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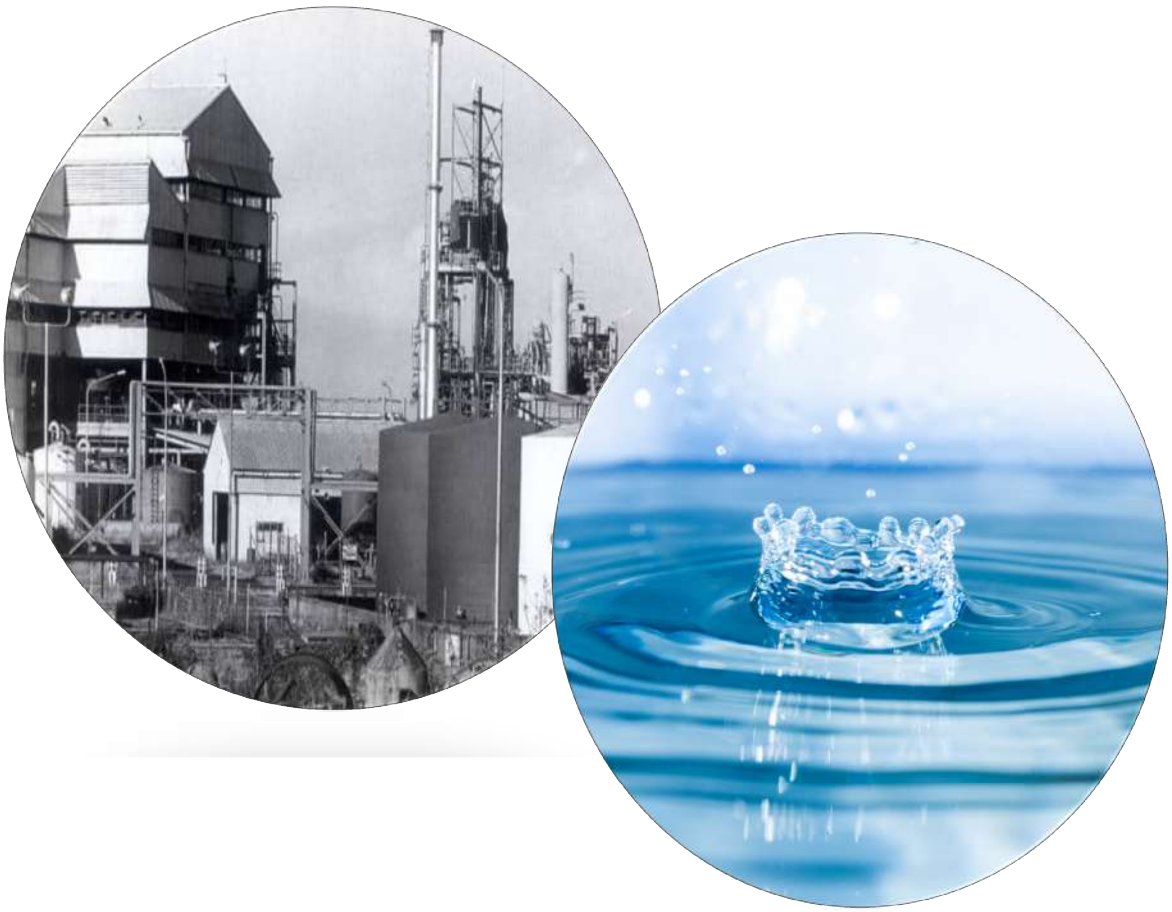

NATIONAL INSTITUTE FOR RESEARCH IN ENVIRONMENTAL HEALTH

BHOPAL BYPASS ROAD, BHAURI, BHOPAL-462030

www.nireh.org nirehbhopal@yahoo.in

A STUDY ON THE PREVALENCE OF MORBIDITY OF SELECTED POPULATION/FAMILIES WITH REFERENCE TO THE DRINKING WATER UTILIZATION

Prepared by

Dr Nalok Banerjee

Scientist C

National Institute for Research in Environmental Health
(Indian Council of Medical Research)
Kamla Nehru Hospital Building
Bhopal – 462 001

LIST OF CONTRIBUTORS

Principal Investigator	
Dr. Nalok Banerjee	Scientist C, NIREH, Bhopal
Advisors	
Dr. HR Rajmohan	Former Scientist G and Officer in charge, Regional Occupational Health Centre, Bengaluru
Dr. Anil Prakash	Director-in- Charge & Scientist G, NIREH, Bhopal
Dr. Yogesh Sabde	Scientist E, NIREH
Co-Investigator(s)	
Dr. Sushil Singh	Scientist C, NIREH, Bhopal
Mrs Moina Sharma	Scientist B, NIREH, Bhopal
Dr. K.K. Soni	Scientist B, NIREH, Bhopal
Dr. Ruma Galgalekar	Scientist B, NIREH, Bhopal
Field Coordinators	
Mr. Abdul Mateen Khan	Technical Assistant, NIREH, Bhopal
Dr. Vijay Singh Rathore	Technical Assistant, NIREH, Bhopal
Technical support	
Mr. Rajendra Pandey	Technician A, NIREH, Bhopal
Project staff	
Dr. Y. Venkatesh	Scientist- B (Medical), NIREH, Bhopal
Dr. Sujit Nigam	Scientist- B (Medical), NIREH, Bhopal
Dr. Shambhawi Tiwari	Scientist- B (Medical), NIREH, Bhopal
Mr. Aditya Banerjee	Research Assistant, NIREH, Bhopal
Ms. Tanvi Chincholkar	Research Assistant, NIREH, Bhopal
Ms. Priya Chitriv	Research Assistant, NIREH, Bhopal
Mr. Imran Khan	Data Entry Operator, NIREH, Bhopal

ABSTRACT

The leakage of mixture of toxic gases from the pesticide plant of Union Carbide India Limited (UCIL), Bhopal, in December, 1984, killed thousands of people and adversely affected health of about 0.5 million population exposed to gases. Subsequent closure of the factory gave rise to the issue of disposal of chemical waste dumped in the factory premises. This undisposed chemical waste generated concern in the community regarding likely chemical contamination of underground water being consumed by them causing adverse health effects, especially among those residing nearer to the factory premises. To address the issue of health effects, if any, which might have been caused due to long-term consumption of the allegedly contaminated underground water, a community-based epidemiological study was undertaken which aimed at determining prevalence of morbidities and their correlation with drinking water utilization pattern among the population residing at variable distances from UCIL factory premises. Information relevant to past and present water utilization pattern, present morbidities along with significant past medical history of 10,827 individuals residing at variable distances *viz*. 0-1 km radial distance from UCIL boundary (Stratum I) and 2.5-5.0 km radial distance from UCIL boundary (Stratum II) was collected. The most prevalent diseases reported in the surveyed population were hypertension and diabetes mellitus. Correlation of morbidities, likely to be caused due to the consumption of water contaminated with biological or chemical contaminants with various risk factors, revealed no significant association between the morbidities and distance from UCIL factory. Also, no significant association was seen between prevalent morbidities and drinking water consumption pattern. It was concluded that the communities, irrespective of distance of their residences from UCIL factory or source of their drinking water, were equally vulnerable to various morbidities.

INTRODUCTION

Following the Bhopal Gas Tragedy in the intervening night of 2/3 December, 1984 and consequent closure of Union Carbide India Limited (UCIL) factory, a large inventory of toxic chemicals remained inside the insecticide manufacturing plant and UCIL factory premises. The issue of the presence of residual toxic substances in the UCIL premises was raised by several quarters and it was feared that percolation of the toxic substances from the factory premises down the soil might have contaminated the underground water supply resulting in adverse health effects on the residents consuming the contaminated water, especially those living nearby to UCIL factory premises. The morbidities with reference to alleged ground water and soil contamination around UCIL factory premises remained an important environmental issue to be scientifically answered. Hence, this study was proposed with the following objectives-

OBJECTIVES

i) To study the prevalence of morbidities in the population with reference to the use of water sources for drinking purpose

ii) To correlate the morbidities in the study population with reference to the utilization of water sources for drinking purpose

REVIEW OF LITERATURE

2.1 *Water contamination and health effects*

Water is considered to be polluted/contaminated by the presence of any foreign substance (organic, inorganic, radiological and biological origin) in water which tend to degrade its quality so as to constitute hazard or impair the usefulness of the water (1). There are several factors such as rapid and haphazard urbanization, massive industrialization, agricultural runoff, social and religious practices of the communities etc. which work together and are responsible for deteriorating the overall quality of water. Water may commonly be contaminated by three main categories of pollutants *viz.* biological, chemicals and physical causing various health effects (Table-1).

Table 1: Various contaminants causing water pollution and their associated health effects

Type of contaminants	Sources	Health Effects
Biological Bacterial, Parasitic and Viral (*Clostridium botulinum, Campylobacter jejuni, Vibrio cholera, E.coli, Salmonella typhi, Giardia lamblia, Cryptosporidium parvum,* Hepatitis A, Rotavirus, Adenoviruses, Enteroviruses etc.) (2)(3)(4)	Domestic, Municipal, & Agriculture wastes	Diarrheal diseases (cholera, typhoid, paratyphoid, viral diarrhea), giardiasis, cryptosporidiosis, dehydration, constipation, nausea, stomach cramps, fatigue, Appetite loss etc.
Chemical Nitrate & Nitrites, Arsenic, Fluoride, Mercury, Phosphates, Lead, Poly-Chlorinated Biphenyls, Pesticides, Detergents, Cadmium, Dyes, Cyanides(3)(4)(5)	Domestic, Municipal, Commercial, Industrial & Agricultural wastes	Acute & chronic toxicity, neurological, respiratory & reproductive disorders, malignancies, CKD, liver & immunological dysfunctions, hypertension insomnia, death, other NCD's
Physical Suspended solid particles, dead carcasses etc. (3)	Domestic, Municipal, Commercial, Industrial & Agricultural wastes	Communicable and non-communicable diseases, low birth weight, congenital malformation

2.2 *Biological water contamination*

People in India are prone to water-borne diseases and outbreaks when they consume untreated surface and ground water for drinking and various household purposes. As per a

WHO report (6) cholera (caused by *Vibrio cholera* O1 and O139) was the most endemic amongst the population residing near the Ganga River followed by acute dysentery (*Shigella spp*). Kindhauser (2003) reported that incidence of typhoid and paratyphoid (caused by *Salmonella typhi and S. paratyphi*) has increased 10 times worldwide (7). All these pathogens are transmitted through faeces and urine and enter human body through oro-fecal route once the person comes in contact with the contaminated water. Legionnaire's disease has emerged as one of the potent water borne infection responsible for the recent water-borne outbreaks in developed nation (8). In India different strains of *Legionella* are resistant to chlorine, hence can grow in stagnant warm water bodies/biofilm resulting in aerosol which when inhaled target phagocyte cells causing Legionnaire's disease and Pontiac fever (9). Viral gastroenteritis occurs in two epidemiologic patterns, diarrhea that is endemic in children and outbreaks that affect people of all ages. Rotavirus represents 80% of the total viral etiology of diarrheal cases with 140 million cases of diarrhea per year worldwide (10). Lopman *et al* (2003) reported that Norovirus was responsible for >85% of all nonbacterial outbreaks of gastroenteritis during 1995- 2000 in Europe (11). These groups of viruses are generally transmitted by faecally contaminated food and water. Other waterborne non-diarrheal disease-causing viruses include Hepatitis A and E, Flavivirus, Enteroviruses (Polio) etc. (12, 13). In India, waterborne parasites include *Cryptosporidium parvum*, *Giardia lamblia* and *Entamoeba histolytica*. Studies in southern India in both hospital and community settings have reported Cryptosporidiosis as the commonest cause of parasitic diarrhea in children under the age of 3 years (14, 15). Amoebiasis is more common in the developing world people living in tropical areas with poor sanitation (16, 17).

2.3 *Chemical water contamination*

Many chemical water pollutants increase cancer risk. Exposure to these pollutants can occur by drinking contaminated water or bathing in it. One major chemical water pollutant that increases cancer risk comes from chlorination. An epidemiologic study by Cantor *et al* (2006) suggested that long-term exposure to disinfection by-products (trihalomethane, trichlorethylene) in drinking water increases the risk of bladder cancer and possibly colon, rectal and esophageal cancers though, precise dose-response relationship associated with increased cancer risk is unclear (18). Some of the strongest evidences for cancer risk associated with contaminated water involves heavy metals and arsenic. Recently, Cao *et al* in China (19) and Keshavarzi *et al* in Iran (20) reported higher incidence of esophageal cancer in association with higher concentration of methyl ethylamine, morpholine, N-methylbenzylamine, nitrate and chloride in water. According to Pandey and Singh (2015) traces of heavy metals (Cr, Pb, Ni, Co, Mn, Fe, Hg, Fl etc.) detected in Ganga river might be responsible for the large number of gall bladder cancer cases, especially among the Indian population settled on the Ganga river plains as reported in Indian National Cancer Registry Program (NCRP) report (21). Pandey (2006) suggested higher concentration of cadmium in Varanasi in the sewage, irrigation water in and around the Ganga river basin may have led to gall bladder cancer (22). Bánfalvi (2011) and Ercal et al. (2001) reported that arsenic, cadmium, chromium, and nickel leads to disruptions in tumor suppressor gene expression, damage repair process and metabolic enzymatic activities via oxidative damage (23, 24). Apart for the industries, another prominent source for heavy metal pollution in India is immersion of idols in rivers and ponds. Reddy et al. reported 26 elements including As, Cd, Cr, Ni, Pb, Cu. Fe, Mn, and Zn from both treated and un-treated sewage samples in significantly higher concentrations than the maximum permissible limits of national standards of drinking water, thus affecting the health of the population (25). Apart from carcinoma other symptoms of heavy metal exposure are anemia, diabetes and hypertension which are linked to drinking water contaminated with inorganic form of arsenic (iAs). As per Longnecker and Daniels (2001), higher intakes of arsenic and 2,3,7,8-tetrachlorodibenzo-p-dioxin were suggestive of a direct association with diabetes (26). Chronic exposure to chemicals affects pancreas through damaging insulin secreting β-cells leading to insufficient insulin secretion, possibly through increased oxidative stress. The exposure also affects the liver and interference with normal glucose metabolism leads to insufficient energy production. All these factors lead to diabetes mellitus in susceptible individuals (27). Likewise, studies have found that arsenic exposure increases the risk of developing hypertension. In Bangladesh a dose-effect relationship between levels of arsenic in drinking water and the prevalence of hypertension among the affected population was demonstrated (28). Dichloro-diphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCB's), bisphenol A (BPA), polybrominated diphenyl ethers (PBDE's) are known to be estrogenic disruptor compounds (29). It has been suggested that exposure to DDT *in utero* can increase a child's risk of childhood obesity, inhibits proper development of female reproductive organs that adversely affects reproduction in adulthood (30)(31)(32). Chloracne, a rare skin disorder, is resulted from environmental exposure of polychlorinated dibenzo-*p*-dioxins, and chlorinated azo- and azoxybenzenes which are the primary constituents of herbicides. *Para*-tertiary butyl phenol, *para*-tertiary butyl catechol, monobenzyl ether of hydroquinone, hydroquinone and related compounds have been implicated in certain cases of chemical leukoderma (33). Studies suggest that water contaminated with arsenic, alachlor, atrazine etc. for prolonged period of time can lead to chronic conjunctivitis (34, 35).

2.4 *Potable water supply system in Bhopal*

The majority of Bhopal's drinking water requirement is met by municipal sources drawing water from two surface water sources *viz*. the Upper Lake and the Kolar reservoir (36). More recently, Bhopal Municipal Corporation has augmented the Bhopal water supply from lotic source i.e. river Narmada in certain areas. Besides municipal piped water supply covering about 67% population, approx. 33% of the population in Bhopal depends on non-municipal ground water sources *viz.* 541 tube wells, 1295 hand pumps and 42 large dug wells (37). The municipal water supply is treated using conventional water treatment techniques, while the groundwater is used without any treatment. Unhygienic conditions near pipelines and groundwater sources, breakages and leakages in pipeline, flow of sewage in open unlined drains, disposal of solid waste in vicinity of water sources etc. are some of the known factors responsible for contamination of potable water (38, 39).

2.5 *Status of ground water contamination in Bhopal subsequent to gas tragedy*

One of the initial studies were conducted by National Environmental Engineering Research Institute (NEERI), Nagpur in 1990 to determine the extent of contamination in the area of UCIL solar evaporation ponds (SEPs) with reference to the presence of 22 chemicals, including methylene chloride, ortho-dichlorobenzene, carbon tetrachloride, carbaryl, alpha-naphthol and chloroform (40). NEERI after testing 93 wells in a 10-kilometer radius of SEPs, including 11 test wells and 82 public drinking wells, concluded that the water in all the wells was within drinking water standards and the soil within 2.5 km of the SEP was not chemically contaminated (40). Greenpeace Research Laboratory conducted similar studies in 1999, 2002 and 2004 focusing primarily on soil and drinking water, SEPs and the chemical stockpiles in the premises of UCIL. Soil samples collected from the plant site and in the vicinity of the formulation unit showed the presence of elevated levels of heavy metals *viz*. mercury, chromium, copper, nickel and organochlorines such as hexachloroethane, hexachlorobutadiene, hexachlorocyclohexane isomers

(HCH), DDT and chlorinated benzenes. Soil samples taken from SEP were found less contaminated. The water samples taken from wells located at the northern and southern boundaries of UCIL premises recorded very high concentrations of carbon tetrachloride (1.7 - 3.4 mg/L) and chloroform (0.1-2.59 mg/L), trichlorobenzenes (highest concentration being 180 µg/L) and dichlorobenzenes (highest concentration being 2.8 mg/L) (41, 42). The Greenpeace study concluded that large stockpiles of chemicals and unknown waste in UCIL premises contained toxic and persistent chemicals and though many chemicals were present at concentrations too low to show acute toxicity, they might pose a health threat to residents in the surrounding communities due to chronic exposure (43). Srishti (2000) reported the presence of chemicals (dichloromethane, chloroform, HCH isomers) and heavy metals (nickel, mercury, chromium) in soil, water samples and also in the breast milk. However, their sampling sites of soil and water were not clear (44). National Institute of Occupational Health (NIOH), Ahmedabad in 2005 analyzed blood, soil, and water samples for organochlorine pesticides (such as DDT and hexachlorocyclohexane 3 [HCH]), mercury and for volatile organic compounds (VOCs) in water. But for one soil sample from the plant site recording high value of mercury, the levels of mercury, DDT and HCH in water and soil samples were found comparable to other parts of the country whereas no discernible trend in the levels of pesticides in the blood samples with respect to the location of the residences of sampled subjects from UCIL plant and SEPs was found (45). Apprehensions were expressed that over a period the toxic materials dumped inside the factory premises and non-operational/unmaintained SEPs behind the factory premises might have seeped and leached in to the ground water and nearby water bodies affecting the health of those consuming the potentially polluted water in any form (46). Mishra *et al* conducted an epidemiological study to find out symptomatic morbidity status of the communities living around the SEPs behind UCIL boundary wall in the context of usage of allegedly polluted water due to the toxic waste (47). In this study though relatively, higher morbidities were seen in people above 24 years of age compared to those below 24 years yet no correlation of the morbidities with the alleged water contamination could be established. The study concluded that the possible contributing factor for higher morbidities in people above 24 years of age could be exposure to toxic gases at the time of accident besides some other unknown factors (47,48,49). In 2009, Centre for Science and Environment (CSE) concluded, based upon limited sampling, that the land within the UCIL factory campus and waste disposal site was highly contaminated with pesticides, chlorinated benzenes, and heavy metals. Although CSE found pesticides in the water samples broadly above the limits set by the Bureau of Indian Standards, carbaryl and aldicarb pesticides, likely to be associated with plant operations, were found in only four and one samples, respectively. The remaining contaminants (chlorinated benzenes and organochlorides) could have resulted from agricultural use (45). National Environmental Engineering Research Institute, Nagpur in 2010 suggested that due to the confined nature of the main aquifer around UCIL premises the chances of ground water contamination was minimal. Nevertheless, presence of contaminated water in several wells in and around UCIL premises suggested that the aquifer system in that area has hydraulic connectivity with the surface water and the main aquifer may be leaky (46). Kataria and Ambhore (50) and Kataria et al (51) studied the physio-chemical parameters of drinking water of Bhopal. They reported the chloride values ranging from 78.4-132 ppm, well below the desired limit of 250 mg/l and permissible limit of 1000 mg/l of ISI. Similarly the values for nitrate, sulphate, phosphate and fluoride were also well below the desirable limits ranging between 3.0-17.4, 34.8-92.4, 0.80-2.1 and 0.80-1.24 ppm respectively (50, 51). In 2012, CSIR-IITR conducted the study to evaluate the presence of heavy metals in groundwater and reported the concentration of lead as 0.023 µg/L, which is twice the permissible limit of 0.01 µg/L. It was suggested that though the pesticide contamination might be due to the past UCIL activities, the contamination resulting from agricultural usage of pesticides cannot be ruled out. It was also concluded that the presence of inorganics have no relation with past UCIL activities (52). In June 2013, Centre of Science and Environment presented an analysis of 15 studies conducted over the last 20 years to assess soil and groundwater contamination in and around UCIL. It was concluded that contaminants found were similar and could be linked to chemicals used and wastes generated by UCIL, however, there were variations in reports, submitted by national authorities, in the context of groundwater contamination in the surrounding area of UCIL (45).

MATERIAL AND METHODS

3.1 *Study Area*

As per 2011 Census Bhopal population is 2,371,061 (males 1,236,130, females 1,134,194). As of 2015, there are 85 municipal wards under Bhopal Municipal Corporation. For the purpose of study Bhopal municipal area was approximately divided in to 3 strata with respect to their distances from the UCIL factory i.e. area between 0-1 km radius, between 1.0 - 2.5 km radius and 2.5 – 5.0 km radius from UCIL factory. The study covered two strata i.e. Stratum I (area between 0-1 km radius having a population of 1,91,126 residing in 7 municipal wards) and Stratum II (area between 2.5-5.0 km radius with a population of 8,49,310 residing in 32 municipal wards) (Figure -1).

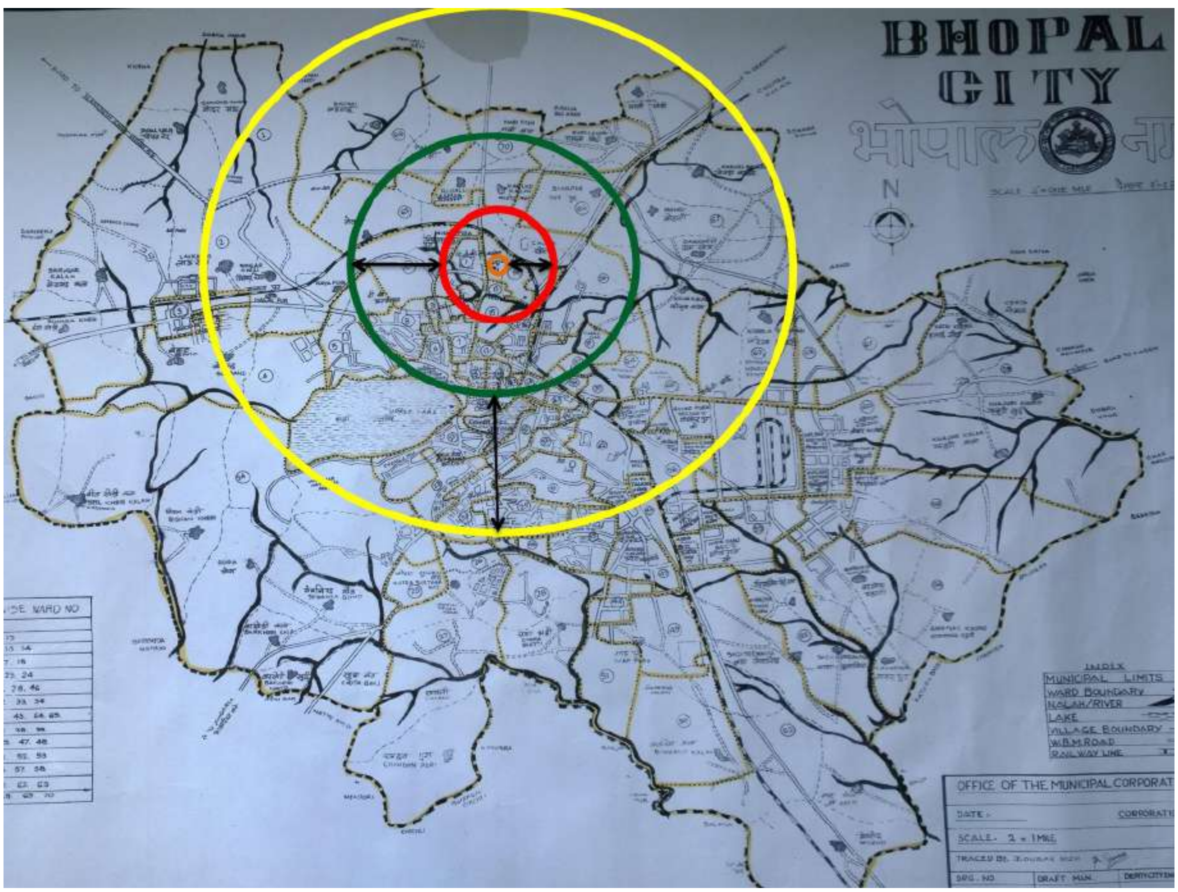

Figure-1: Map of Bhopal showing study areas (The area lying in between the orange circle (UCIL factory) and the red circle represents Stratum I. Similarly, the area between the green and the yellow circle represents Stratum II)

Ward numbers and their locations under the two study strata are shown in Figure 2.

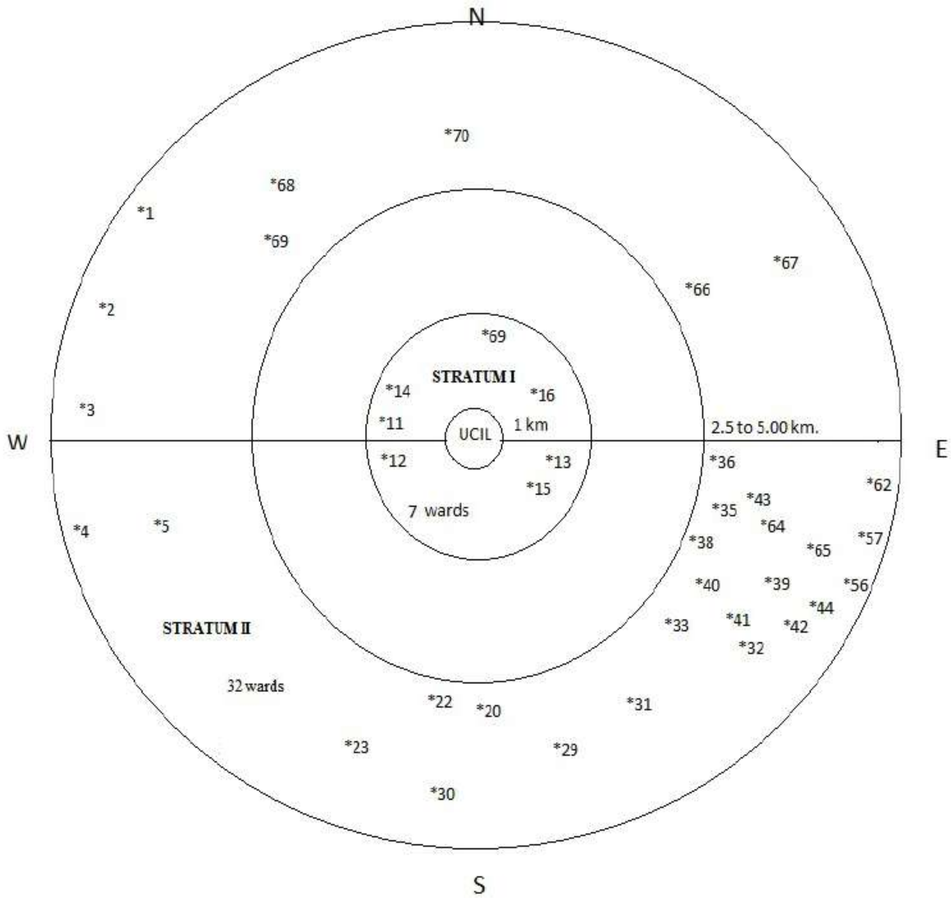

Figure-2: The study area (The three circles represent different strata marked around the UCIL factory. Target areas are labeled (Stratum I and II) with the approximate location of the municipal wards falling under these strata)

3.2 *Sample size*

The sample size was calculated based on stratified random sampling method as suggested by the Epidemiological Research Expert Group of NIREH. The sample size determination was based on 9.4% prevalence of morbidities in general population of Bhopal as recorded in 47th round of morbidity survey (July-December, 2013) under the Long-Term Population Based Epidemiological study of NIREH. For each stratum under the study, a sample of 1,092 families (comprising of about 5,460 individuals) was calculated which was sufficient to detect a difference of 2% points in the morbidity between two strata with 95% confidence and 90% power.

3.3 *Sampling frame*

The target number of families to be covered in each ward was calculated proportionately to the population of that ward (Table-2). All the wards falling under each stratum were covered in the study.

Table 2: Municipal ward-wise sample size

Sl. No.	Ward name & number	Population as per BMC	Sample size (no. of individuals) in each ward	No. of families to be covered in each ward
(a) Stratum I (wards falling in between 0-1 km radius from UCIL factory)				
1.	Geetanjali (11)	25322	723	145
2.	Shahjahanabad (12)	20253	579	116
3.	J.P. Nagar (13)	19438	555	111
4.	Motilal Nehru (14)	18531	529	106
5.	Ibrahimganj (15)	29476	842	168
6.	Ram Mandir (16)	22560	644	129
7.	Chhola (69)	55564	1587	317
	Total (7 wards)	**1,91,126**	**5,460**	**1,092**
(b) Stratum II (wards falling in between 2.5-5.0 km radius from UCIL factory)				
1.	Gandhi Nagar (01)	27615	178	36
2.	C.T.O. (02)	55451	356	71
3.	Hemu Colony (03)	23818	153	31
4.	Sadhu Baswani ward (04)	25563	164	33
5.	Kohe-fiza (05)	30403	195	39
6.	Moti Masjid (20)	21320	137	27
7.	Rani Kamlapati (22)	17994	116	23
8.	Vivekanand (23)	17094	110	22
9.	Shivaji ward (29)	17898	115	23
10.	Jawaher Lal Nehru (30)	23652	152	30
11.	Pt. M M Malviya (31)	26621	169	34
12.	R. Nath Tagore (32)	15832	102	20
13.	Jahangirabad (33)	13591	87	17
14.	Chandbad (35)	23161	149	30
15.	Kapda Mill ward (36)	31376	202	40
16.	Aish Bagh (38)	43623	280	56
17.	Bag Farhat Afza (39)	12815	82	16
18.	Maharani LaxmiBai (40)	12690	82	16
19.	Jinsi (41)	14019	90	18
20.	Maida Mill (42)	19792	126	25
21.	Netaji S. C. Bose (43)	23878	154	31
22.	M. Pratap ward (44)	10823	70	14
23.	Kasturba ward (56)	27093	174	35
24.	Barkheda ward (57)	16549	106	21
25.	Indrapuri ward (62)	44437	286	57
26.	Guru Nanak (64)	18813	121	24
27.	Punjabi Baag (65)	41067	264	53
28.	Rajiv Ward (66)	40882	263	52
29.	Damkheda ward (67)	27311	176	35
30.	Badwai ward (68)	12725	82	16
31.	Chhola ward (69)	55564	357	71
32.	Karond (70)	55840	354	71
	Total (32 wards)	**8,49,310**	**5,460**	**1,092**

Targeted number of families (n=1092 in each stratum) to achieve the calculated sample size were chosen randomly. The first family in each colony/ ward was selected randomly from the generated list of random numbers and thereafter in stratum I every 35th family was included till the samples size in that colony/ward was achieved. Likewise, in stratum II every 156th family, after random selection of the first family in each colony/ward, was included till the samples size in that colony/ward was achieved. In case of refusal for participation in the study by any family that household was dropped and next household was taken.

3.4 *Data collection*

The project team visited the field areas for collection of data on a daily basis (Figure-3). After identification of the household, as explained above, the family members were approached. The study was explained to them and a bilingual information sheet was provided for their record. After obtaining informed written consent a pretested structured questionnaire comprising of following sections was administered.

3.4.1 *Family proforma*: Details regarding the total no. of members in the family, religion, caste, type of house, availability of toilet, availability of kitchen, availability of electricity, type of cooking fuel used, presence of domestic animals and cattle shed, disposal of dung and urine etc. was obtained.

3.4.2 *Individual proforma*: General socio-demographic particulars such as age, sex, marital status, literacy status, education level, current employment, status of gas exposure and proof pertaining to it (obtained from those who willingly provided), alcohol and tobacco use habits, disability status etc. was recorded for each individual in the family.

3.4.3 *Water utilization pattern*: Details regarding both past and present source(s) of water with duration of use, any treatment of water prior to drinking and its storage practices were noted.

3.4.4 *Clinical examination*: A medico in the team clinically examined the available and willing family members at the time of visit. If any individual presented with any form of morbidity, the symptoms and duration of illness was noted and a diagnosis was made. Any abnormality found during the clinical examination was recorded as `Present morbidity'. In addition, record of any significant past morbidities/ illness (which may/ may not have resulted in hospitalisation) as recalled by the individual, was noted, along with the year and place of hospitalisation and termed as `Past morbidity'. This information on `past morbidity' was collected for all the surveyed individuals of the family, irrespective of their availability at the time of visit.

3.5 *Data entry and analysis*

After filling up of the complete questionnaire a unique family ID to the household and individual IDs to each member of the family were assigned. The completed forms were daily scrutinised and data was entered in a custom-made database using Microsoft Visual FoxPro 6.0.

Figure-3: Glimpses of the field work

Data was analyzed in STATA 10.0 software. Descriptive analysis was done to determine the profile of surveyed population and related aspects. Bivariate and multivariate analysis was done to establish correlation between the groups of morbidities likely related to biological and chemical water contamination and various risk factors. For the multivariate analysis, models in order to predict occurrence of the morbidities were generated by Multiple Logistic Regression (MLR) analysis of risk factors with the morbidity occurrence for significant adjusted p-values (first for $p<0.250$, followed by $p<0.005$).

RESULTS

A total of 2,184 families (10,827 individuals) were surveyed during the study. In stratum I (0-1 km from UCIL boundary), covering 7 Bhopal municipal wards, data was collected for 5,467 individuals (1,092 families) whereas in stratum II (2.5-5.0 km from UCIL boundary) 5,360 individuals (1,092 families), residing in 32 municipal wards were surveyed. The average family size was ~5 in both the strata.

4.1 *Socio-demographic characteristics*

The questionnaire administered recorded basic socio-demographic information and gas exposure status during 1984 Bhopal gas tragedy for all individuals in the surveyed families (Table-3). In stratum I, significantly more number of surveyed people (21.3%) were found exposed to gas than in stratum II (18.2%). There were more illiterates (16.1%) in stratum I than stratum II (8.7%), the difference being highly significant. Though the school level educated (primary, middle, and secondary levels) individuals were more in stratum I (65.1%), the number of college level educated individuals was higher (13.4% graduates) in the stratum II as compared to stratum I (7.3%).

Table-3: Socio-demographic profile of surveyed population

	Stratum I (n=5,467)	Stratum II (n=5,360)	Total (n=10,827)
Age Groups (in years)			
Up to 5	466 (8.5%)	473 (8.8%)	939 (8.7%)
6-15	1027 (18.8%)	943 (17.6%)	1970 (18.2%)
16-30	1886 (34.5%) ***	1640 (30.6%)	3526 (32.6%)
31-45	1160 (21.2%)	1177 (21.9%)	2337 (21.6%)
46-60	646 (11.8%)	750 (13.9%)***	1396 (12.9%)
>60	282 (5.2%)	377 (7.0%)***	659 (6.1%)
Gender			
Male	2800 (51.2%)	2735 (51.0%)	5535 (51.1%)
Female	2667 (48.8%)	2625 (49.0%)	5292 (48.9%)
Religion			
Hindu	3048 (55.8%)	3629 (67.7%)***	6677 (61.7%)
Muslim	2390 (43.7%)***	1596 (29.8%)	3986 (36.8%)
Others#	29 (0.5%)	135 (2.5%)***	164 (1.5%)
Caste			
General	3082 (56.4%)	3100 (57.8%)	6182 (57.1%)
Scheduled caste	318 (5.8%)	434 (8.1%)***	752 (6.9%)
Scheduled tribe	89 (1.6%)	172 (3.2%)***	261 (2.4%)
Other backward classes	1904 (34.8%)***	1596 (29.8%)	3500 (32.3%)
Do not know	74 (1.4%)	58 (1.1%)	132 (1.2%)

Gas exposure status			
Gas exposed	1167 (21.3%)***	973(18.2%)	2140 (19.8)
Not exposed	4300 (78.7%)	4387 (81.8%)***	8687 (80.2%)
Literacy status			
Age< 4 yrs	335 (6.1%)	311 (5.8%)	646 (6.0%)
Illiterate	880 (16.1%)***	468 (8.7%)	1348 (12.5%)
Literate	204 (3.7%)	256 (4.8%)***	460 (4.2%)
Primary	990 (18.1%)***	775 (14.5%)	1765 (16.3%)
Middle	1402 (25.6%)***	1150 (21.5%)	2552 (23.6%)
Secondary	1168 (21.4%)	1320 (24.6%)***	2488 (23%)
College	398 (7.3%)	720 (13.4%)***	1118 (10.3%)
Technical	90 (1.7%)	360 (6.7%)***	450 (4.2%)
Occupation			
Service	287 (5.2%)	566 (10.6%)***	853 (7.9%)
Agriculture	2 (0.04%)	9 (0.17 %)*	11 (0.1%)
Skilled labour	174 (3.2%)	155 (2.9%)	329 (3.0%)
Unskilled labour	764 (13.9%)***	468 (8.7%)	1232 (11.4%)
No occupation	3588 (65.6%)	3498 (65.3%)	7086 (65.5%)
Others	652 (11.9%)	664 (12.3%)	1316 (12.2%)
Duration of residence in the present location (in years)			
Up to 5	1682 (30.8%)	1739 (32.4%)	3421 (31.6%)
6-10	1027 (18.8%)	1146 (21.4%)***	2173 (20.1%)
11-15	781 (14.3%)	786 (14.7%)	1567 (14.5%)
16-20	763 (13.9%)***	625 (11.7%)	1388 (12.8%)
21-25	466 (8.5%)***	384 (7.2%)	850 (7.9%)
26-30	410 (7.5%)***	300 (5.6%)	710 (6.6%)
>30	338 (6.2%)	380 (7.1%)	718 (6.6%)

*p<0.05, **p<0.01,***p<0.001- based on Two-sample test of proportion (χ^2 test)

Include other religious groups such as Sikh, Christian, Jain, etc;

Occupation data revealed that “No occupation” was the biggest category (65.5%) with almost equal distribution in both the strata. This category included unemployed individuals, students, housewives, retired persons, and children below age of 4 years. In Stratum II, significantly higher number of people (10.6%) belonged to “Service” category as compared to stratum I (5.2%). On the other hand, the “unskilled labour” class people were significantly more (14%) in stratum I compared to stratum II (8.7%). This indicates that population in stratum I was relatively weak socio-economically than in stratum II.

In stratum I, 15.3% and in stratum II 12.7% of the surveyed subjects were addicted to tobacco and/ or drinking alcohol. These included individuals who chew tobacco on a regular basis (7.6% in stratum I and 5.5% in stratum II), followed by those smoking tobacco (3.8% in stratum I and 2.7% in stratum II). Less than 1% alcoholics were recorded in both the strata.

In stratum I, about 1% and in stratum II about 1.5% of the surveyed individuals were recorded with any disability. The various disabilities included partial/ complete blindness, partial/ complete deafness, disability due to paralytic conditions, old age, chronic diseases, polio and mental retardation.

4.2 *Housing characteristics*

Information on the type of house, availability of toilet, kitchen in the house, light source, presence of domestic animals etc was collected (Table-4). A majority of individuals (~90%) resided in pucca (well-built) house having access to toilet facilities (93.6%) with similar distribution in the two strata.

Table-4: Distribution of individuals based on housing characteristics

	Stratum I (n=5,467)	**Stratum II (n=5,360)**	**Total (n=10,827)**
Type of House			
Kutcha	479 (8.8%)	461 (8.6%)	940 (8.7%)
Pucca	4988 (91.2%)	4899 (91.4%)	9887 (91.3%)
Toilet Facility			
Present	5141 (94%)	4993 (93.1%)	10134 (93.6%)
Absent	326 (6%)	367 (6.9%)	693 (6.4%)
Type of cooking fuel used			
Electricity	162 (3%)***	69 (1.3%)	231 (2.1%)
LPG/ Natural gas	4278 (78.3%)	4728(88.2%)***	9006 (83.2%)
Biogas	0 (0.00%)	0 (0.00%)	0 (0.00%)
Kerosene	528 (9.7%)***	294 (5.5%)	822 (7.6%)
Coal/ lignite	9 (0.2%)***	0 (0.00%)	9 (0.1%)
Wood	462 (8.5%)***	249 (4.6%)	711 (6.6%)
Straw/ shrubs/ grass	10 (0.2%)	10 (0.2%)	20 (0.18%)
Agricultural crop waste	2 (0.04%)	3 (0.06%)	5 (0.05%)
Dung cakes	16 (0.3%)	7 (0.1%)	23 (0.21%)

*p<0.05, **p<0.01,***p<0.001- based on Two-sample test of proportion (χ^2 test)

Majority of the households had a separate kitchen (68.7% in stratum I and 77.2% in stratum II). Relatively higher number of households in stratum I (29.7%) had kitchens within the living rooms than the stratum II (21.4%). LPG was being used as the cooking fuel in majority of the houses (83.2%), though its usage was significantly higher in stratum II (88.2%) than stratum I (78.3%). Usage of coal, wood, kerosene as cooking medium was found significantly higher in stratum I.

4.3 *Drinking water utilisation pattern*

Sources of supply of drinking water in the study area were clubbed in two categories *viz.* Municipal and Non-municipal. The water supplied by Bhopal Municipal Corporation piped directly into households / yards or supplied through public taps or supplied through tankers in various localities has been put under "Municipal" category whereas water from sources such as bore wells, tube wells, dug wells, surface waters, etc. has been categorized as "Non municipal". The "Combined", category indicates water mixed and utilised from both Municipal and Non-municipal sources. The drinking water source found at the time of survey in the households has been recorded as the "Present source". For the majority i.e. 81% individuals in stratum I and 83.6% in stratum II municipal water was the present source of drinking water (Table-5) and the difference was significant. Source of drinking water used prior to the present source was recorded as the "Previous source".

Table-5: Water utilization pattern for drinking purpose

	Stratum I (n=5,467)	Stratum II (n=5,360)	Total (n=10,827)
Present Source#			
Municipal†	4422 (80.9%)	4480 (83.6%)***	8902 (82.2%)
Non-Municipal††	998 (18.3%)***	841 (15.7%)	1839 (17%)
Combined†††	47 (0.9%)	39 (0.7%)	86 (0.8%)
Previous Source			
Municipal†	3066 (56.1%)	3990 (74.4%)***	7056 (65.2%)
Non-Municipal††	2367 (43.3%)***	1347 (25.1%)	3714 (34.3%)
Combined†††	34 (0.6%)	23 (0.4%)	57 (0.5%)
Pre-treatment of Drinking Water			
Treated##	815 (14.9%)	1797 (33.5%)***	2612 (24.1%)
Not treated	4652 (85.1%)***	3563 (66.5%)	8215 (75.9%)

*p<0.05, **p<0.01,***p<0.001- based on Two-sample test of proportion (χ^2 test)

#Present Source refers to the source of water being utilized at the time of survey †**Municipal sources** include piped water, water tanker supply ††**Non-municipal sources** include bore well, tube well, dug well, streams, lakes, etc. †††**Combined Source** refers to mixing of water from municipal and non-municipal sources prior to use for drinking purpose; **## Treatment** include boiling of water, using candle based or membrane based filters, chemical treatment of water, or any other modern purification methods available

The change in drinking water source might be due to change in residences, time variation with respect to establishment of municipal water supply in different areas, and change in the primary source from which the water is piped. Previous source of municipal water for drinking purpose was significantly higher in stratum II (74.4%) as compared to stratum I (56.1%) individuals utilising it. On the other hand previous source of non-municipal water for drinking purpose was significantly higher in stratum I (43.3%) than stratum II (25.1%). In Stratum II significantly higher number of people (33.5%) used any kind of treatment such as boiling of water, using candle based or membrane based filters, chemical treatment of water, Ultraviolet (UV) exposure or reverse osmosis (RO) as compared to 14.9% people in stratum I.

4.4 *Morbidity patterns in the surveyed population*

Present/current morbidities in the study population were determined through clinical examination of the available and willing individuals in the surveyed families by a qualified doctor. About 85% individuals in targeted families under stratum I and 87% under stratum II were examined clinically for morbidities. Overall, 18.9% of individuals in each stratum were found to be presently suffering from one or more morbid condition / illness at the time of survey. In addition to the present morbidities, past history of significant morbidities (especially with reference to drinking water consumption), termed as `past morbidities', which may or may not have lead to hospitalisations, was recorded for all the individuals of the surveyed families (whether available or not available in the selected household during survey).

4.4.1 System wise morbidity pattern:

Various morbidities recorded in the surveyed population were clubbed under the following 17 systems *viz.* **cardiovascular system** (hypertension, ischemic heart diseases chronic/acute, other circulatory diseases); **respiratory system** (bronchitis/COPD, upper respiratory tract infection, pulmonary tuberculosis, other respiratory diseases); **GIT system** (gastric acute/chronic, hepatic diseases, typhoid/enteric diseases, diarrhoeal diseases, infective hepatitis, other GIT related diseases); **musculo-skeletal system** (arthritis, other musculoskeletal system related diseases); **ophthalmic system** (refractive error, cataract, other eye diseases); **auditory system** (ear related diseases); **skin and subcutaneous tissue** (eczema/dermatitis, other skin diseases) **neurological** (neurological diseases/disorders); **mental health** (anxiety, depression, neuritis, other mental disorders); **uro-genital system** (renal failure, renal stones/calculi, other uro-genital diseases);

obstetrics & gynaecological (gynaecological and obstetrics related diseases); **endocrine system** (thyroid related disorders, diabetes mellitus); **blood** (anaemia, other related diseases); **congenital anomalies** (congenital malformations, mental growth retardation etc.); **cancer/neoplasm** (neoplasm/cancer); **accidental injuries** (all accidental injuries) **others** (ill defined systems/diseases, other forms of tuberculosis, other infectious diseases, gout, other nutritional and metabolic disorders). System-wise `present' and `past' morbidities in the surveyed population is given in Table - 6. Frequency distribution shows that top 5 systems encompassing `present morbidities' in both the strata were cardiovascular, respiratory, gastrointestinal, musculoskeletal, and ophthalmic systems with cardiovascular morbidities occupying the top most position. Between the two strata, cardiovascular morbidities and endocrine related morbidities were significantly higher (p<0.01) in stratum II, whereas gastrointestinal tract morbidities (p<0.05), auditory system/ear related morbidities (p<0.01), neoplasm/cancers (p<0.01) and congenital morbidities (p<0.01) were significantly higher in stratum I. Prevalence of other present morbidities were comparable in the two strata (Figure-4).

Table-6: System wise morbidities recorded in the surveyed population

System	Present morbidities		Past morbidities	
	Stratum I (N=4,641)	Stratum II (N =4,665)	Stratum I (N=5,467)	Stratum II (N=5,360)
Cardiovascular	267 (5.75 %)	351(7.5%)**	110 (2.01%)	127 (2.37 %)
Respiratory	144 (3.10%)	130 (2.85%)	123 (2.25%)	122 (2.27%)
GIT	110 (2.37 %)*	78 (1.7%)	542 (9.91%)	497 (9.27 %)
Musculo-skeletal	177 (3.81%)	152 (3.26 %)	21 (0.38%)	21 (0.39%)
Eye	118 (2.54%)	120 (2.57 %)	58 (1.06%)	70 (1.31%)
Ear	22 (0.47%)**	5 (0.11%)	6 (0.11%)	5 (0.09%)
Skin	29 (0.63%)	36 (0.77%)	17 (0.31 %)	18 (0.34%)
Neurological	40 (0.86%)	36 (0.77%)	59 (1.07%)	56 (1.04%)
Mental health	11 (0.23 %)	12 (0.26%)	8 (0.15%)	9 (0.17%)
Genito-urinary	14 (0.30%)	15 (0.32%)	50 (0.91%)	57 (1.06%)
Gynecology & Obstetrics	15 (0.32%)	7 (0.15%)	41 (0.74%)	34 (0.63%)
Endocrine	130 (2.80%)	213(4.57)**	28 (0.51%)	34 (0.63%)
Blood	16 (0.35%)	15 (0.32%)	15 (0.27%)	13 (0.24%)
Congenital morbidities	12 (0.26%)**	2 (0.04%)	11 (0.20%)	12 (0.22 %)
Cancer/ neoplasms	12 (0.26%)**	2 (0.04%)	25 (0.45%)	19 (0.35%)
Accidental injuries	10 (0.21%)	3 (0.04%)	76 (1.39%)	87 (1.62%)
Others	49 (1.05 %)	28 (0.60%)	103 (1.88%)	121 (2.26 %)

*p<0.05, **p<0.01 - Two-sample test of proportion (χ^2 test)

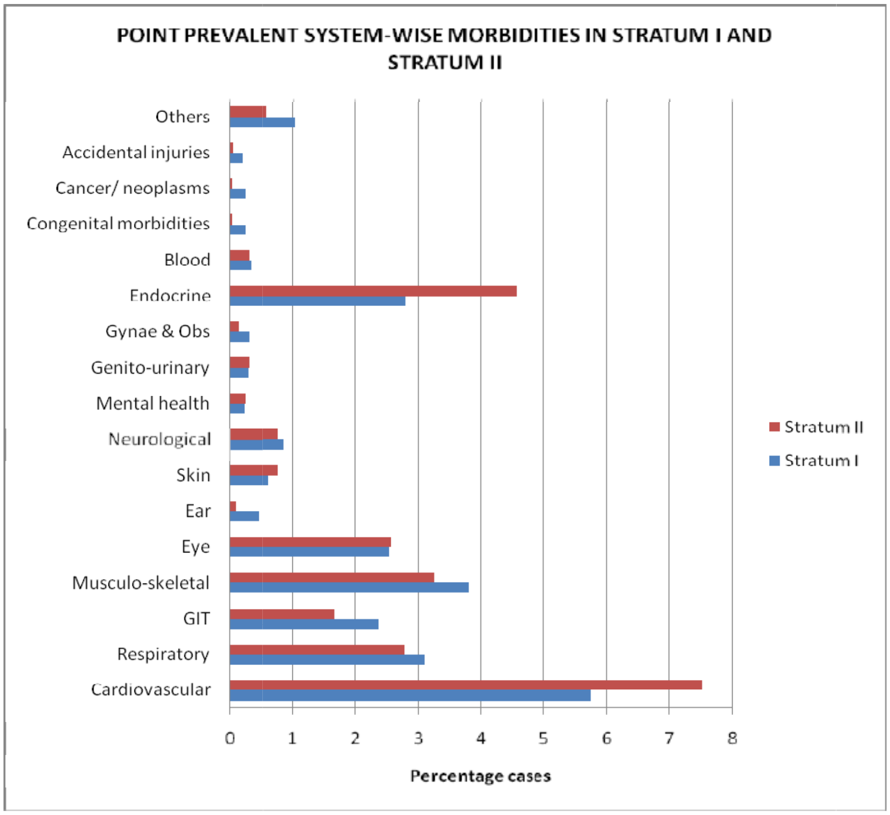

Figure-4: Present morbidities pattern in the surveyed population

Data on `past morbidities' revealed the highest prevalence of gastrointestinal tract related morbidities, followed by respiratory and cardiovascular morbidities in both the strata, with non- significant difference between the strata (Figure-5).

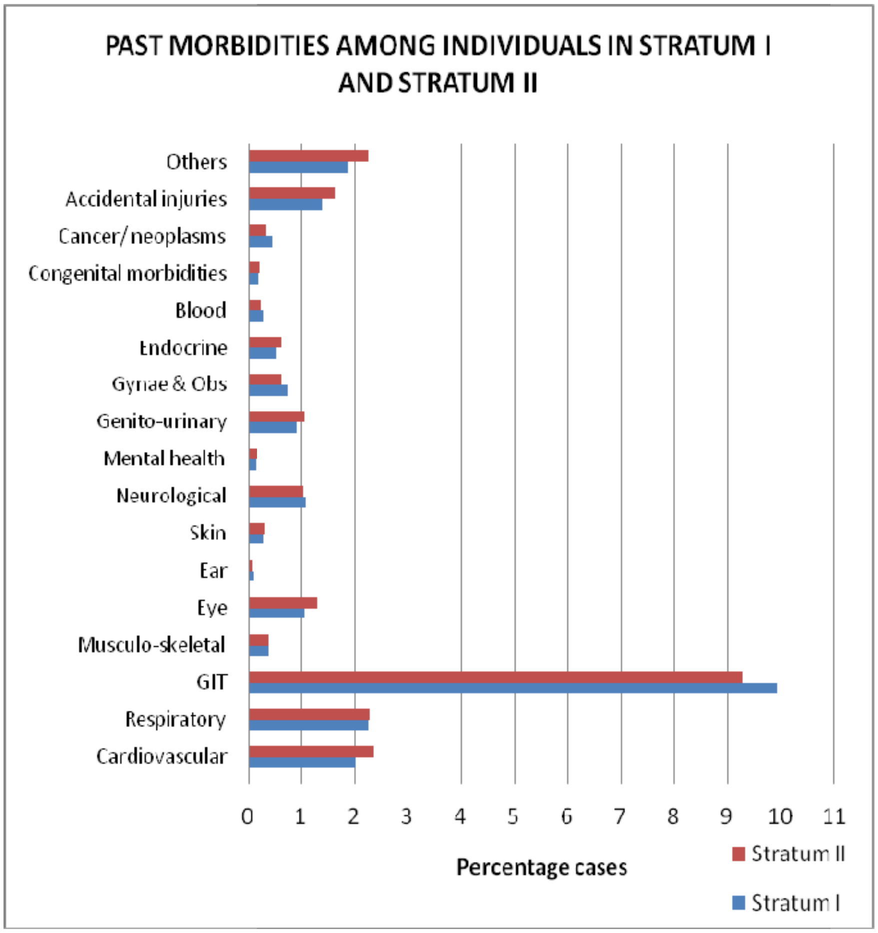

Figure-5: Past morbidities pattern in the surveyed population

4.4.2 Disease wise morbidity pattern:

Disease wise morbidities recorded in the surveyed population is presented in Table-7. The most prevailing `present morbidities' in the surveyed population were hypertension followed by arthritis, diabetes mellitus, refractive error, gastritis, and respiratory conditions such as URI and bronchitis in both the strata. Present prevalence of hypertension (4.7% in stratum I & 6.4% in stratum II ; $p<0.01$) and diabetes mellitus (2.0% in stratum I & 3.36% in stratum II ; $p<0.001$) was found significantly higher in stratum II. On the other hand present prevalence of ear disease (0.47% in stratum I & 0.11% in stratum II ; $p<0.01$) , neoplasm/cancer (0.25% in stratum I & 0.04% in stratum II ; $p<0.01$), mental growth retardation (0.19% in stratum I & 0.02% in stratum II ; $p<0.05$) and upper respiratory tract infections (1.46% in stratum I & 0.96% in stratum II ; $p<0.05$) were found significantly higher in stratum I. Present prevalence of other individual diseases was found comparable in the two strata.

Table 7: Disease wise morbidity pattern in the surveyed population

Morbidities	Present Morbidities		Past Morbidities	
	Stratum I (N=4641)	Stratum II (N=4665)	Stratum I (N=5467)	Stratum II (N=5360)
Typhoid/ Enteric Diseases	3 (0.06%)	3 (0.06%)	207 (3.78%)*	155 (2.89%)
Diarrhoeal Diseases	14 (0.30%)	6 (0.13%)	97 (1.77%)	78 (1.45%)
Pulmonary Tuberculosis	5 (0.11%)	6 (0.13%)	21 (0.38%)	16 (0.30%)
Other forms of Tuberculosis	0 (0.0%)	0 (0.0%)	3 (0.05%)	5 (0.09%)
Infective Hepatitis	1 (0.02%)	0 (0.0%)	106 (1.93%)	122 (2.28%)
Other Infectious Diseases	12 (0.25%)	6 (0.13%)	48 (0.87%)	58 (1.08%)
Neoplasm/ Cancer	12 (0.25%)**	2 (0.04%)	25 (0.45%)	19 (0.35%)
Endocrinal Disorders (Thyroid-related)	37 (0.79%)	56 (1.20%)	2 (0.04%)	4 (0.07%)
Diabetes Mellitus	93 (2.0%)	157 (3.36%)***	26 (0.48%)	30 (0.56%)
Gout	2 (0.04%)	1 (0.02%)	2 (0.04%)	0 (0.0%)
Other Nutritional and Metabolic Disorders	6 (0.13%)	4 (0.08%)	3 (0.05%)	0 (0.0%)
Anemia	16 (0.34%)	15 (0.32%)	15 (0.27%)	13 (0.24%)
Mental Health Disorders	11 (0.23%)	12 (0.25%)	8 (0.14%)	9 (0.17%)
Mental Growth Retardation	9 (0.19%)*	1 (0.02%)	2 (0.04%)	2 (0.04%)
Neurological Diseases/ Disorders	40 (0.86%)	36 (0.77%)	59 (1.07%)	56 (1.04%)
Refractive Error	82 (1.76%)	77 (1.65%)	10 (0.18%)	3 (0.05%)
Cataract	18 (0.38%)	30 (0.64%)	38 (0.69%)	57 (1.06%)
Other Eye Diseases	18 (0.38%)	13 (0.27%)	10 (0.18%)	10 (0.19%)
Ear Diseases	22 (0.47%)**	5 (0.11%)	6 (0.10%)	5 (0.09%)
Hypertension	220 (4.74%)	298 (6.38%) **	43 (0.78%)	51 (0.95%)
Ischemic Heart Diseases (Chronic/ Acute)	24 (0.51%)	21 (0.45%)	26 (0.47%)	38 (0.70%)
Other Circulatory system Diseases	23 (0.49%)	32 (0.68%)	41 (0.74%)	38 (0.70%)
Bronchitis/ COPD	52 (1.12%)	65 (1.39%)	20 (0.37%)	17 (0.32%)
Upper Respiratory Tract Infection	68 (1.46%)*	45 (0.96%)	3 (0.06%)	5 (0.09%)
Other Respiratory Diseases	19 (0.41%)	14 (0.30%)	79 (1.44%)	84 (1.57%)
Gastritis (Acute/ Chronic)	61 (1.31%)	50 (1.10%)	24 (0.43%)	21 (0.39%)
Hepatic Diseases	3 (0.06%)	3 (0.06%)	23 (0.42%)	15 (0.28%)
Other GIT related diseases	28 (0.6%)	16 (0.34%)	85 (1.55%)	106 (1.98%)
Renal Failure	1 (0.02%)	2 (0.04%)	4 (0.07%)	4 (0.07%)
Renal Stones /Calculi	8 (0.17%)	10 (0.21%)	32 (0.6%)	33 (0.62%)
Other Genito-urinary Diseases	5 (0.11%)	3 (0.06%)	14 (0.25%)	20 (0.37%)
Eczema/ Dermatitis	13 (0.28%)	15 (0.32%)	4 (0.07%)	3 (0.06%)
Other Skin diseases	16 (0.34%)	21 (0.45%)	13 (0.23%)	15 (0.28%)
Arthritis	159 (3.42%)	128 (2.74%)	4 (0.07%)	8 (0.15%)
Other Musculoskeletal System related diseases	18 (0.38%)	24 (0.51%)	17 (0.31%)	13 (0.24%)
Congenital deformities	3 (0.06%)	1 (0.02%)	9 (0.16%)	10 (0.19%)
Ill-defined symptoms/ diseases	29 (0.62%)	17 (0.36%)	47 (0.85%)	58 (1.08%)
Accidental Injuries	10 (0.21%)	3 (0.06%)	76 (1.39%)	87 (1.62%)
Gyanecology and Obstetrics related morbidities	15 (0.32%)	7 (0.15%)	41 (0.74%)	34 (0.63%)

*p<0.05, **p<0.01,***p<0.001- based on Two-sample test of proportion (χ^2 test)

Among `past morbidities' the prevalence of typhoid (3.8% in stratum I & 2.9% in stratum II) among GIT related morbidity was found significantly higher in stratum I ($p<0.05$). Other most commonly recorded past morbidities included respiratory cases (of bronchial asthma, allergic rhinitis, URI, pneumonia, and hospitalisation due to respiratory distress), different neurological conditions and, eye conditions (mostly cataract) with comparable prevalence in the two strata (Table-7).

4.4.3 *Observed morbidities and their association with consumption of contaminated drinking water*

Drinking of contaminated water can lead to adverse effects on human health. However, it is difficult to establish the cause and effect relationship between the observed morbidities and its likely cause in an epidemiological study like this because of multiple confounders. Since one of the objectives of our study was to correlate the observed morbidities with reference to the utilization of water source for drinking purpose, we clubbed various morbidities recorded in the study as likely to be associated with Biological contaminants or Chemical contaminants as below-

Water contaminants	Likely associated morbidities (2,3,4,5)
Biological	GIT Infections-Typhoid, Diarrhoeal diseases & Infective hepatitis
Chemical	Cancer, Diabetes, Thyroid, Anemia, Mental Retardation, Neurological, Hypertension, Liver diseases, Renal failure, Renal Stones, Congenital Morbidities, & Gynaecology and Obstetrics related

The prevalence of likely morbidities due to the consumption of drinking water contaminated with biological agents (mostly GI system related such as typhoid, diarrhoeal diseases and infectious hepatitis) was similar in the two strata with reference to present as well as past morbidities (Table-8). However, prevalence of present morbidities likely to be caused by chemical contaminants (cancer, diabetes, thyroid, anemia, mental retardation, neurological, hypertension, liver diseases, renal failure, renal stones, congenital morbidities, Obst & Gynae related) was found significantly higher ($p<0.01$) in stratum II (10.2%), compared to stratum I (8.51%). Prevalence of past morbidities was similar in both the strata.

Table-8: ***Overall distribution of morbidities likely associated with biological and chemical contaminants***

Morbidities (associated with)	Present		Past	
	Stratum I (n=4,641)	Stratum II (n=4,665)	Stratum I (n=5,467)	Stratum II (n=5,360)
Biological Contaminants	18 (0.39%)	9 (0.19%)	386 (7.06%)	333 (6.21%)
Chemical Contaminants	395 (8.51%)	476 (10.20%)**	258 (4.72%)	251 (4.68%)

**$p<0.01$ - based on Two-sample test of proportion (χ^2 test)

4.4.4 *Distribution pattern of morbidities associated with likely water contaminants*

Distribution pattern of clubbed morbidities likely associated with biologically or chemically contaminated drinking water in relation to various demographic characteristics was studied with reference to `present morbidities' (Table-9) as well as `past morbidities' (Table-10).

Table-9: Distribution of present morbidities likely associated with exposure to biological and chemical contaminants in drinking water

Demographic characteristic	Biological contaminants		Chemical contaminants	
	Stratum I (n=4,641)	Stratum II (n=4,665)	Stratum I (n=4,641)	Stratum II (n=4,665)
Age Group (in years)				
Upto 5	4 (0.09%)*	0 (0.0%)	2 (0.04%)	2 (0.04%)
6-15	2 (0.04%)	2 (0.04%)	15 (0.32%)*	5 (0.11%)
16-30	5 (0.11%)	3 (0.06%)	48 (1.03%)**	23 (0.49%)
31-45	5 (0.11%)	2 (0.04%)	91 (1.94%)	102 (2.19%)
46-60	2 (0.04%)	1(0.02%)	149 (3.21%)	190 (4.07%)*
>60	0 (0.0%)	1(0.02%)	90 (1.94%)	154 (3.30%)***
Gender				
Male	3 (0.06%)	2 (0.04%)	143 (3.08%)	202 (3.44%)**
Female	15 (0.32%)	7 (0.15%)	252 (5.43%)	274 (5.87%)
Religion				
Hindu	10 (0.22%)	4 (0.06%)	199 (4.29%)	296 (6.35%)***
Muslim	8 (0.30%)	5 (0.11%)	194 (4.18%)*	154 (3.30%)
Others	0 (0.0%)	0 (0.0%)	2 (0.04%)	26 (0.56%) ***
Gas exposure				
Gas exposed	4 (0.09%)	3 (0.06%)	225 (4.85%)	226 (4.84%)
Not exposed	14 (0.30%)	6 (0.13%)	170 (3.66%)	250 (5.36%)***
Literacy status				
Age< 4 yrs	3 (0.06%)	0 (0.0%)	3 (0.06%)	3 (0.06%)
Illiterate	3 (0.06%%)	3 (0.06%)	131 (2.82%) **	90 (1.93%)
Literate	0 (0.0%%)	0 (0.0%)	18 (0.39%)	23 (0.49%)
Primary	3 (0.06)	2 (0.04%)	51 (1.10%) *	33 (0.71%)
Middle	6 (0.13)	1 (0.02%)	67 (1.44%)	60 (1.29%)
Secondary	3 (0.06)	1(0.02%)	79 (1.70%)	119 (2.56%) **
College	0 (0.0)	1 (0.02%)	36 (0.78%)	80 (1.71%) ***
Technical	0 (0.0)	1 (0.02%)	10 (0.22%)	68 (1.46%) ***
Occupation				
No occupation	15 (0.32%)*	5 (0.11%)	267 (5.75%)	324 (6.95%) *
Unskilled labour	0 (0.0%)	0 (0.0%)	14 (0.30%)	7 (0.15%)
Skilled labour	1 (0.02%)	1 (0.02%)	43 (0.93%) ***	12 (0.26%)
Agriculture	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.02%)
Service	1 (0.02%)	2 (0.04%)	29 (0.62%)	81 (1.74%) ***
Others	1 (0.02%)	1 (0.02%)	42 (0.90%)	51 (1.09%)
Present drinking water source				
Municipal	15 (0.32%)	8 (0.17%)	328 (7.07%)	365 (7.82%)
Combined	0 (0.0%)	0 (0.00%)	1 (0.02%)	6 (0.13%)
Non-municipal	3 (0.06%)	1 (0.02%)	66 (1.42%)	105 (2.25%)**
Past drinking water Source				
Municipal	11 (0.24%)	8 (0.17%)	228 (4.91%)	359 (7.69%)***
Combined	0 (0.0%)	0 (0.00%)	1 (0.02%)	4 (0.09%)
Non-municipal	7 (0.15%)*	1 (0.02%)	166 (3.58%)**	113 (2.42%)
Pre-treatment of drinking water				
Treated	4 (0.09%)	2 (0.04%)	82 (1.77%)	229 (4.91%) ***
Non-treated	14 (0.30%)	7 (0.15%)	313 (6.74%) **	247 (5.29%)

*p<0.05, **p<0.01,***p<0.001- based on Two-sample test of proportion (χ^2 test)

Table-10: Distribution of past morbidities likely associated with exposure to biological and chemical contaminants in drinking water

Demographic characteristics	Biological contaminants		Chemical contaminants	
	Stratum I (n=5,467)	**Stratum II (n=5,360)**	**Stratum I (n=5,467)**	**Stratum II (n=5,360)**
Age group (in years)				
Upto 5	27 (0.49%)	18 (0.33%)	5 (0.09%)	8 (0.15%)
6-15	84 (1.54%)	72 (1.34%)	20 (0.37%)	10 (0.19%)
16-30	139 (2.54%)	115 (2.15%)	44 (0.80%)	37 (0.69%)
31-45	62 (1.13%)	63 (1.18%)	67 (1.23%)	62 (1.16%)
46-60	49 (0.89%)	40 (0.75%)	80 (1.46%)	82 (1.53%)
>60	25 (0.46%)	25 (0.47%)	42 (0.77%)	52 (0.97%)
Gender				
Male	193 (3.53%)	184 (3.43%)	119 (2.18%)	116 (2.16%)
Female	193 (3.53%) *	149 (2.78%)	139 (2.54%)	135 (2.52%)
Religion				
Hindu	230 (4.21%)	219 (4.65%)	138 (2.52%)	149 (2.78%)
Muslim	154 (2.82%) **	100 (1.87%)	118 (2.16%)	89 (1.66%)
Others*	2 (0.04%)	14(0.26%) **	2 (0.04%)	13 (0.24%) **
Gas exposure				
Gas exposed	296 (5.41%)	249 (4.65%)	136 (2.49%)	130 (2.42%)
Not exposed	90 (1.65%)	84 (2.57%)	122 (2.23%)	121 (2.26%)
Literacy status				
Age< 4 yrs	17 (0.31%)	12 (0.22%)	4 (0.07%)	5 (0.09%)
Illiterate	47 (0.86%) **	22 (0.41%)	67 (1.23%) **	34 (0.63%)
Literate	18 (0.33%)	18 (0.34%)	7 (0.13%)	19 (0.35%) *
Primary	85 (1.55%) **	52 (0.97%)	36 (0.66%)	31 (0.59%)
Middle	78 (1.43%)	70 (1.31%)	52 (0.95%) *	33 (0.62%)
Secondary	98 (1.79%)	84 (1.57%)	63 (1.15%)	61 (1.14%)
College	39 (0.71%)	51 (0.95%)	24 (0.44%)	41 (0.76%) *
Technical	4 (0.07%)	24 (0.45%) ***	5 (0.09%)	27 (0.50%) ***
Occupation				
No occupation	262 (4.79%) *	210 (3.92%)	168 (3.07%)	149 (2.78%)
Unskilled labour	11(0.20%)	13 (0.24%)	6 (0.11%)	11 (0.21%)
Skilled labour	43 (0.79%)	28 (0.52%)	27 (0.49%)	19 (0.35%)
Agriculture	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.02%)
Service	20 (0.36%)	32 (0.59%)	24 (0.44%)	30 (0.56%)
Others	50 (0.91%)	50 (0.93%)	33 (0.60%)	41(0.76%)
Present drinking water source				
Municipal	318 (5.82%)	281 (5.24%)	215 (3.93%)	200 (3.73%)
Combined	4 (0.07%)	6 (0.11%)	2 (0.04%)	3 (0.06%)
Non-municipal	64 (1.17%)	46 (0.86%)	41 (0.75%)	48 (0.89%)
Past drinking water Source				
Municipal	188 (3.44%)	239 (4.46%)**	143 (2.62%)	188 (3.51%)***
Combined	8 (0.15%)*	1 (0.02%)	1 (0.02%)	21 (0.39%)
Non-municipal	190 (3.48%)***	93 (1.74%)	114 (2.08%)***	61 (1.14%)
Pre-treatment of drinking water				
Treated	60 (1.09%)	102 (1.90%) **	43 (0.79%)	74 (1.38%) **
Non-treated	326 (5.96%)***	231 (4.31%)	215 (3.93%)	177 (3.30%)

*p<0.05, **p<0.01,***p<0.001- based on Two-sample test of proportion (χ^2 test)

4.4.5 *Exploration of various risk factors with regard to prevalence of morbidities associated with consumption of contaminated drinking water*

In order to explore the association of morbidities (present and past) with drinking water utilization, Multiple Logistic Regression (MLR) analysis was carried out. The risk factors considered were distance from UCIL factory (in terms of stratum) , present and previous sources of drinking water, pre-treatment practices being undertaken prior to consumption of water, age, gender, gas exposure status during Bhopal gas tragedy, literacy status, occupation, religion, addictions, and availability of toilet facilities in households. Two groups of morbidities- likely associated with biological and chemical contamination were analysed for association with these factors. Prevalent and past morbidities were considered separately for analysis. With repeated multiple regression analysis, adjusting for all factors, final models for prevalence of two morbidity groups were obtained. (Tables 11-14).

4.4.5.1 *Morbidities likely associated with biological contaminants in drinking water*

No significant association (p>0.05) was observed between prevalence of morbidities (present or past) likely due to consumption of drinking water contaminated with biological contaminants, and the distance from the UCIL factory (stratum I or II), when adjusted for significant confounding variables (Table 11 and 12). In the final model generated for biological contaminants associated present morbidities (Table- 11), female gender was found significantly associated with GI infections (OR 3.80, 95% CI 1.44 - 10.04 and Pseudo R^2= 0.0333) suggesting that the female population is at a higher risk of suffering from a present GI infection as compared to the male population.

Table-11: Final model for prevalence of present morbidities likely associated with biological contaminants in drinking water

Biological contaminant associated morbidities (Present)	Odds Ratio (adjusted)	p-value (adjusted)	95% Confidence Interval		Unadjusted Pseudo R^2
Stratum	2.005871	0.089	0.899936	4.470893	0.0084
Female Gender	3.800282	0.007	1.437763	10.04487	0.0250

Pseudo R^2= 0.03

In the final model generated for biological contaminants associated past morbidities (Table-12) factors such as age, literacy status, gas exposure status during Bhopal gas tragedy and past source of drinking water were found significantly associated with biologically contaminant associated morbidities (Pseudo R^2 of 0.0082). The model indicates that with increasing age, there was a lower risk of occurrence of biologically contaminant associated morbidities. On the other hand higher literacy status, exposure to gas during Bhopal gas tragedy and consumption of non-municipal water in past, increased the risk of contracting infections likely caused by biological pathogenic agents.

Table-12: Final model for prevalence of past morbidities likely associated with biological contaminants in drinking water

Biological contaminant associated morbidities (Past)	Odds Ratio (adjusted)	p-value (adjusted)	95% Confidence Interval		Unadjusted Pseudo R^2
Stratum	1.125245	0.142	0.961142	1.317365	0.0006
Age	0.991564	0.002	0.986236	0.996921	0.0000
Literacy status	1.177864	0.000	1.09204	1.270433	0.0022
Gas Exposure	1.611954	0.000	1.291937	2.011241	0.0017
Past Drinking Water Source	1.128429	0.003	1.042247	1.221739	0.0017

Pseudo R^2= 0.0082

The observed low pseudo R^2 values suggested that given regression models (even with the significant odds ratios for the identified risk factors) can predict very low proportions (less than 3% of present morbidities and 0.8% of past morbidities) of the total variability of the outcome variable.

4.4.5.2 *Morbidities likely associated with chemical contaminants in drinking water*

Similar to biological contaminants associated morbidities, those morbidities (present or past) likely to be caused by chemical contaminants in drinking water did not show any significant association with the distance of localities from the UCIL factory (stratum I and II) (Table 13 and 14). The final model shows that the present morbidities likely to be associated with chemical contaminants in drinking water show significant association with age, gender, occupation, gas exposure status during Bhopal gas tragedy and religion, with a high Pseudo R^2 of 0.2721 (Table-13). Increasing age, female gender, higher literacy status, people belonging to occupational groups such as skilled labours and service, gas exposure during Bhopal gas tragedy, and people of Muslim religion, were at higher risk of suffering from chemical contaminant associated morbidities. This model is a strong predictor of occurrence of the studied group of diseases with the ability to explain 27% of such occurrences.

Table-13: Final model for prevalence of present morbidities likely associated with chemical contaminants in drinking water

Chemical contaminant associated morbidities (Present)	Odds Ratio (adjusted)	p-value (adjusted)	95% Confidence Interval		Unadjusted Pseudo R^2
Stratum	1.056091	0.525	0.892446	1.249742	0.0014
Age	1.074849	0.000	1.069205	1.080523	0.2458
Gender	1.562027	0.000	1.282651	1.902254	0.0030
Literacy Status	1.286725	0.000	1.180876	1.402062	0.0047
Occupation*					
• Unskilled Labour	0.8995119	0.685	0.539468	1.49985	0.0103
• Skilled Labour	0.690895	0.028	0.496722	0.960972	
• Agriculture	0.4458679	0.523	0.037335	5.324739	
• Service	1.35849	0.026	1.037293	1.779146	
• Other occupation	0.8448445	0.232	0.640912	1.113666	
Gas Exposure	1.774802	0.000	1.488182	2.116623	0.1026
Religion*					
• Muslims	1.519786	0.000	1.279411	1.805323	0.0033
• Other religions	1.32854	0.266	0.805412	2.19145	

Pseudo R^2= 0.2721

[*Occupation=0 (No occupation), Religion=1 (Hindu) omitted by Stata 10 software for the reason of being naturally coded while performing MLR]

From the final model generated for occurrence of chemical contaminants associated past morbidities factors like age, gender, literacy status, gas exposure during Bhopal gas tragedy, religion and pre-treatment of water were found significantly associated (Table-14). Similar to the model for present morbidities of this group, increasing age, female gender, higher literacy status, being gas exposed, and being of Muslim religion puts individuals at higher risk of such diseases. An additional risk factor suggested to be associated as per this model is not carrying out any pre-treatment of drinking water at home. However, the Pseudo R^2 for this model was only 0.0962, hence a poor predictor of occurrence of the analysed group of morbidities.

Table-14: Final model for prevalence of past morbidities likely associated with chemical contaminants in drinking water

Chemical contaminant associated morbidities (Past)	Odds Ratio (adjusted)	p-value (adjusted)	95% Confidence Interval		Unadjusted Pseudo R^2
Stratum	1.047028	0.638	0.864429	1.2682	0.0000
Age	1.037491	0.000	1.031658	1.043358	0.794
Sex	1.385736	0.001	1.151005	1.668337	0.0012
Literacy Status	1.19633	0.000	1.084413	1.319798	0.0016
Gas Exposure	1.824573	0.000	1.47066	2.263656	0.0519
Pre-treatment of drinking water	1.439711	0.003	1.136508	1.823805	0.0001
Religion*					
• Muslims	1.251602	0.023	1.03072	1.519818	0.0023
• Other religions	1.679422	0.077	0.946275	2.980592	

Pseudo R^2= 0.0962

[*Religion=1 (Hindu) omitted by Stata 10 software for the reason of being naturally coded while performing MLR]

DISCUSSION

The present study determined the prevalence of various morbidities with reference to the drinking water utilization among the population residing at variable distance(s) from the UCIL factory i.e. 0-1 km (stratum I) and 2.5-5.0 km (startum II) with the underlying hypothesis that the population residing closer to the factory is more prone to adverse effects of consuming the allegedly contaminated underground water.

About 82% of the surveyed population in the study was found to presently have access to the municipal drinking water supply whereas in 2011, the municipal water supply covered about 67% population of Bhopal, thus, leaving 33% population dependent on underground water sources at that time (37). The water supplied by the Bhopal Municipal Corporation is generally chlorinated. Chlorination of drinking water, one of the most significant advances in public health protection (53), kills a broad spectrum of pathogens present in water, thus, providing protection from water borne infections to a large extent. Untreated water from underground sources is relatively unsafe for drinking because of the possibility of contamination of underground water reservoirs due to improper and inefficient solid waste management practices, open septic tanks, open defecation practices which might lead to percolation of contagious/ toxic substances into underground water resources, thus polluting them (39, 54). Over a period of time there has been a decrease in the dependency on non-municipal water sources for drinking purposes in the surveyed areas, especially in stratum I, where about 43% population was previously dependant on non-municipal sources of water compared to present 18%.

In stratum II (areas away from UCIL factory) the present prevalence of hypertension was found significantly higher (6.4%) than in stratum I (4.7%) with overall prevalence of 5.6% in the surveyed population. A lower hypertension prevalence of 2.7% was reported in Bhopal district in Annual Health survey, 2012 (55). ICMR-INDIAB study reported a much higher prevalence (26.3%) of hypertension in the country among individuals ≥ 20years of age, among which ~5.5% cases were self-reported (already diagnosed) (56). In our study, prevalence of hypertension among individuals ≥ 20years of age was about 9%. A trend similar to hypertension was observed for diabetes mellitus in the present study (overall present prevalence 2.7%) with significantly higher prevalence in stratum II (3.4%) as compared to stratum I (2.0%). The WHO–ICMR Indian NCD Risk Factor Surveillance study (57) reported 4.5% prevalence of self-reported diabetes. Although termed as lifestyle related diseases, studies have suggested chronic exposure to inorganic arsenic might lead to hypertension (58) and diabetes (27). A suggested health effect due to long-term consumption of chemically contaminated water has been chronic renal failure. In our study overall present chronic renal failure was recorded in 0.03% surveyed individuals with comparable prevalence in the two strata. Another renal condition suggestively caused by drinking chemically contaminated water has been formation of renal stones/ calculi. As per the national figures, 0.5-0.7% population suffers from renal stones (59). In our study, overall 0.2% individuals were found presently suffering from the presence of renal stones whereas 0.6% had reportedly received medical treatment in the past for this condition.

While the prevalence of present gastrointestinal morbidities such as typhoid/enteric fever, diarrhoeal disease, and infective hepatitis was low and comparable in the two strata, their past prevalence was much higher. This might be due to improved access to the treated municipal water supply in various localities of Bhopal over a period of time. Overall past prevalence of typhoid/enteric fever was 3.3% with significantly higher prevalence in stratum I (3.8%) than in stratum II (2.9%). It is worth mentioning that in north India a much higher prevalence of typhoid (9.7%) has been reported (60). Overall past prevalence of diarrhoea and infective hepatitis in the present study recorded were 1.6% and 2.1% respectively with comparable prevalence in the two strata. The prevalence of viral hepatitis in our study compares well with 1.9% national prevalence of infective hepatitis (61). These gastrointestinal morbidities are likely to be directly related to consumption of biologically contaminated water.

Multiple Logistic Regression analysis of the two groups of present and past morbidities i.e. morbidities likely associated with consumption of biologically and chemically contaminated drinking water, and the potential risk factors revealed that the stratum, representing distance of residence from the UCIL factory, was not associated with either present or past occurrence of the morbidities. This indicate that distance from UCIL factory was not a significant predictor for occurrence of morbidities, thereby, implying that population living nearer to UCIL factory (stratum I) or at a considerable distance from it (stratum II) were equally prone to morbidities likely to be caused by the long-term consumption of allegedly contaminated water.

In Multiple Logistic Regression analysis present morbidities likely due to the consumption of biologically contaminated water, were found significantly associated with female gender, who were at higher risk of being affected than males. Individuals of younger age, individuals with higher literacy status, gas exposed individuals during 1984 Bhopal gas tragedy and individuals who consumed non-municipal water were at a higher risk of suffering from biological contaminants associated diseases in the past. A recent study exploring risk factors of typhoid fever in Allahabad region (62) suggested that individuals belonging to lower age groups (comprising of children with somewhat lower immunity), students (with less awareness about hygiene and importance of clean water consumption) and young workers (more prone to be exposed to outside water and food) were at higher risk of contracting typhoid fever. Mishra et al (2013) reported higher levels of symptomatic morbidities among the gas exposed population of 1984 Bhopal gas tragedy compared to non-exposed population (47). 'Population based long term epidemiological study on health effects of MIC gas' of NIREH (63) also reported a much higher all cause morbidity prevalence (25.4%) in gas exposed population, compared to 9.8% prevalence among non-exposed population. It need to be understood that the very low values of pseudo R^2 (0.0082) for this model (Table-12) suggests that the identified risk factors, though significantly associated, explain just a minute fraction of overall past morbidities in the study population.

In Multiple Logistic Regression analysis present morbidities likely due to the consumption of chemically contaminated water were found significantly associated with, age, gender, higher literacy status, occupation (skilled labour and service workers), gas exposure status, and religion. This model had a higher Pseudo R^2 value of 0.27 and hence, can be considered a good predictor of occurrence of these diseases. Similar to present morbidities, past morbidities under this group of diseases had age, gender, literacy status, gas exposure status, religion and pre-treatment of drinking water as significant associated risk factors. However, the pseudo R^2 of this model was a low 0.096, rendering this model a poor predictor of the chemically contaminant associated diseases occurred in the past among the population surveyed.

The group of diseases likely to be caused by the consumption of chemically contaminated water included lifestyle diseases, such as hypertension, diabetes, and thyroid dysfunction, and for such morbidities age and gender are important non-modifiable risk factors which tend to play a role in their occurrence. Similarly, higher literacy status and a better paid occupation, being associated with better lifestyle, maybe indicative of presence of these diseases. Also, there are multiple risk factors responsible for manifestation of these diseases, and hence, cannot be attributed to any particular risk factor. Gas exposure, a significant factor as explained above, makes this group of population more prone to adverse health effects.

CONCLUSIONS

Based on the results of the study, following conclusions can be drawn –

a. Similar morbidity patterns existed between the two strata. The most prevalent present morbidities were hypertension and diabetes mellitus, with a higher prevalence in stratum II whereas the most prevalent past morbidities were related to GI infections in both the strata.
b. The surveyed population was equally vulnerable to various morbidities irrespective of distance of their residences from the UCIL factory. In other word, the risk of suffering from any morbidity is not related to the nearness of their residences to the UCIL factory.
c. Though in the past higher consumption of non-municipal water increased the risk of contracting GI related morbidities (likely due to contamination of biological pathogens), the present predominant source of drinking water i.e. municipal water is unrelated to the morbidities likely associated with either chemical or biological contamination of water.
d. Gas exposed persons are more vulnerable to suffering from various morbidities.

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Morbidity profile of communities in Bhopal city (India) vis-à-vis distance of residence from Union Carbide India Limited plant and drinking water usage pattern

Banerjee N[1], Banerjee A[1], Sabde Y[1], Tiwari RR[1], Prakash A[1], NIREH Epidemiology Research Group**

**NIREH Epidemiology Research Group [Chincholkar T[1], Chitriv P[1], Tiwari S[1], Rajmohan HR[2], Singh S[1], Sharma M[1], Soni KK[1], Galgalaker R[1]]
[1]ICMR-National Institute for Research in Environmental Health, Bhopal, Madhya Pradesh, India, [2]NIOH-Regional Occupational Health Centre (Southern), Nirmal Bhawan, Devenahalli, Bengaluru, Karnataka, India

Address for correspondence:
Dr. Anil Prakash,
E-mail: anilprakashin@yahoo.co.in

ABSTRACT

Objective: A cross-sectional study was undertaken to assess the prevalence of morbidities in communities residing at variable distances from the closed down insecticide manufacturing plant premises of Union Carbide India Limited (UCIL), Bhopal, India and to determine association of morbidities, if any, with their drinking water usage pattern and distance of localities from the UCIL plant. **Materials and Methods:** A total of 10,827 individuals belonging to 2,184 families, residing within 0-1 km (Stratum I) and 2.5-5.0 km (Stratum II) radial distances from UCIL plant were surveyed and 9,306 of them (86%) were clinically examined. Data were analyzed to examine the association between the groups of morbidities, likely due to biological and chemical water contamination, and the distance of locality from the UCIL plant. Multiple logistic regression was used to explore the risk factors for morbidities. **Results:** Nearly similar prevalence (25.3% in stratum I, 25.8% in stratum II) and the trend of all-cause morbidities were recorded in the two strata. While morbidities related to gastrointestinal tract system ($P < 0.05$), auditory system ($P < 0.01$), neoplasm/cancers ($P < 0.01$) and congenital anomalies ($P < 0.01$) were significantly higher in stratum I, the prevalence of hypertension (6.4% stratum II, 4.7% stratum I; $P < 0.01$) and diabetes mellitus (3.4% stratum II, 2.0% stratum I; $P < 0.001$) was found significantly higher in stratum II. No association ($P > 0.05$) was observed between the prevalence of morbidities, likely due to the consumption of biologically or chemically contaminated drinking water, and the distance of locality/stratum from the UCIL plant. **Discussion and Conclusion:** By and large similar pattern of morbidities were recorded in the two strata suggesting that the communities, irrespective of the distance of their residences from UCIL plant or sources of their drinking water, are equally vulnerable to various morbidities.

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Introduction

In the intervening night of 2/3 December 1984, more than 40 tons of mixture of toxic gases, including methyl isocyanate, phosgene, hydrogen cyanide, carbon monoxide, monomethyl amine, etc., leaked from the carbaryl insecticide manufacturing plant of Union Carbide India Limited (UCIL), in Bhopal city (India) killing about 3,800 people and causing multiple system morbidities to nearly 63,000 exposed individuals.[1] Subsequently, the UCIL plant was closed down leaving behind huge quantities of chemicals unattended inside as well as around the plant premises in the form of solar evaporation ponds (SEPs).[2] It was apprehended that over a period, the uncared for toxic chemicals in SEPs might have leached into the groundwater thus, adversely affecting the health of those consuming the alleged polluted water in any form.[3,4] During the last three decades, several government and private organizations carried out studies to assess the status of groundwater and soil contamination in and around UCIL plant[5-8] with divergent results, thus, complicating the situation and creating confusion in the minds of people. Meanwhile, in view of public concern of potential ill effects on human health of consuming allegedly polluted groundwater, the state government of Madhya Pradesh in 2006 made provision for supplying the treated piped municipal water supply in localities surrounding UCIL plant. Nevertheless, concern continued to persist in the minds of people, especially those residing nearby to UCIL plant, that consumption of chemically contaminated water had adversely affected and compounded their health problems. To address this concern, a community-based cross-sectional study was undertaken to determine the prevalence of morbidities and its association, if any, regarding the drinking water sources (Municipal treated water supplied through pipeline, tankers, public taps, etc., or Non-municipal untreated groundwater taken through bore wells, dug wells, hand pumps, etc.) among the communities residing nearby (0-1 km) and distant (2.5-5.0 km) areas from UCIL plant. The underlying assumption was that morbidities would be higher in the areas nearby to UCIL plant (0-1 km) if the common belief of drinking water there being chemically contaminated causing health problems among the residents is correct.

Materials and Methods

Study setting, subjects, and sampling

Taking UCIL plant as the central point the municipal area of Bhopal city was notionally divided into three circles *viz*. the innermost circle having a radial distance of 0-1 km, middle circle having a radial distance of 1.0-2.5 km and the outer circle having a radial distance of 2.5-5.0 km. The cross-sectional study was carried out during 2014-2016 covering the population residing within the innermost circle (i.e. a radial distance of about 0-1 km, termed as Stratum I, population 1,91,126 divided into 7 municipal wards) and the outermost circle (i.e. 2.5-5.0 km, termed as Stratum II, population 8,49,310 divided in 32 municipal wards) from the UCIL plant. The areas falling in the middle circle, that is, between the radial distance of 1.0 and 2.5 km from the UCIL plant were not surveyed because of resource constraint. The localities around 1 km radially from the UCIL plant (Stratum I, i.e. nearby to the UCIL plant) were most affected during Bhopal gas disaster in 1984 and allegedly the groundwater of this area got contaminated chemically. On the other hand, localities at a radial distance of 2.5-5.0 km from the UCIL plant (Stratum II, i.e. far away from the UCIL plant) were mostly not affected during the gas disaster and were chosen to compare morbidity pattern in these areas to the morbidity pattern in Stratum I, thus, serving as a control.

The sample size for the study was calculated with the help of the 'Sampsize' program (sampsize.sourceforge.net) using the formula $N = Z^2 \times P \times (1\text{-}P)/C^2$ where Z = Z value, *P* = Prevalence of morbidity and C = Confidence level. A prevalence of 9.4% of all-cause morbidity in the general population of Bhopal in 2013, as recorded in the long-term population-based epidemiological study of ICMR-NIREH,[9] precision of 1% and confidence level of 99% was considered for calculating the sample size. The value of 1 for the design effect was considered since the study was a cross-sectional one. Accordingly, for each stratum a sample of 1,092 families (or 5,460 individuals assuming 5 persons/family) was worked out ($N= (2.5322)^2 \times 0.094 \times 0.906/(0.01)^2 = 5{,}460$). Families, the sampling unit, and individuals, the study unit, were selected in a systematic random manner covering all the municipal wards falling under the two strata and proportionately to the population of each ward. The calculated sampling interval (35 for stratum I and 156 for stratum II) was applied uniformly in each ward of that stratum to select the families for the survey. Accordingly, after selecting the first family in each ward randomly, every 35th family inwards falling under stratum I and every 156th family inwards falling under stratum II was surveyed systematically till the sample size for that ward was achieved. In case of refusal for participation in the study by any family that household was dropped and the next household was taken.

Ethical considerations

The study was approved by the Institutional Ethics Committee of the National Institute for Research in Environmental Health vide no. NIREH/BPL/IEC-7/2014-15/732, dated 9/10/2014. In the identified households, as mentioned under section 2.1, the Head of the family was approached, explained about the study and an information sheet detailing about the study and rights of the participants etc., in local language was offered to him. After obtaining written informed consent from the Head all-available members of the family were enrolled separately in the study. The consent to include the children was taken from either of the parents or the Head.

Data collection

The selected households, as per the sampling frame, were approached and a semi-structured questionnaire seeking information on details of the household, socio-economic status, occupation, gas exposure status (in the night of 2/3 December, 1984) based on the available government documents, pattern of water usage along with sources of water supply with duration of use etc., was administered by a trained researcher. The information related to the children was collected from either of the parents. Further, a physician of the survey team clinically examined all the available members of the family. The family was visited second time on the same day/next day to cover the unavailable members, if any, during the first visit. If an individual of the surveyed family presented with any morbidity at the time of survey, the symptoms and duration of illness(es) were noted, based on which a diagnosis was made. In addition, past medical records, if available, and review of medication taken was also undertaken by the physician for determining past disease/morbidity status. No attempt was made to laboratory analyze the drinking water in the surveyed localities to detect the presence of contaminants if any (either chemical or biological) or to assess the exposure to contaminants in the surveyed population.

Data analysis

After scrutiny, data entry was done and analyzed in SPSS 24 software. Various morbidities recorded were broadly classified likely to be due to (i) consumption of biologically contaminated water[10] or (ii) consumption of chemically contaminated water.[11] Descriptive analysis based on the two-sample test of proportion (χ^2 test) was carried out to see differences in various socio-economic variables and morbidity prevalence in the surveyed population. Bivariate and multivariate analysis was done to establish an association between the group of morbidities, likely related to biological and chemical water contamination, and various risk factors using STATA 10.0 software. Multiple Logistic Regression (MLR) models were generated to identify significant risk factors for the occurrence of morbidity. For this, the risk factors significant at $\alpha = 0.25$ were identified and included in the final model. In the final model, the factors found significant at $\alpha = 0.05$ were considered to be significant.

Results

A total of 2,184 families (10,827 individuals) were surveyed during the study. In stratum I, data were collected for 5,467 individuals (1,092 families), whereas in stratum II, 5,360 individuals (1,092 families) were surveyed.

Socio-demographic characteristics

Socio-demographic profile suggested that overall people in stratum I belonged to relatively lower socio-economic status compared to stratum II [Table 1]. Significantly higher number of Illiterate people (16.1%), people belonging to Muslim religion (43.7%), unskilled labor class (13.9%) resided in stratum I compared to stratum II. A majority (>90%) in both the strata lived in pucca houses with similar extent of access to the toilet facility (93.6%). Nearly 20% of the surveyed population was found exposed to MIC gas during the 1984 disaster with a significantly higher number of gas exposed persons living in stratum I (21.3%) than stratum II (18.2%).

Drinking water sources

Information on the ‘present’ (during last 1 year) and the ‘past’ (prior to last 1 year) source(s) of drinking water in the surveyed households was categorized either as ‘municipal’ or `non-municipal’. The ‘municipal’ sources included direct treated piped water supply in the households and through common public taps or water supplied through tankers in localities lacking pipeline by the Municipal Corporation of Bhopal. Water collected directly from ground water sources such as bore wells, shallow hand pumps, dug wells, ponds, etc., were clubbed under ‘non-municipal’ sources. A ‘combined’ category, encompassing only a miniscule number of families, indicated water collected, mixed and utilized from both municipal and non-municipal sources of water supply. The use of non-municipal water sources (data not shown) was found significantly higher ($P < 0.001$) in stratum I as compared with stratum II both in the past (43.3% vis-a-vis 25.1%) as well as present (18.3% vis-a-vis 15.7%). With the gradual augmentation of municipal water supply over a period of time the majority of families in both the strata were presently using municipal water sources, though the proportion was significantly higher ($P < 0.001$) in stratum II (83.6%) compared to stratum I (80.9%). The majority of the families in both the strata were found consuming raw water without any pre-treatment (data not shown).

Prevalence and pattern of morbidities

About 85% of the surveyed individuals under stratum I ($n = 4,641$) and 87.0% under stratum II ($n = 4,665$) could be examined clinically. The overall prevalence of morbidities was found similar in the two strata with 25.3% individuals in stratum I ($n = 1,176$) and 25.8% individuals in stratum II ($n = 1.205$) found suffering from any morbidity (one or more morbid conditions/illnesses) at the time of survey [Table 2]. In both the strata morbidities related to cardiovascular, respiratory, gastrointestinal, musculoskeletal and ophthalmic systems occupied top five positions.

The most prevailing morbidity was hypertension followed by arthritis, diabetes mellitus, refractive error, gastritis, and respiratory conditions such as upper respiratory tract infections and bronchitis in both the strata with significantly higher prevalence of hypertension (4.7% in stratum I and 6.4% in stratum II; $P < 0.01$) and diabetes mellitus (2.0% in stratum I and 3.4% in stratum II; $P < 0.001$) in stratum II. In contrast, prevalence of ear diseases (0.47% in stratum I and 0.11% in stratum II; $P < 0.01$), neoplasm/cancer (0.25% in stratum I and 0.04% in stratum II; $P < 0.01$), mental growth retardation (0.19% in stratum I and 0.02% in stratum II; $P < 0.05$) and upper respiratory tract infections (1.4% in stratum I and 0.96% in stratum II; $P < 0.05$) were found significantly higher in stratum I.

Morbidities likely associated with consumption of biologically and chemically contaminated water

Of the various morbidities recorded in the study, only those likely associated with the usage of contaminated water, were clubbed under probable causes of biological contaminants (Gastro Intestinal Tract infections, typhoid, diarrheal diseases and infective hepatitis related) or chemical contaminants (cancer, diabetes, thyroid, anemia, mental retardation, neurological, hypertension, liver diseases, renal failure, renal stones, congenital morbidities, obstetrics, and gynecology related). The prevalence of morbidities likely due to the consumption of biologically contaminated drinking water

Table 1: Socio-demographic profile of surveyed population

	Stratum I (*n*=5,467)	Stratum II (*n*=5,360)	Total (*n*=10,827)
Age Groups (in years)			
Up to 5	466 (8.5%)	473 (8.8%)	939 (8.7%)
6-15	1027 (18.8%)	943 (17.6%)	1970 (18.2%)
16-30	1886 (34.5%)***	1640 (30.6%)	3526 (32.6%)
31-45	1160 (21.2%)	1177 (21.9%)	2337 (21.6%)
46-60	646 (11.8%)	750 (13.9%)***	1396 (12.9%)
>60	282 (5.2%)	377 (7.0%)***	659 (6.1%)
Gender			
Male	2800 (51.2%)	2735 (51.0%)	5535 (51.1%)
Female	2667 (48.8%)	2625 (49.0%)	5292 (48.9%)
Type of House			
Kutcha	479 (8.8%)	461 (8.6%)	940 (8.7%)
Pucca	4988 (91.2%)	4899 (91.4%)	9887 (91.3%)
Religion			
Hindu	3048 (55.8%)	3629 (67.7%)***	6677 (61.7%)
Muslim	2390 (43.7%)***	1596 (29.8%)	3986 (36.8%)
Others	29 (0.5%)	135 (2.5%)***	164 (1.5%)
Literacy			
Age <4 years	335 (6.1%)	311 (5.8%)	646 (6.0%)
Illiterate	880 (16.1%)***	468 (8.7%)	1348 (12.5%)
Literate	204 (3.7%)	256 (4.8%)***	460 (4.2%)
Primary	990 (18.1%)***	775 (14.5%)	1765 (16.3%)
Middle	1402 (25.6%)***	1150 (21.5%)	2552 (23.6%)
Secondary	1168 (21.4%)	1320 (24.6%)***	2488 (23%)
College	398 (7.3%)	720 (13.4%)***	1118 (10.3%)
Technical	90 (1.7%)	360 (6.7%)***	450 (4.2%)
Gas exposure in 1984			
Gas exposed	1167 (21.3%)***	973 (18.2%)	2140 (19.8%)
Not exposed	4300 (78.7%)	4387 (81.8%)***	8687 (80.2%)
Occupation			
Service	287 (5.2%)	566 (10.6%)***	853 (7.9%)
Agriculture	2 (0.04%)	9 (0.17%)*	11 (0.1%)
Skilled labor	174 (3.2%)	155 (2.9%)	329 (3.0%)
Unskilled labor	764 (13.9%)***	468 (8.7%)	1232 (11.4%)
No occupation	3588 (65.6%)	3498 (65.3%)	7086 (65.5%)
Others	652 (11.9%)	664 (12.3%)	1316 (12.2%)

*$P<0.05$, ***$P<0.001$ based on the two-sample test of proportion (χ^2 test). <openepi.com/two by two/two by two.htm>

was found similar in the two strata [Table 3]. However, the prevalence of morbidities likely due to the consumption of chemically contaminated water was found significantly higher ($P < 0.01$) in stratum II (10.2%) compared to stratum I (8.5%).

Risk factors for morbidities likely associated with consumption of contaminated water

MLR was used to explore the association of morbidities with various risk factors such as distance of the locality/stratum from UCIL plant, source of drinking water, pre-treatment practices prior to water consumption, age, gender, gas exposure status consequent to Bhopal gas tragedy, literacy status, occupation, religion, addictions, and availability of toilet facilities in households. Morbidities – likely associated with consumption of biologically and chemically contaminated water – were analysed separately for association with these factors and with repeated multiple regression, adjusting for all factors, final models for the prevalence of two morbidity groups were obtained.

For morbidities likely associated with consumption of biologically contaminated water

Table 4 shows the final model of MLR. The model was generated to identify the significant risk factors for the occurrence of morbidities associated with consumption of biologically and chemically contaminated water respectively at $\alpha = 0.05$. The adjusted odds ratio for morbidities likely associated with consumption of biologically contaminated water was 2.00 (95% confidence interval 0.89-4.47) for stratum I. This means no significant association ($P > 0.05$) was observed between prevalence of morbidities likely due to the consumption of

Table 2: Prevalence of various morbidities in the surveyed population

Disease	Stratum I (*n*=4,641)	Stratum II (*n*=4665)
Typhoid/Enteric Diseases	3 (0.06%)	3 (0.06%)
Diarrheal Diseases	14 (0.30%)	6 (0.13%)
Pulmonary Tuberculosis	5 (0.11%)	6 (0.13%)
Other forms of Tuberculosis	0 (0.0%)	0 (0.0%)
Infective Hepatitis	1 (0.02%)	0 (0.0%)
Other Infectious Diseases	12 (0.25%)	6 (0.13%)
Neoplasm/Cancer	12 (0.25%)**	2 (0.04%)
Endocrinal Disorders (Thyroid-related)	37 (0.79%)	56 (1.20%)
Diabetes Mellitus	93 (2.0%)	157 (3.4%)***
Gout	2 (0.04%)	1 (0.02%)
Other Nutritional and Metabolic Disorders	6 (0.13%)	4 (0.08%)
Anemia	16 (0.34%)	15 (0.32%)
Mental Health Disorders	11 (0.23%)	12 (0.25%)
Mental Growth Retardation	9 (0.19%)*	1 (0.02%)
Neurological Diseases/Disorders	40 (0.86%)	36 (0.77%)
Refractive Error	82 (1.8%)	77 (1.7%)
Cataract	18 (0.38%)	30 (0.64%)
Other Eye Diseases	18 (0.38%)	13 (0.27%)
Ear Diseases	22 (0.47%)**	5 (0.11%)
Hypertension	220 (4.7%)	298 (6.4%)**
Ischemic Heart Diseases (Chronic/Acute)	24 (0.51%)	21 (0.45%)
Other Circulatory system Diseases	23 (0.49%)	32 (0.68%)
Bronchitis/COPD	52 (1.1%)	65 (1.4%)
Upper Respiratory Tract Infection	68 (1.4%)*	45 (0.96%)
Other Respiratory Diseases	19 (0.41%)	14 (0.30%)
Gastritis (Acute/Chronic)	61 (1.3%)	50 (1.1%)
Hepatic Diseases	3 (0.06%)	3 (0.06%)
Other GIT related diseases	28 (0.6%)	16 (0.34%)
Renal Failure	1 (0.02%)	2 (0.04%)
Renal Stones/Calculi	8 (0.17%)	10 (0.21%)
Other Genito-urinary Diseases	5 (0.11%)	3 (0.06%)
Eczema/Dermatitis	13 (0.28%)	15 (0.32%)
Other Skin diseases	16 (0.34%)	21 (0.45%)
Arthritis	159 (3.4%)	128 (2.7%)
Other Musculoskeletal System-related diseases	18 (0.38%)	24 (0.51%)
Congenital deformities	3 (0.06%)	1 (0.02%)
Ill-defined symptoms/diseases	29 (0.62%)	17 (0.36%)
Accidental Injuries	10 (0.21%)	3 (0.06%)
Gynecology and Obstetrics related morbidities	15 (0.32%)	7 (0.15%)
Total	1,176 (25.3%)	1,205 (25.8%)

*$P<0.05$, **$P<0.01$, ***$P<0.001$- based on Two-sample test of proportion (χ^2 test)

Table 3: Distribution of morbidities likely associated with consumption of biologically and chemically contaminated water

Morbidities (associated with)	Stratum I (*n*=4,641)	Stratum II (*n*=4,665)
Biological Contaminants	18 (0.39%)	9 (0.19%)
Chemical Contaminants	395 (8.5%)	476 (10.2%)**

**$P<0.01$ based on the two-sample test of proportion (χ^2 test)

biologically contaminated drinking water, and the distance from the UCIL plant (stratum I or II), when adjusted for significant confounding variables. In the final model generated for biological contaminants associated morbidities, the female gender was found significantly associated with Gastro-Intestinal Tract infections (OR 3.80, 95% CI 1.43-10.04, $P = 0.007$) [Table IV]. With the observed low Pseudo R^2 value of 0.0333, the regression model (even with the significant odd ratios for the identified risk factors) was very weak explaining only 3% of the variance.

For morbidities likely associated with consumption of chemically contaminated water

Similar to the biological contaminants-associated morbidities, morbidities likely to be caused by consuming chemically contaminated water did not show any significant association with the distance of locality/stratum from the UCIL plant (Adjusted Odds ratio 1.05, 95% CI 0.89-1.24) [Table 4]. The final model with relatively higher Pseudo R^2 of 0.2721showed that the people of advancing age, of female gender, of higher literacy status, of Muslim religion, service class occupational groups, and gas exposed, were at higher risk of suffering from chemical contaminant associated morbidities. This model was relatively better with the ability to explain 27% of the variance.

Discussion

This study stemmed from the perpetual concern in the community that subsequent to the Bhopal Gas tragedy in 1984 several tons of unattended chemical waste, lying in UCIL plant premises and its solar evaporation ponds, has contaminated the ground water sources and the consumption of this contaminated water has already adversely affected and is still affecting the health of those residing nearby to the UCIL plant and consuming contaminated water. The results of several past environmental studies on the underground water and soil by reputed scientific organizations[5-8] in and around UCIL plant, Bhopal have been at variance, thus, creating confusion in the minds of people. In 1990, CSIR-National Environmental Engineering and Research Institute (NEERI), Nagpur determined the extent of chemical contamination in soil in a 2.5-km radius area of the solar evaporation ponds and water of 93 wells (11 abandoned and 82 in use) in a 10-km radius of the solar evaporation ponds concluding that the water in all the wells was within drinking standards and the soil was not chemically contaminated.[5] In contrast, the results of similar studies conducted during 1999-2004 by the Greenpeace Research Laboratory, UK, showed the presence of high concentrations of carbon tetrachloride, chloroform, trichlorobenzenes and dichlorobenzenes in the water of wells located at the northern and southern boundaries of UCIL plant and elevated levels of heavy metals *viz*. mercury, chromium, copper, nickel and organo chlorines such as hexachloroethane, hexachlorobutadiene, hexachlorocyclohexane isomers (HCH), DDT and chlorinated benzenes in the soil samples collected from the UCIL plant premises.[6] Another study in 2010 by CSIR-NEERI suggested that due to the confined nature of main aquifer around UCIL plant the chances of ground water contamination was minimal.[7] CSIR-Indian Institute of Toxicological Research, Lucknow in 2013 reported high concentration of lead in the ground water.[8] All these studies reported and characterized various chemical contaminants in the water and soil in and around UCIL plant but none evaluated health impact outcome of the chemical contamination of water, if any, on the communities residing nearby to the UCIL plant. To fill this gap in knowledge and to address the perpetual health concern of people, we determined the prevalence of morbidities related to drinking water sources and its usage pattern among the communities residing nearby to the UCIL plant premises (in the radial distance range of 0-1 km i.e. stratum I) and compared with the prevalent morbidities in communities residing in far away areas (in the radial distance range of 2.5-5.0 km i.e. stratum II) from the UCIL plant with the underlying hypothesis that the communities living closer to the UCIL plant were more likely to suffer from the adverse health consequences related to the consumption of allegedly contaminated ground water, if the common belief of drinking water there being contaminated chemically is correct.

The low and comparable prevalence of gastrointestinal tract morbidities in our study, likely related to the consumption of biologically contaminated drinking water, can be attributed to the improved access of the community to the chlorinated municipal water supply over a period in the two strata. In our study, access to the municipal drinking water supply was reported by 82% of the surveyed population compared to 67%

Table 4: Final model for prevalence of morbidities likely associated with consumption of biologically or chemically contaminated water

Variable	Odds Ratio (adjusted)	*P* (adjusted)	95% Confidence interval		Unadjusted Pseudo R^2	pseudo R^2
Biological contaminants						
Stratum	2.005871	0.089	0.899936	4.470893	0.0084	0.0333
Female Gender	3.800282	0.007	1.437763	10.04487	0.0250	
Chemical contaminants						
Stratum	1.056091	0.525	0.89244	1.249742	0.0014	0.2721
Age	1.074849	0.000	1.06920	1.080523	0.2458	
Female Gender	1.562027	0.000	1.28265	1.902254	0.0030	
Literacy status	1.286725	0.000	1.18087	1.402062	0.0047	
Occupation						
Unskilled labor	0.8995119	0.685	0.53946	1.49985	0.0103	
Agriculture	0.4458679	0.523	0.03733	5.324739		
Service	1.35849	0.026	1.03729	1.779146		
Other occupation	0.8448445	0.232	0.64091	1.113666		
Gas exposure	1.774802	0.000	1.48818	2.116623	0.1026	
Religion						
Muslim	1.519786	0.000	1.27941	1.805323	0.0033	
Other religions	1.32854	0.266	0.80541	2.19145		

α=0.05

population in 2011.[12] The dependency of the communities on non-municipal water sources has decreased over a period of time, especially in stratum I where in the past 43% population depended on non-municipal sources of water as compared to present 18%. We found communities, especially females, living in stratum I (nearby to the UCIL plant) at higher risk of suffering from biologically contaminated water associated diseases though, the association was very weak (pseudo R^2 0.0333), explaining only 3% variability. Lower value of pseudo R^2 suggests a lot of variation and consequently inadequate and doubtful goodness-of-fit of such model.

Significantly higher prevalence of morbidities, likely related to the consumption of chemically contaminated drinking water was recorded in stratum II (10.2%) compared to stratum I (8.5%) with hypertension and diabetes mellitus being the main contributors in this group of morbidities. Though termed as lifestyle-related diseases, studies have suggested that chronic exposure to inorganic arsenic might lead to hypertension[13] and diabetes mellitus.[14] Overall, 5.6% prevalence of hypertension was recorded in our study. Earlier, the Annual Health Survey 2012-13 of Government of India[15] reported a lower hypertension prevalence of 2.7% in Bhopal. At the country level, ICMR-INDIAB study reported a much higher prevalence of hypertension (26.3%) among ≥20 years old individuals.[16] In comparison, we found 9% prevalence of hypertension among ≥ 20 years of age in the present study. Compared to the overall prevalence of 2.7% diabetes in our study, WHO-ICMR Indian Non Communicable Diseases risk factor surveillance study reported 4.5% prevalence of self-reported diabetes.[17] Chronic renal failure, suggested to be a health consequence of long-term consumption of chemically contaminated water,[18] was recorded in 0.03% subjects in our study with comparable prevalence in the two strata. Formation of renal stone/calculi, another renal condition suggestively caused by consuming chemically contaminated water,[19] was recorded in 0.2% individuals in our study which is lower than national figure of 0.5%-0.7%.[19]

We found, by and large, similar pattern of morbidities in the two strata with hypertension and diabetes being the most prevalent morbidities. This suggested that population in both the strata, irrespective of nearness/distance of their residences from the UCIL plant, were equally vulnerable to various morbidities. Nevertheless, relatively higher prevalence of neoplasm/cancer and mental growth retardation in stratum I, though their numbers were far and few between in both the strata, is a matter of concern and needs proper investigation on its probable causes. Further, it can also be inferred that the present predominant source of drinking water, that is, treated municipal water in the two strata is perhaps not related to the morbidities likely associated with either biological or chemical contamination of water.

Strength/Limitations of the Study and Conclusion

Though the strength of the study is a large sample size, that is, clinical examination of about 10,000 individuals of Bhopal to generate information on the morbidity patterns about drinking water sources among the communities residing at variable distances from the UCIL plant, it has a limitation of recall bias of the respondents and non-exclusiveness of the drinking water sources used by the respondents. Another limitation of this study is not characterizing the extent and nature of contamination of groundwater sources, route of exposure based on water usage such as drinking, skin absorption etc., and lack of exposure-assessment approach to better understand the morbidities caused due to the contaminated ground water. Arguably absence of this component reduces validity of results to a large extent, nonetheless, study brings out the fact that populations residing nearby to the UCIL plant are not at any additional risk of suffering from various morbidities. This should dispel the fear of people living close to the UCIL plant about being suffering from adverse health consequences due to the consumption of chemically contaminated water. Nevertheless, it would be prudent to undertake long-term follow-up of these residents. Further, exploration of pollutant-specific morbidities based on the toxicology of likely pollutant(s) instead of general morbidities would have made the study more robust. Any future study in this area must consider these issues for providing specific answers to the concern of chemical contamination of the water sources and its impact on human health in Bhopal.

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Declaration of patient consent

The authors certify that they have obtained appropriate signed patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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