Objective: A cross-sectional study was undertaken to assess the prevalence of morbidities in communities residing at variable distances from the closed 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.

KEY WORDS: Bhopal gas disaster, drinking water contamination, morbidity pattern, toxic waste

Received: 22-07-2019
Review completed: 26-10-2019
Accepted: 23-12-2019
Published: 01-04-2020

Access this article online
Quick Response Code:
Website: www.jpmonline.com
DOI: 10.4103/jpgm.JPGM_391_19
PubMed ID: 32167062

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: reprints@medknow.com

How to cite this article: Banerjee N, Banerjee A, Sabde Y, Tiwari RR, Prakash A, NIREH Epidemiology Research Group. 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. J Postgrad Med 2020;66:73-80.
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 mostly 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 $N = Z^2 \times P \times (1-P)/C^2$ 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 ($N= (2.532)^2 \times 0.094 \times 0.906/(0.01)^2 = 5,460$). 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 morbidty 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 or (ii) consumption of chemically contaminated water. Descriptive analysis based on the two-sample test of proportion ($\chi^2$ 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 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 (45.3% 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
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 biologically contaminated water and the risk factors.
biologically contaminated drinking water, and the distance from the UCL 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.

| Disease                          | Stratum I (\(n=4,641\)) | Stratum II (\(n=4,665\)) |
|----------------------------------|--------------------------|---------------------------|
| 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 (\( \chi^2 \) test)

biologically contaminated drinking water, and the distance from the UCL 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 drinking water...
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 0.2721 showed 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][6] 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.[6] 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 $R^2$ | $\text{pseudo } R^2$ |
|------------------------|-----------------------|-------------|-------------------------|-------------------------|---------------------|
| 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. 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 45% 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 R² 0.0333), explaining only 3% variability. Lower value of pseudo R² 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 and diabetes mellitus. Overall, 5.6% prevalence of hypertension was recorded in our study. Earlier, the Annual Health Survey 2012-13 of Government of India 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. 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 4.3% prevalence of self-reported diabetes. Chronic renal failure, suggested to be a health consequence of long-term consumption of chemically contaminated water, 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, was recorded in 0.2% individuals in our study which is lower than national figure of 0.5%-0.7%.

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.

Acknowledgements

We are thankful to the surveyed community members for their cooperation and participation in the study. The advice of Dr. S.M. Mehdendale, Additional Director General, ICMR in data analysis and interpretation is gratefully acknowledged. Intramural grant for the study provided by Indian Council of Medical Research in the form of an intramural project is acknowledged.

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.

Financial support and sponsorship

Indian Council of Medical Research as an intramural activity of ICMR-National Institute for Research in Environmental Health, Bhopal.

Conflicts of interest

There are no conflicts of interest.

References

1. Tachakra SS. The Bhopal disaster. J R Soc Health 1987;107:1-2.
2. Dhara R. Health effects of the Bhopal gas leak: A review. Epidemiol Prev 1992;14:22-31.
3. Mishra B, Banerjee N, Singh S, Tiwari S. An epidemiological study of symptomatic morbidities in localities around solar evaporation ponds and behind Union Carbide factory, Bhopal. Natl J Community Med 2013;4:588-93.
4. Mishra B, Banerjee N. MIC leak disaster and environmental
contamination: Time to act now. Natl J Community Med 2014;5:13-20.
5. Assessment of pollution damage due to Solar Evaporation Ponds at UCIL, Bhopal. A Report by National Environmental Engineering Research Institute, Nagpur, India; 1990. p. 1-154.
6. Labunska I, Santillo D. High Levels of Chlorinated Organic Compounds, Including Tetrachloromethane, in Water from Well Adjacent to Former Union Carbide India Ltd (UCIL) Pesticide Plant, Bhopal (India). Technical note by Greenpeace Research Laboratories, Department of Biological Sciences, University of Exeter, Exeter UK; 2004. p. 1-12.
7. Assessment and Remediation of Hazardous Waste Contaminated Areas in and around M/s Union Carbide India Ltd (UCIL) Pesticide Plant, Bhopal: Final Report. Nagpur, India: National Environmental Engineering Research Institute; 2010. p. 1-75.
8. Analysis of Soil and Ground Water Samples in Bhopal: Results of Ground, Water and Soil Samples Collected from UCIL Premises, Bhopal in November, 2012. Final Report. Lucknow, India: CSIR-Indian Institute of Toxicology Research; 2013. p. 1-50.
9. Annual Report 2013-2014. National Institute for Research in Environmental Health (Indian Council of Medical Research), Bhopal. 2014. p. 5-9.
10. Hunter PR, Waite M, Ronchi E, editors. Drinking Water and Infectious Disease: Establishing the Links. 1st ed. London: CRC Press; 2002. p. 1-256.
11. Guidelines for Drinking-Water Quality. 4th ed. Switzerland: World Health Organization; 2011. p. 1-518.
12. Narayan S, Srinivasa RK, Pandey P, Banerjee S, Chaudhuri J. Madhya Pradesh: Bhopal. In: Excreta Matters: 71 Cities: A survey. New Delhi, India: Publisher Centre for Science and Environment; 2012. p. 237-45.
13. Islam MR, Khan I, Attia J, Hassan SMN, McEvoy M, D’Este C, et al. Association between hypertension and chronic arsenic exposure in drinking water: A cross-sectional study in Bangladesh. Int J Environ Res Public Health 2012;9:4522-36.
14. Sung T, Huang J, Guo H. Association between arsenic exposure and diabetes: A meta-analysis. Bio Med Res Int 2015;2015:368087.
15. Annual Health Survey- 2012-13 Fact Sheet: Madhya Pradesh. Office of The Registrar General & Census Commissioner, India, Ministry of Home Affairs, Government of India. p. 32-47.
16. Bhansali A, Dhandania VK, Deepa M, Anjana RM, Joshi SR, Joshi PP, et al. Prevalence of and risk factors for hypertension in urban and rural India: The ICMR-INDB study. J Hum Hypertens 2015;29:204-9.
17. Mohan V, Mathur P, Deepa R, Deepa M, Shukla DK, Menon GR, et al. Urban rural differences in prevalence of self-reported diabetes in India-the WHO-ICMR Indian NCD risk factor surveillance. Diabetes Res Clin Pract 2008;80:159-66.
18. Miller AC, Arquilla B. Chronic diseases and natural hazards: Impact of disasters on diabetic, renal, and cardiac patients. Prehospital Disaster Med 2008;23:185-94.
19. Barrett JR. Chemical contaminants in drinking water: Where do we go from here? Environ Health Perspect 2014;122:A 80.