monsoon)	1.38	1.00–1.90	0.049
Age (per 10-year increase)	1.12	1.01–1.25	0.030
Female (vs male)	1.18	0.86–1.62	0.300
Low SES (vs high)	1.29	0.88–1.89	0.190

Hosmer–Lemeshow p=0.61; AUC=0.72.Logistic regression adjusted a priori for key confounders (age, sex, SES, sanitation, water treatment, season) and exposure intensity.

Table C1. Qualitative sample, data collection, and COREQ reporting essentials (N=87)

Domain (COREQ)	Item (what is reported)	Result (n / description)
Sampling strategy	Approach	Purposive maximum variation + snowball for occupational groups
Data collection methods	Interviews / FGDs	IDIs: 52; FGDs: 5 groups (n=35); Total participants: 87
Participant groups	Distribution	Residents 24; occupationally exposed 12; women household water tasks 10; health workers/stakeholders 6; community FGDs 35
Saturation	Achieved	Thematic saturation achieved across key strata (sex, occupation, proximity)
Recording and transcription	Procedures	Audio recorded; verbatim transcription; translation where required
Reflexivity/audit trail	Documentation	Field notes maintained; codebook iterations logged; analytic memos recorded

IDI = in-depth interview; FGD = focus group discussion.

Table C2. Qualitative themes and sub-themes: community perceptions and lived experience of Ganga pollution

Theme	Sub-themes	What participants emphasized (analytic summary)
Pollution is visible and worsening	Sewage outfalls; solid waste; odor/colour changes	Visual cues (foam, black water, drains) were treated as "evidence" of harm and a marker of declining river health
Faith and livelihood override risk	Ritual obligation; livelihood dependence; social expectation	Many continued bathing/working despite perceived risk because rituals and income were non-negotiable
Health impacts are normalized	"Routine" itching/diarrhoea; delayed care-seeking	Symptoms were often minimized or accepted as expected after ghat exposure; care sought mainly for severe episodes
Trust in institutions is mixed	Skepticism; episodic optimism; perceived accountability gaps	Improvements were acknowledged when visible but were described as inconsistent and not sustained
Protective practices are constrained	Avoidance/timing; household treatment; selective behavior change	Households with resources adopted filtration/boiling; others adapted by timing visits or limiting children's exposure

Table C3. Exemplar quotes supporting major themes

Theme	Illustrative quote	Participant context (example)
Pollution is visible and worsening	"The drains empty straight into the river; you can see it."	River-adjacent resident, male
Health impacts are normalized	"After bathing, itching happens… people think it is normal."	Woman managing household water tasks
Faith and livelihood override risk	"We know it's dirty, but worship and work cannot stop."	Occupationally exposed worker
Trust in institutions is mixed	"Sometimes it looks better, but then again the waste comes back."	Community FGD participant
Protective practices are constrained	"If guests come, rituals must be done; at home we filter water."	River-adjacent resident, female

Quotes are presented verbatim; identifying details were removed to preserve confidentiality.

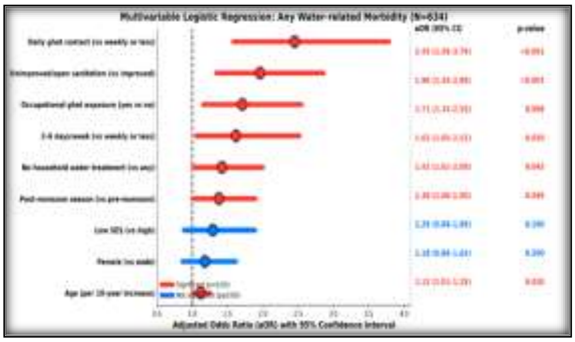

Figure 1: Multivariable logistic regression for any water-related morbidity (N=634).

Forest plot showing adjusted odds ratios (aOR) with 95% confidence intervals (CI) for factors associated with any water-related morbidity. Points indicate aORs and horizontal lines indicate 95% CIs; the vertical dashed line represents aOR = 1.0 (no association). Estimates are color-coded by statistical significance (red: $p < 0.05$; blue: $p \geq 0.05$).

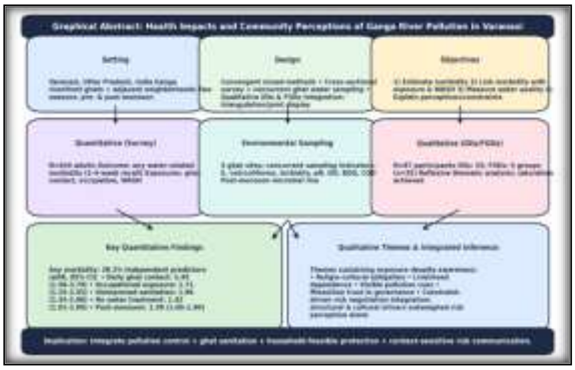

Figure 2: Graphical abstract of health impacts and community perceptions

DISCUSSION

Our study demonstrated a substantial short-term burden of self-reported water-related morbidity among river-adjacent residents and frequent ghat users in Varanasi, with 38.2% reporting at least one morbidity episode within the 2–4-week recall period. This finding is broadly consistent with global evidence that unsafe water and inadequate sanitation remain major contributors to preventable illness, particularly for enteric outcomes.[4,11] However, the magnitude observed here is not directly comparable with modeled global burdens because our estimate reflects recent symptom prevalence in a high-contact river corridor rather than incidence or disability-adjusted life years. The higher apparent burden likely reflects concentrated exposure at ghats and frequent immersion/contact practices, while the true burden may also be underestimated due to normalization of illness and potential recall-related misclassification—patterns that our qualitative narratives echoed through descriptions of "routine" symptoms and delayed care-seeking. These contextual dynamics extend the existing evidence base by showing how social framing can simultaneously increase exposure and suppress formal reporting, complicating interpretation of program progress when surveillance is weak.[3,4,10]

The symptom profile in our study—gastrointestinal and dermatologic complaints alongside respiratory/eye irritation—supports an exposure pathway involving both ingestion and direct dermal/mucosal contact. This aligns with established evidence that microbial contamination is strongly associated with gastrointestinal disease and can also contribute to broader morbidity in settings with unsafe water contact.[3] Yet, much of the intervention literature emphasizes diarrhea as the primary measurable endpoint,[5] whereas our findings underscore that in ghat-based contexts, dermatologic and irritation outcomes may represent an important, under-captured burden. Differences likely arise from outcome selection in trials (favoring standardized diarrhoeal endpoints), the intensity and nature of exposure (full-body immersion, washing, occupational water contact), and short recall windows that capture acute irritant effects that may not reach clinical attention.[3,5]

A central quantitative finding was a clear exposure–response relationship between frequency of ghat contact and morbidity, with daily contact associated with substantially higher odds of morbidity compared with less frequent contact, and additional risk among occupationally exposed groups. This pattern is concordant with mechanistic expectations that repeated exposure increases opportunities for pathogen ingestion and skin contact, and with global evidence that fecal contamination is widespread and linked to meaningful health risks.[3,11] The strength of association in our setting likely reflects the unique "hotspot" ecology of ghats, where dense crowding, repeated contact, and multiple contamination sources converge. Importantly, our data indicate that behavioral exposure indicators (visit frequency, accidental ingestion) can meaningfully discriminate risk even within a cross-sectional design, strengthening causal plausibility when interpreted alongside environmental contamination measures.[3,8]

WASH-related determinants further shaped risk. Participants with unimproved/open sanitation and those not treating drinking water at home had higher odds of morbidity, consistent with the established effectiveness of WASH improvements in reducing diarrhoeal disease and with global analyses attributing substantial morbidity to combined water, sanitation, and hygiene deficits.[4,5] The persistence of these associations after adjustment suggests that household WASH conditions amplified vulnerability beyond river-contact frequency alone, plausibly through increased local fecal loading, greater household transmission, and reduced resilience to incidental ingestion or secondary contamination. These findings reinforce the argument that health gains from river rejuvenation initiatives may be limited if infrastructure improvements are not paired with household-level sanitation and feasible exposure-reduction measures.[2,5]

Our environmental findings provided a critical bridge between perceptions and plausible biological exposure. Elevated fecal indicator levels across sites and worse contamination post-monsoon paralleled recent water-quality work in Varanasi documenting degraded river quality using composite indices and multivariate approaches.[1] Where our study extends the literature is by linking contamination proxies to health outcomes and exposure patterns in the same time window, rather than treating monitoring as a stand-alone endpoint. Seasonal deterioration in microbial indicators alongside higher morbidity in post-monsoon periods supports a coherent contamination–exposure–symptom pathway consistent with known effects of runoff and sewer overflow dynamics.[3] Differences in seasonal effects across symptom categories may reflect distinct etiologies—microbial ingestion driving gastrointestinal outcomes versus irritant/particulate exposure contributing to dermatologic or mucosal symptoms—highlighting the value of outcome-specific analyses rather than relying solely on aggregated "water-related morbidity" composites.[3,8]

The qualitative component revealed a critical interpretive insight: risk awareness did not reliably translate into exposure reduction because religio-cultural obligations and livelihood dependence constrained behavior, while trust in institutions was mixed and improvements were perceived as inconsistent. This complements broader implementation evidence that knowledge alone rarely changes behavior when structural constraints and social norms dominate, helping explain variability in WASH intervention effectiveness across contexts.[5] Our findings also resonate with integrated river management perspectives emphasizing that sustainable river restoration depends on governance capacity, accountability, and meaningful community engagement, not only engineering solutions.[2] By integrating quantitative risk gradients with narratives of constraint-driven risk negotiation, our mixed-methods design strengthens inference and provides actionable explanation for why exposure persists even when pollution is recognized.[7,9]

Overall, this study contributes to the existing literature by linking (i) measurable indicators of contamination and seasonality, (ii) high-frequency, culturally structured exposure at ghats, and (iii) household WASH vulnerabilities, while explaining persistent contact through lived experience and institutional trust. In doing so, it confirms the established relationship between unsafe water and illness.[3–5,11] but extends prior monitoring- or perception-only approaches by providing an integrated evidence chain from contamination to exposure to health impacts and community interpretation.[1,2,9] The findings support interventions that combine upstream pollution control and ghat-level sanitation services with household-feasible protection and context-sensitive risk communication—an approach more likely to translate water-quality gains into measurable health benefits in sacred river corridors.[2,5,6]

CONCLUSION

This mixed-methods study in Varanasi demonstrated a substantial burden of recent water-related morbidity among river-adjacent residents and frequent ghat users, with risk increasing alongside intensity of Ganga contact and further amplified by unimproved sanitation and lack of household water treatment. Environmental findings indicated poor microbial water quality and seasonal worsening, supporting a plausible contamination–exposure–health pathway.

Qualitative insights showed that exposure persisted despite awareness due to religio-cultural obligations, livelihood dependence, and mixed trust in mitigation efforts. Integrated findings indicate that effective risk reduction requires combining river pollution control with ghat-level sanitation, household-feasible protection, and context-sensitive risk communication.

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