Appendix II

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Groundwater Contamination near the Union Carbide Plant at Bhopal

A Draft Research Report

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Environmental Quality Monitoring Group
PSI
Dehra Doon

Groundwater Contamination Near The Union Carbide India Ltd. Plant At Bhopal

I. INTRODUCTION

The world's most devastating industrial disaster occurred on the night of 3rd December, 1984. Toxic MIC (methyl iso-cyanate) gas escaped into the ambient air of Bhopal city from the premises of the UCIL plant and resulted in an unprecedented public health emergency, the legacy of which stays on till date to haunt the surviving victims and their future generations. On that night, people woke up with irritating cough and severe burning sensation in the eyes, followed by suffocation that soon became intolerable. Thousands of people were killed instantly as the MIC gas clouded Bhopal city. While the official death toll stands at 5000, voluntary organisations working at Bhopal report a figure of about 20,000 **(1)**. It is estimated that as many as 500,000 people have suffered permanent, adverse health impacts due to the gas release **(2)**. A joint study conducted by researchers of ITRC and medical practitioners of Lucknow revealed that the immediate impacts of the exposed population were manifested mainly through three types of physiological problems; ophthalmological (eye-related), respiratory and neurological **(3)**. The disaster not only claimed a large number of human, animal and plant lives, but also left a catastrophic imprint on the entire vegetation and soil biota of the area **(4)**. The legacy of the poisonous gas has even been passed over to the future generations, to the children **(5)** of the affected populace. Human rights activists, and survivor organisations have been fighting a relentless battle against both the government and the offending company, the Union Carbide Corporation (now owned by Dow Chemicals Ltd.). The point they have been raising for almost two decades now is that the accident occurred due to improper operating conditions and inadequate safety arrangements in the plant, for which the residing population was made to bear the brunt. Hence, it is the responsibility of the violators to take responsibility of this inexplicable act and to compensate for the loss of human lives and property. An out of court settlement did grant the victims some compensation, but till date they are faced with problems of

unavailability of proper medical attention, unemployment [6] and are looking straight down a dark tunnel of uncertainty.

The Union Carbide India Ltd. (UCIL), located in a crowded working class neighbourhood in Bhopal, the capital of Madhya Pradesh, was established to manufacture phosgene, monomethyl amine, methyl iso-cyanate and the pesticide carbaryl, also known as Sevin, all aimed at the growing Indian agro-chemical market. It operated from 1977 to 1984 till the date of the accident after which the plant was shut down. The UCIL plant dealt with a multitude of organic compounds to manufacture the pesticide carbaryl (Sevin). Phosgene and Monomethyl amine (MMA) were the main raw materials involved in the process of manufacturing Methyl iso-cyanate (MIC), which in turn was used in combination with excess alpha-naphthol to produce Sevin. By-products like chloroform, carbon tetrachloride, MMA, ammonium chloride, dimethyl urea were all collected and recycled back to the process.

On the night of December 3, 1984, the inadvertent entry of water in to a MIC storage tank resulted in a runaway chemical reaction resulting in rapid rise in pressure and temperature. The heat generated by this reaction, the presence of high concentrations of chloroform and iron catalyst resulted in the release of toxic MIC gas [8]. The factory was closed after the accident and a series legal battles and controversies followed. But, **little attention was paid to the fate of the accident site of the abandoned UCIL factory**. It was not realised then, that the miseries of the panting population would be compounded and complicated by the huge quantum of the toxic organic substances that lay unheeded inside the redundant plant.

It was at the instance of people like Abdul Jabbar of Bhopal Gas Peedit Mahila Udyog Sangathan (BGPMUS) and Satinath Sarangi of Bhopal Group for Information and Action (BGIA) that this issue was raised in public. Series of studies followed their plea to reveal that toxic substances stored inappropriately inside the plant site were mingling with the soil [9] and posing threats of reaching and contaminating the aquifer if not contained properly. Some of the latter studies endorsed the fact that the quality of groundwater in the area was getting affected.

Table 1: List of studies undertaken from time to time in Bhopal confirming groundwater contamination.

Sl No.	Organisation	Research Findings
1	National Toxics Campaign Fund (1990)	Groundwater of communities adjacent to the factory contained **Dichlorobenzene** (722 ppb) and **Trichlorobenzene** (24 ppb).
2	NEERI, Nagpur and M/s Arthur D Little Inc., USA (1993)	• Water quality within an area of radius 1 km. met the quality standards. • Presence of **Volatiles** and **Semi- volatiles** in tested soil samples. • Recommended the need to undertake a detailed investigation.
3	PHE Deptt., Bhopal (1996)	High levels of **COD** was detected in water of Arifnagar, Kainchi chhola, JP Nagar, Atal Ayub Nagar.
4	IICT, Hyderabad (1996)	• The IICT study showed the presence of **Heavy metals** (Cadmium, Chromium, Copper, Lead, Manganese Nickel and Zinc) in **wastes** dumped within the factory. **Naphthol** and other volatile organic matter were also detected in the same waste.
5	Greenpeace International (1999)	• Chloroform, Carbon Tetrachloride, Tricholroethane, Tetrachloroethane, Hexachloroethane,, Chlorobenzene, Dichlorobenzenes and Trichlorobenzenes were detected in the groundwater by Organic Screening Analysis. • Concentrations of Chloroform, Carbontetrachloride, Dichlorobenzenes and Trichlorobenzenes in groundwater were seen to exceed WHO standards at **JP Nagar** and **Atal Ayub Nagar**.
6	Other Media (1999-2000)	• Concentrations of heavy metals in various handpump water samples were found to be above the recommended standards (BIS and WHO). • Water samples of Annu Nagar, Atal Ayub Nagar, J.P.Nagar, Kainchi Chola, Nawab colony, New Arif Nagar, Rajgarh colony and Shakti Nagar contained **Nickel** in concentrations higher than the WHO guideline value. **Mercury** was detected in elevated concentrations in water of Anu Nagar, New Arif Nagar, Rajgarh Colony and Shakti Nagar. Concentration of **Lead** exceeded the BIS Standard value in Kainchi chola. • **Chloroform** and **Dichloromethane** were detected in levels higher than the WHO guideline values, in water samples of Annu Nagar, Atal Ayub Nagar, J.P.Nagar, Kainchi Chola, Nawab colony, New Arif Nagar, Rajgarh colony and Shakti Nagar.

Abdul Jabbar of Bhopal Gas Peedit Mahila Udyog Sangathan contacted Peoples' Science Institute with the suspicion that contaminants from the UCIL plant was leaching from the storage area and affecting the groundwater of the area. His concern was supported by the fact that people living in low income colonies (basties) adjacent to the erstwhile plant often complained of pungent smelling water coming out of handpumps in that area. In absence of alternative supplies these people were forced to drink this water. Peoples' Science Institute decided to investigate this public health issue and started working on a monitoring study from September, 2001.

II. OBJECTIVES

The main objective of PSI's monitoring exercise was to assess the degree of groundwater contamination, if any, in the vicinity of the erstwhile UCIL plant particularly in the context of the huge quantum of the ill-contained toxic wastes lying unheeded inside. The idea of this monitoring was to test the probability of contaminants leaching from the plant into the groundwater.

Scope

After discussions with Abdul Jabbar, it was decided to focus the monitoring exercise on colonies adjoining the UCIL plant. Particularly in areas from where complaints about pungent water in handpumps had been received. A survey of the available literature relating to the studies conducted beforehand on the abandoned factory site brought out the fact that during 1967-1977 the effluents were dumped inside a large pit near the eastern boundary wall of the plant **(10)**. An ex-factory worker, having worked for 10 years at the UCIL plant gave a list of the chemicals that were routinely dumped within the factory premises **(11)**.

The list reads as follows:

Sl No.	Toxic substances	Quantity (MT)
1	Ortho dichlorobenzene	250
2	Carbon tetrachloride	200
3	Chloroform	100
4	Methyl Chloride	50
5	Methanol	10
6	Mercury	1
7	Sevin	50
8	Alpha Naphthol	50

Table 2: List of Chemicals dumped inside the factory premises from 1977-84.

In view of the potential hazards exhibited by Mercury in Japan (Minamata disease), [12] and Iraq (epidemic due to ingestion of contaminated bread prepared from wheat and other cereals with alkyl-mercury fungicide residues, in 1971-72 affecting over 6000 people and causing 500 deaths) [13], PSI initiated an investigation to assess the concentration of mercury in the groundwater of the area adjoining the Union Carbide plant, treating Mercury as an indicator or tracer of pollution from the dumped solids and sludge.

Toxic Effects of Mercury [14]

Metallic mercury is a liquid at room temperature, but the metal evaporates readily into the air and can be carried to long distances. Mercury can enter the human body from air, contaminated water or food. Once mercury enters the human body, it can remain there for a long period. Human nervous system is very sensitive to Mercury. Exposure to sufficiently high levels of Mercury causes permanent damages to the brain and the Kidneys. Mercury may affect many different areas of the brain and their associated functions, resulting in a variety of symptoms. These include personality changes (irritability, shyness, nervousness), tremors, changes in vision (constriction or narrowing of the visual field), deafness, muscle incoordination, loss of sensation, and difficulties with memory (**Source: Agency for Toxic Substances and Disease Registry, USPHS**).

III. METHODOLOGY

As explained earlier, the main objective of the present was determination of the concentration of mercury in the groundwater of the area surrounding the UCIL plant. In order to do the assessment, water was collected from groundwater sources used by the low- income community residing in the area. The sources of groundwater in the area were handpumps, tubewells and wells.

a. Sample collection

A sampling schedule was developed, samples were collected from handpumps, tubewells and wells in the area in the pre-monsoon and the post-monsoon seasons, with a view to understand the effect of precipitation on the concentration of mercury in groundwater.

b. Testing of samples

The tests employed for determining the concentration of mercury (and Chloroform in the last round of monitoring) were done in accordance with Standard Methods [15], [16] (APHA, AWWA and WPCF) using an Atomic Absorption Spectrophotometer (GBC 932 plus) fitted with the Hydride Generator HG 3000 (Gas Chromatograph NUCON 5765 fitted with the ECD was used for determination of Chloroform concentration in water).

IV. RESULTS AND DISCUSSIONS

The monitoring started with collection and assessment of water samples from the area in September, 2001 (post-monsoon). The results of the analysis of the collected samples showed the presence of mercury in most of them, with maximum concentration recorded at Arif Nagar, located less than half a km to the north-west of the plant. Apart from Arif Nagar, concentration of mercury was seen to surpass the Bureau of Indian Standards specification of 1µg/L in New Arif Nagar, Atal Ayub Nagar, Risaldar Colony, Nawab Colony etc. The concentrations of mercury in groundwater of the area were plotted on a map. It was clearly seen that the worst affected area was the area immediately adjoining the UCIL plant site. In the absence of any other source of such a toxic chemical and in such high concentrations, it was easily realised that the source was inside the plant. This hypothesis was further supported by the fact that the maximum

concentration of Mercury was found in groundwater in areas just adjoining the plant. The concentration of mercury decreased in areas away from the site. It was also noticed that the concentration of mercury followed a particular trend, decreasing progressively in sites towards the north, north-east direction from the plant (see maps in Appendices). Consultation of Toposheet of the area **(17)** (refer Appendices), and the Central Ground Water Board report on the hydro-geological framework of Bhopal city **(18)** (refer Appendices), suggested the flow of groundwater in the north, north-eastern direction from the UCIL plant. So, there was a possibility that the contaminants from the plant site were moving with the groundwater in the direction of its flow. Mercury was not detected in groundwater towards the west and south of the plant, i.e., in the direction opposite to the flow of groundwater of the area. The results obtained in the first phase of monitoring made the second phase (pre-monsoon 2002) even more interesting.

Table 3: Mercury concentration in groundwater in the 3 study periods

Sl No	Sampling Station	Source type	Direction w.r.t. UCIL	Mercury concentration (µg/L) Post-Monsoon, 2001	Mercury concentration (µg/L) Pre-Monsoon, 2002	Mercury concentration (µg/L) Post-Monsoon, 2002
1	Karod Colony	TW	NW	2	1	*
2	Nawab Colony	HP	N	42	12	*
3	Arif Nagar	TW	NW	70	9	2
4	New Arif Nagar	HP	NW	40	10	6
5	Gareeb Nagar (Old)	TW	NE	24	24	5
6	Gareeb Nagar (Chandwari)	HP	NE	9	*	*
7	Atal Ayub Nagar	HP	NE	56	4	8
8	Chhola Naka	HP	NE	ND	2	*
9	Kainchi Chhola	TW	E	22	2	*
10	Selai Kendra, J.P.Nagar	HP	E	14	*	*
11	Risaldar Colony	TW	E	ND	12	9
12	Indira Colony	TW	NE	*	10	6
13	Panchwati Colony	HP	N	*	2	*
14	Sunder Nagar	TW	NE	*	*	14
15	Nishatpura	HP	NE	*	*	3
16	Rajendra Nagar	TW	E	ND	*	*
17	Green Park Colony	TW	W	ND	ND	*
18	Kazik Camp	TW	S	*	ND	*
19	Puththa Mill	HP	S	*	ND	*
20	Bus Stand	HP	S	*	ND	*

Note:

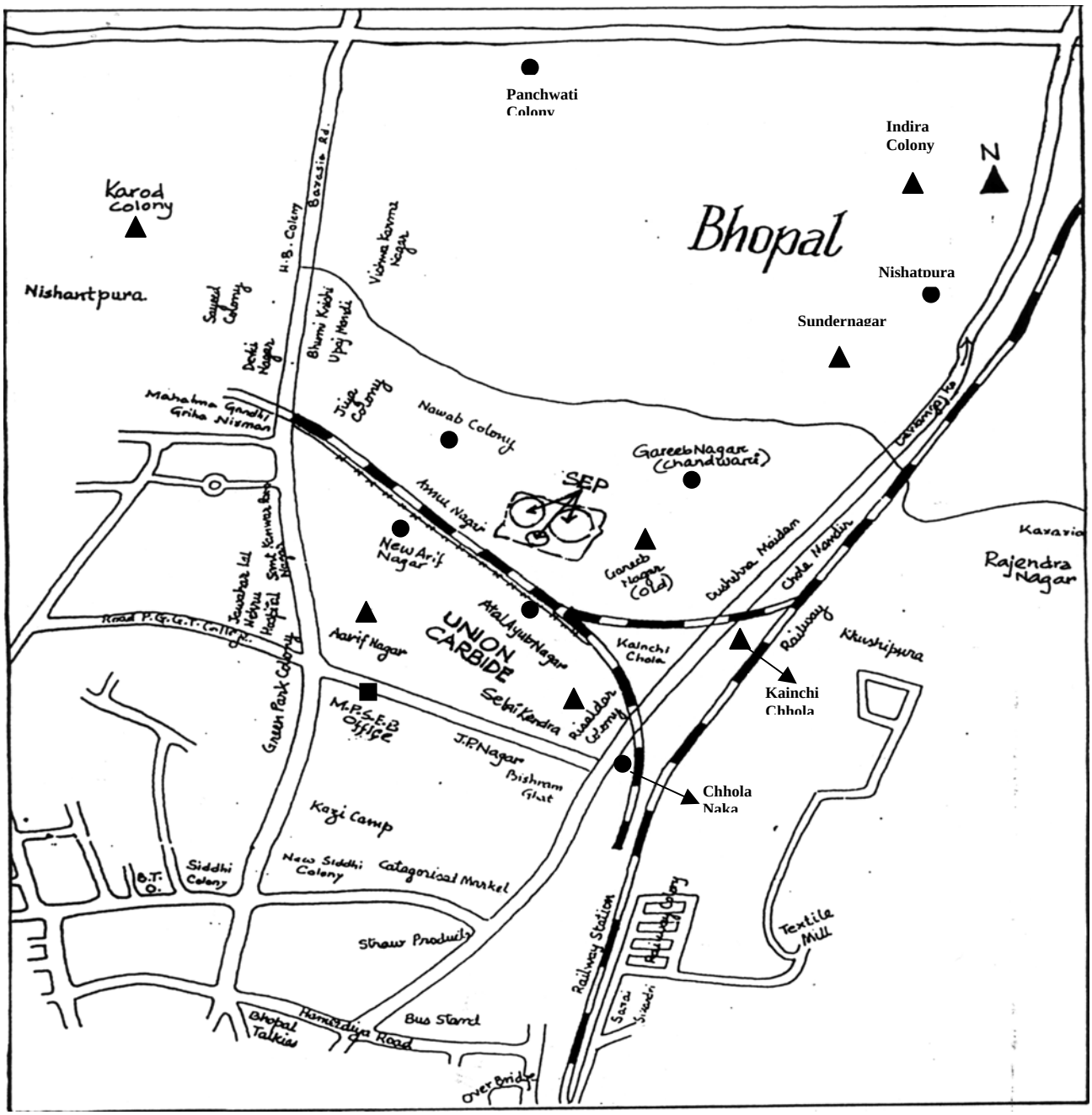
TW- Tubewell, **HP-** Handpump, **OW-** Openwell, **ND-** Not Detected, * Not Done.

After analysing the samples collected from the same sites (and a few additional sites) in April 2002, it became clear that mercury was leaching from the sources inside the erstwhile plant, and was being carried with rain water to the groundwater of the area. The pre-monsoon concentrations of mercury at the same sites were drastically reduced (as compared to the post-monsoon period), indicating no fresh additions from the source, in absence of rainwater.

Therefore, it beacme evident that mercury (and possibly other toxic chemicals) that are lying exposed and unheeded inside the redundant UCIL plant are leaching along with rainwater and is contaminating the groundwater.

A final monitoring was undertaken in October 2002. The number of sites this time were cut down to 8. 5 of them were located near the plant, from the area that was being considered as being most affected. And 3 sites from places towards the north east of the plant located progressively away from it. Higher concentration of Mercury was found in samples from areas close to the plant as compared to areas located away from it. It confirmed the earlier investigation report, and supported the possibility of movements of the contaminants along with the groundwater. The values this time, however, were lower than the values recorded during the post-monsoon monitoring in 2001. This suggested the possibility of lesser addition of mercury from its source inside the plant to the groundwater in 2002.

Fig: A map of Bhopal city showing sites with concentration of **Mercury** in groundwater **exceeding** the BIS Standard (**1µg/L**)



Legend:

▲ Tubewell

● Handpump

■ Openwell

During the post-monsoon monitoring of groundwater near the Union Carbide factory, water samples were collected for analyzing Chloroform concentration in them. The decision to analyse water samples for Chloroform was supported by the fact that huge quantum of Chloroform was dumped within the factory (See Table 2). Chloroform is designated as a possible carcinogen (Group 2B) by the International Agency for Research on Cancer (IARC), and is therefore, an extremely hazardous substance from the public health point of view. Very high concentration of **Chloroform** was detected in the water of **Atal Ayub Nagar**. The water was seen to contain **984µg/L** of chloroform; much higher than the WHO prescribed **standard of 200µg/L** [(19)] for drinking water. Chlkoroform was, however, not detected in the other samples.

V. CONCLUSIONS AND RECOMMENDATIONS

The situation is grave and poses threats of magnanimous proportions to the health and wellbeing of the people residing in the area. In order to resolve the crisis, it is absolutely imperative to contain the toxic chemicals lying inside the UCIL plant premises. Since, it is not known exactly when this phenomenon of leaching of toxic chemicals from sources inside the abandoned plant started, it is necessary to know the extent to which the contamination has spread over time. It should also be useful, if possible, to predict the rapidity with which the toxic chemicals are proliferating in the aquifer of the region. This would help prepare a strategy to counter the situation in future target areas that are likely to be contaminated in subsequent times. The recommendations that emerge out of this study are:

Action-oriented

- A rapid, action- oriented **Clean-up Operation** to remove the toxic hazardous wastes lying openly within the factory premises and to store them in sealed non-corrodable containers. This would prevent leaching of the hazardous wastes in to the soil and groundwater. Therefore, further proliferation of the toxic substances in adjoining areas would be minimised.
- All the sealed containers of the hazardous wastes recovered from the Carbide factory should be disposed off properly in **Disposal sites for Hazardous wastes** identified by

the State Government {as per the provisions of the **Hazardous Wastes (Management and Handling) Rules, 1989**}

- Areas, which have already been detected for groundwater contamination by the present study (and **other studies** taken up from time to time), should be provided with **alternative source of drinking water**. The authorities responsible for water supply and maintenance in Bhopal city should consult the Central Groundwater Board (North Central Region office at Bhopal) to examine possibilities of meeting the demand of drinking water in the affected areas through harvested and treated rainwater.

Research -oriented

- There is a need to undertake routine monitoring of the area under threat from the leaching chemicals.
- Theoretical prediction (by the help of mathematical modeling) of the movement of the contaminants from the UCIL would help in devising a mitigation strategy.

VI. REFERENCES

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1. Result Tables:

Table A : Sample analysis (Post-monsoon, 2001)

Sl. No.	Sampling Site	Source Type	Direction w.r.t. source	Depth (m)	Mercury concentration (µg/l)
1.	Karod Colony	Tubewell	NW	35	2
2.	Nawab Colony / Annu Nagar	Handpump	N	70	42
3.	Solar Evaporation Pond	Pond	NE	N.A.	38
4.	Arif Nagar	Tubewell	NW	70	70
5.	New Arif Nagar	Handpump	NW	95	40
6.	Gareeb Nagar (old)	Tubewell	NE	50	24
7.	Gareeb Nagar (chandwari)	Handpump	NE	65	9
8.	Atal Ayub Nagar	Handpump	NE	15	56
9.	Chhola Naka	Handpump	NE	35	ND
10.	J.P.Nagar	Handpump	SE	70	28
11.	M.P.S.E.B. Office, J.P. Nagar	Openwell	S	5	17
12.	Risaldar Colony	Tubewell	E	70	ND
13.	Rajendra Nagar	Tubewell	E	60	ND
14.	Kainchi Chhola	Tubewell	E	65	22
15.	'Selai Kendra', J.P.Nagar	Handpump	E	25	14
16.	Green Park Colony	Tubewell	W	18	ND

Note: Drinking Water Specification of the **Bureau of Indian Standards** (**BIS**) (IS 10500: 1991) lays down a non-relaxable limit of **1µg/l** of **Mercury** in **drinking water**

Note: Some of the data on depth of the water sources were taken from the Nagar Nigam and the local inhabitants reported the rest.

Abbreviations: NA- Not Available, ND- Not Detected, N- North, NE- North East, NW- NorthWest, S-South, SE- South East, E- East, W-West.

Table B: Sample analysis (Pre-monsoon, 2002)

Sl. No.	Sampling Site	Source Type	Direction w.r.t. source	Depth (m)	Mercury concentration (µg/l)
1.	Karod Colony	Tubewell	NW	35	1
2.	Nawab Colony / Annu Nagar	Handpump	N	70	12
3.	Arif Nagar	Tubewell	NW	70	9
4.	New Arif Nagar	Handpump	NW	95	10
5.	Atal Ayub Nagar	Handpump	NE	15	4
6.	Chhola Naka (Chhola mandir)	Handpump	NE	35	2
7.	M.P.S.E.B. Office, J.P. Nagar	Openwell	S	5	2
8.	Risaldar Colony	Tubewell	E	70	12
9.	Kainchi Chhola	Tubewell	E	65	2
10.	Gareeb Nagar (old)	Tubewell	NE	50	24
11.	Solar Evaporation Pond	Pond	NE	NA	12
12.	Indira Colony	Tubewell	NE	30	10
13.	Panchwati colony	Handpump	N	85	2
14.	Green Park Colony	Tubewell	W	18	ND
15.	Kazik Camp	Tubewell	S	NA	ND
16.	Putha Mill, Chola Road	Handpump	S	NA	ND
17.	Bus Stand	Handpump	S	NA	ND

Table C: Sample analysis (Post-monsoon, 2002)

Sl. No.	Sampling Site	Source Type	Direction w.r.t. source	Depth (m)	Mercury concentration (µg/l)
1.	Arif Nagar	Tubewell	NW	70	2
2.	New Arif Nagar	Handpump	NW	95	6
3.	Atal Ayub Nagar	Handpump	NE	15	8
4.	Risaldar Colony	Tubewell	E	70	9
5.	Gareeb Nagar (old)	Tubewell	NE	50	5
6.	Sunder Nagar	Tubewell	NE	35	14
7.	Nishatpura	Handpump	NE	20	3
8.	Indira Colony	Tubewell	NE	35	6