

Summary of Studies Conducted on Contamination of Union Carbide Site and Surrounding Areas in Bhopal

Summary of Findings			
Organic Contamination in Soil Samples			
Organic Contamination in Stockpile Waste Samples			
Heavy metal Contamination in Soil Samples			
Organic Contamination in Water Samples			
Heavy metal Contamination in Water Samples			
Summary of Studies			
	Year	Organisation/Institute	Title
1	2013	Indian Institute of Toxicology Research	Analysis of Soil and Groundwater Samples in Bhopal
2	2010	National Environmental Engineering Research Institute (NEERI) and National Geophysical Research Institute (NGRI)	Assessment and Remediation of Hazardous Waste contaminated Areas in and around M/s Union Carbide India Ltd., Bhopal
3	2010	Indian Institute of Chemical Technology	Technical and Tender Document for Detoxification, Decommissioning and Dismantling of Union Carbide Plant
4	2009	Centre for Science and Environment	Contamination of Soil and Water inside and outside the Union Carbide India Limited, Bhopal
5	2009	Central Pollution Control Board	A Study by Central Pollution Control Board
6	2002	Greenpeace	Chemical Stockpiles at Union Carbide India Limited in Bhopal: an investigation
7	2002	Fact Finding Mission & Shrishti	Surviving Bhopal: Toxic Present, Toxic Future
8	2001-02	Peoples Science Institute	Groundwater Contamination near the Union Carbide Plant at Bhopal
9	1999	Greenpeace	The Bhopal Legacy
10	1997	NEERI	Assessment of Contaminated Areas due to Past Waste Disposal Practices by EILL, Bhopal
11	1996	State Research Laboratory, Public Health Engineering Department, Government of Madhya Pradesh	Report of Chemicals Found in Water for Communities Around UCIL premises
12	1992	NEERI	Process Package for Disposal of SEP Contents at UCIL, Bhopal
13	1990	Bhopal Group for Information and Action, Bhopal	Union Carbide in Bhopal, India-The lingering legacy
14	1989	Union Carbide Corporation	Site Rehabilitation Project –Bhopal Plant

Introduction

The review of studies conducted shows that contamination inside and outside the plant premises follow a certain trend. Among all the chemicals categorized below, the ones with direct relation with the production process of pesticides have been found most frequently in almost all the studies. The UCIL factory used to manufacture carbaryl (trade name sevin) and aldicarb (trade name temik). It also formulated saviodol, a combination of carbaryl and HCH isomers. Mercury was used as sealant and chromium as coolant. Alpha naphthol was used in production of sevin and dichlorobenzene was used for production of alpha naphthol.

It is evident from the review that these chemicals were found present by almost all major studies in the soil samples taken from within the plant premises. Similarly, groundwater samples collected from surrounding areas also showed a trend. More persistent chemicals like HCH isomers and dichlorobenzene were most commonly at the sites tested in different studies. At least three different studies also found groundwater to be contaminated with mercury. Though, levels of contaminants found both in soil and water samples varied in different studies, it is concluded that the contamination inside the UCIL factory and its surrounding areas is because of unscientific dumping of hazardous chemicals in the plant premises.

While summarizing, certain approximations related to sampling areas are taken. Limited data was available in some cases.

The contaminants found in different studies could be categorized into following groups:

Carbamate Pesticides

- Aldicarb
- Carbaryl

Heavy Metals

- Mercury
- Lead
- Chromium
- Nickel
- Cadmium
- Copper
- Cobalt
- Manganese
- Zinc
- Arsenic

Chlorinated organic compounds

- Dichlorobenzenes
- Trichlorobenzenes
- Tetrachlorobenzenes
- Chloroform
- Carbon tetrachloride

Organochlorines

- Hydrochlorocyclohexenes (HCH isomers)

- DDT and its degradation products

Others

- Naphthalene and its derivatives
- Aromatic compounds
- Aliphatic hydrocarbons

Abbreviations and symbols

- Car – Carbaryl
- Ald – Aldicarb
- HCH – Hydrochlorocyclohexane
- DCB – Dichlorobenzene
- Hg – Mercury
- Cr – Chromium
- Pb – Lead
- TCB – Trichlorobenzene
- Nap – Alpha Naphthol
- Ni – Nickel
- Zn – Zinc
- Cu – Copper
- Mn – Manganese

Summary of Findings: Organic Contamination in Soil Samples

Sampling spot	IITR, 2013	NEERI, 2010	CSE, 2009	CPCB, 2009	Fact finding Mission, 2001-02	Greenpeace, 1999	NEERI, 1997
Temik plant	0.366 (Car) 0.809 (HCH) 0.324 (DCB)	24.3 (Car) 923 (Ald) 36.36 (HCH) 0.000097 (DCB) 42.7(Nap)	29.17 (HCH) 4.94 (TCB)	0.03 (Ald) 21.17 (HCH)			
Formulation plant	0.295 (Car) 2572.67 (HCH) 3.774 (Nap)	1.3 (Car) 3.734 (Ald) 1.152 (HCH) 1.9(Nap)	7.47 (Car) 190.69 (Ald) 3119.37 (HCH) 2048.53 (DCB) 507.05 (TCB)	5.25 (Car) 6193 (HCH)		Detected (HCH)	
Soapstone shed	0.201 (Car) 1.431 (HCH) 0.209 (DCB) 2.186 (Nap)	24.6 (Car) 0.76 (HCH) 14.94(Nap)					
Sevin plant	0.172 (Car) 0.39 (HCH) 0.15 (Nap)	0.126 (Car) 0.77 (HCH) 0.000017 (DCB) 0.54(Nap)	412.83 (HCH) 26.93 (DCB) 23.72 (TCB)	13.468 (HCH)	1.6878 (HCH) 0.1292 (DCB) 0.1927 (TCB)	Detected (HCH)	
MIC storage	0.286 (Car) 0.018 (HCH) 3.549 (Nap)	18.3 (Car) 3.778 (Ald) 0.118 (DCB) 0.661 0.267(Nap)					
BHC store	1.004 (Car) 36.783 (HCH) 0.918 (DCB) 3.195 (Nap)	2.48 (Car) 6.17 (HCH) 1.55(Nap)					
Water treatment plant	0.588 (Car) 4.733 (HCH) 2.499 (DCB) 5.612 (Nap)	0.174 (Car) 1.037 (HCH) 0.000013 (DCB) 0.511(Nap)					
Neutralization pits	0.504 (Car) 0.01 (HCH) 0.203 (DCB) 1.588 (Nap)	10729 (Car) 3.884 (Ald) 13.34 (HCH) 0.165 (DCB) 1460 (Nap)				Detected (HCH) Detected (DCB)	5105 (Ald)
Storage tanks		2.43 (HCH)					
Laboratory	0.127 (Car) 9.368 (HCH)	10.77 (Car) 0.31 (HCH) 0.11 (DCB) 32.9 (Nap)					
Napthol plant	0.196 (Car) 8.979 (HCH)	7.68 (Car) 3.713 (Ald)			0.07 (HCH) 0.1212 (DCB)		

	0.661 (DCB) 3.549 (Nap)	1.44 (HCH) 0.00009 (DCB) 24.23 (Nap)			0.2137 (TCB)		
Solar Evaporation pond			19.83 (HCH) 1.25 (DCB)	0.137 (Car) 1.497 (HCH)	0.0358 (HCH) 0.1215 (DCB) 0.1469 (TCB)	Detected (DCB)	
Disposal area I							365.32 (Car) 74.36 (Ald)
Disposal area II			9858.61 (Car) 116.51 (Ald) 1162.19 (HCH) 237.55 (DCB) 104.68 (TCB)	333.5 (Car) 18410 (HCH) 6.34 (DCB) 10.23 (TCB)			7218 (Car) 92.34 (Ald)

An analysis of findings of studies on chemical contaminants in soil at various sites in UCIL plant premises showed that carbaryl, aldicarb, lindane (HCH), and dichlorobenzene were found present in significant quantities. Some sites such as formulation plant and neutralization pits showed presence of multiple contaminants which were found in most of the studies at these places. For carbaryl, maximum concentration recorded among these spots was 10729 ppm which was found by NEERI in 2010 near neutralization pits. The maximum concentration of 5105 ppm for aldicarb was also found near neutralization pit in NEERI's study in 1997. For total HCH, CPCB in 2009 found maximum concentration of 18410 ppm near BHC store. CSE in 2009 found a maximum concentration of 2084 ppm for dichlorobenzene near soapstone shed.

Summary of Findings: Organic Contamination in Stockpile Waste	
Sampling spot	Greenpeace 2002 (<i>stockpile waste</i>)
Formulation plant	0.001122(Car) 99700 (HCH)
Soapstone shed	0.001839 (Car) 38.5 (HCH)
Sevin plant	0.000083 (Car) 5010 (HCH)
BHC store	0.000962 (Car) 180500 (HCH)
Small shed	0.000026 (Car)
Cycle shed	47.3 (HCH)

Greenpeace in 2002 conducted studies on the stockpile waste lying in the plant premises. The results showed that the waste was highly contaminated with HCH isomers. The concentration of HCH in sample from BHC store was as high as 180500 ppm. Carbaryl was also found present in most of the samples with a highest concentration of 0.001122 ppm near formulation plant.

Summary of Findings: Heavy metal Contamination in Soil Samples						
Sampling spot	IITR, 2013	NEERI-NGRI, 2010	CSE, 2009	CPCB, 2009	Fact finding mission, 2001-02	Greenpeace, 1999
Temik plant	0.084 (Hg) 29.614 (Cr) 88.583 (Pb)	2.22 (Cr) 4.3 (Pb)	74.14 (Hg) 297.7 (Cr) 111.78 (Pb)	48.48 (Hg) 343 (Cr) 92 (Pb)		
Formulation plant	3.568 (Hg) 145.08 (Cr) 26.031 (Pb)	1.29 (Hg) 2.32 (Cr) 4.29 (Pb)	108.4 (Cr)	2.87 (Hg) 183 (Cr) 42 (Pb)		2.6 (Hg) 85.7 (Cr) 19.4 (Pb)
Soapstone shed	1.547 (Hg) 26.186 (Cr) 24.047 (Pb)	2.1 (Hg) 2.97 (Cr)				
Sevin plant	0.088 (Hg) 24.977 (Cr) 30.545 (Pb)	1.83 (Cr) 6.64 (Pb)	8188.33 (Hg) 192.13 (Cr) 84.05 (Pb)	7995.83 (Hg) 451 (Cr) 95 (Pb)	0.152 (Cr)	128000 (Hg) 480.7 (Cr) 174.6 (Pb)
MIC storage	31.751 (Pb)	0.1 (Hg) 3.04 (Cr) 0.98 (Pb)				
BHC store	3.541 (Hg) 30.012 (Cr) 25.458 (Pb)	4.17 (Hg) 3.02 (Cr) 5.99 (Pb)				
Water treatment plant	0.242 (Hg) 37.197 (Cr) 25.263 (Pb)	2.41 (Cr) 4.62 (Pb)				
Neutralization pits	0.098 (Hg) 29.106 (Cr) 24.46 (Pb)	3.07 (Hg) 3.97 (Cr) 7.58 (Pb)				8.1 (Hg) 520.8 (Cr) 406.3 (Pb)
Laboratory	0.089 (Hg) 34.745 (Cr) 40.547 (Pb)	1.98 (Cr) 2.41 (Pb)				
Napthol plant	0.255 (Hg) 38.811 (Cr) 30.926 (Pb)	0.41 (Hg) 3.8 (Cr) 2.03 (Pb)			1.898 (Hg)	
Cycle shed					0.0206 (Cr)	
Solar Evaporation pond			18 (Hg) 1064.57 (Cr) 22.34 (Pb)	28.13 (Hg) 1110 (Cr)	0.5269 (Cr) 0.2767 (Pb)	1.1 (Hg) 73 (Cr) 17 (Pb)
Disposal Area II			1064.61 (Hg) 86.18 (Cr) 46.39 (Pb)	557.53 (Hg) 112 (Cr) 22 (Pb)		

At least six different studies tested for presence in heavy metals in soil and waste samples from UCIL plant premises. Mercury, chromium and lead were among most common heavy metals found. The maximum concentration of mercury was found in a sample from Sevin plant by Greenpeace in 1999. The sample contained more than 12 percent of mercury. CSE in 2009 found maximum concentration of 1064 ppm for chromium in a sample near solar evaporation pond. Greenpeace in 1999 also found a maximum of 406 ppm for lead in a sample from near neutralization pits.

Summary of Findings: Organic Contamination in Groundwater Samples (ppb)					
Sampling spot	IITR, 2013	CSE, 2009	CPCB, 2009	Fact finding mission, 2001-02	Greenpeace, 1999
UCIL Plant		15.4 (HCH) 0.8 (DCB)			60 (DCB)
J. P. Nagar		3.1 (HCH) 0.0008 (DCB)	0.11 (HCH)	1.8 (HCH) 9.4 (DCB)	50 (DCB)
Nawab Colony	0.688 (HCH) 2.027 (DCB)	0.4 (HCH) 0.3 (DCB)	0.72 (HCH)	1.3 (HCH) 1.2 (DCB)	2875 (DCB)
Shiv Shakti Nagar	0.251 (HCH) 9.917 (DCB)				
Blue moon Colony	0.991 (HCH) 3.621 (DCB)	0.6 (HCH) 0.7 (DCB)			
Atal Ayub Nagar		1.1 (HCH) 0.5 (DCB)	0.12 (HCH) 651.91 (DCB)	2.7 (HCH) 0.8 (DCB)	
Anu Nagar	4.249 (DCB)	0.5 (HCH) 0.4 (DCB)		40.2 (HCH) 10.4 (DCB)	
Kanchi Tola	6.375 (DCB)		0.56 (HCH)	3.2 (HCH) 14.7 (DCB)	
Arif Nagar	0.029 (HCH)	1.2 (HCH) 0.2 (DCB)			
Prem Nagar	0.576 (HCH) 5.651 (DCB)	1.7 (HCH) 0.5 (DCB)			
Navjeevan Colony	0.388 (HCH) 8.271 (DCB)				
Garib Nagar		1.4 (HCH) 0.9 (DCB)	0.4752 (HCH)		
Sundar Nagar		0.8 (HCH) 0.4 (DCB)	0.0804 (HCH)		
New Arif Nagar				3 (HCH)	
Shakti Nagar	5.04 (DCB)			36.7 (HCH)	
Preet Nagar	6.411 (DCB)				
Shiv Nagar	8.751 (DCB)	3.5 (DCB)			
Indira Nagar			0.1038 (HCH)		

Groundwater was mainly found contaminated with HCH isomers and chlorinated benzenes. At least four different studies found presence of HCH isomers in groundwater samples. Similarly, at least five of the studies found dichlorobenzene present in the groundwater samples. A maximum concentration of 40.2 ppb of HCH isomers was found by Fact Finding Mission in a sample from Anu Nagar area. Similarly, a maximum of 2875 ppb of dichlorobenzene was found by Greenpeace in 1999 in a sample from Nawab colony.

Summary of Findings: Heavy metal Contamination in Groundwater Samples				
Sampling spot	CSE, 2009	CPCB, 2009	Fact finding mission, 2001-02	Peoples Science Institute, 2001
J. P. Nagar		1590 (Zn) 100 (Mn)	14.9 (Cr) 744.7(Ni) 49.7 (Pb)	
Nawab Colony	90 (Cd) 1220 (Pb)	50 (Cu) 1810 (Zn) 350 (Mn)	9.5 (Cr) 1800 (Ni) 11.7 (Pb)	42 (Hg)
Atal Ayub Nagar		30 (Cu) 40 (Zn)	11.7 (Cr) 1875 (Ni)	56 (Hg)
Anu Nagar			293.9 (Hg) 10.7 (Cr) 903.6 (Ni) 1.3 (Pb)	70 (Hg)
Kanchi Chola		400 (Zn) 20 (Mn)	21 (Cr) 941.7 (Ni) 54.8 (Pb)	
Navjeevan Colony				
Garib Nagar		550 (Zn) 40 (Mn)		24 (Hg)
Sundar Nagar		480 (Zn) 20 (Mn)		
New Arif Nagar			119.7 (Hg) 5.7 (Cr) 1080 (Ni) 39.8 (Pb)	40 (Hg)
Shakti Nagar			31.7 (Hg) 12.6 (Cr) 715.5 (Ni) 11.3 (Pb)	
Shiv Nagar	24 (Hg)			
Indira Nagar		130 (Zn) 2770 (Mn)		
Panchwati		730 (Zn) 20 (Mn)		
Chhola Naka		280 (Zn) 20 (Mn)		
Solar Evaporation Ponds			34.3 (Hg) 11.6 (Cr) 186.1 (Ni) 32.1 (Pb)	

Groundwater in the surrounding areas of the UCIL plant was found contaminated with multiple heavy metals such as mercury, cadmium, chromium, manganese, zinc, lead and nickel. At least three of the studies found mercury contamination at different places. A highest of about 240 ppb of mercury was found in a sample from Anu Nagar by Fact Finding Mission in 2001-02. A highest of 1220 ppb of lead was found by CSE in a sample from Nawab colony in 2009. Fact Finding Mission in 2001-02 found a maximum of 21 ppb of chromium from a sample from Kanchi tola. A sample from Nawab colony was found to contain 1810 ppb of zinc by CPCB in 2009.

Summary of Studies

1	2013	Indian Institute of Toxicology Research	Analysis of Soil and Groundwater Samples in Bhopal
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Sampling

IITR shows tested 10 samples of soil and 30 samples of groundwater from around the UCIL plant. Surface and subsurface soil samples (24 each) were also taken from different sites inside the UCIL premises. Soil samples were also collected from five dug wells inside the premises. One water sample each was taken from these dug wells.

Findings: Soil

The results show that all the soils samples from outside the plant were found to contain lead, nickel, cobalt, copper, zinc and chromium. Mercury was detected in seven of the soil samples. However organic toxicants were observed in very few samples.

Soil samples from inside the premises, both surface and sub-surface, were found to contain organics such as carbaryl, isomers of HCH and α naphthol. The maximum concentrations for carbaryl and α naphthol were 0.720 and 5.576 ppm respectively. Alpha, beta, gamma and delta isomers of HCH were detected in many samples.

Among the heavy metals, lead, chromium, mercury, copper, and zinc were found to be present in samples inside the premises. Mercury was detected in all 24 surface samples tested while it was also detected in 13 of the subsurface samples.

The sub surface samples collected from dug wells were also detected with carbaryl, HCH and α naphthol. The organics were found present upto a depth of two meters in general but traces could be detected in lower samples as well.

Among the metals, just nickel and lead were found to exceed the permissible limits. Mercury was not detected in any of the samples.

Findings: Water

The groundwater samples tested were not detected with aldicarb or carbaryl. Heavy metals were also found absent in most of the samples. However, 19 samples were found to contain α -naphthol, most of the samples had isomers of HCH and all the samples were found containing dichlorobenzene.

2	2010	National Environmental Engineering Research Institute (NEERI) and National Geophysical Research Institute (NGRI)	Assessment and Remediation of Hazardous Waste contaminated Areas in and around M/s Union Carbide India Ltd., Bhopal
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Sampling

The study divided the whole plant area in nine different sites. National Geophysical Research Institute spotted three sites (I, III and V) where contamination was possible.

Soil samples

Five bore wells were dug at different spots inside the UCIL plant. The spots were selected as per the prior understanding of the possible contamination sites. The depths of the wells varied between 25 and 32 m depending on groundwater occurrence. A total of 90 subsurface soil samples were collected from different depths from these bore wells. An additional 27 surface and subsurface (30 cm deep) soil samples were collected from suspected contaminated sites within UCIL premises.

Groundwater samples

Groundwater samples were collected from the five bore wells drilled inside the UCIL premises. Additional sample was taken from an existing bore well near the entrance.

Thirty more samples of groundwater were collected from areas around the premises. The samples were collected from existing sources of groundwater like bore-wells and dug-wells. These samples were collected considering the direction of flow of

groundwater which is generally towards north-east.

Findings: Soil

The study found presence of black and yellow silty clay soil upto 22 to 25 m below the ground level. **The soil had very low permeability (of the order of 10^{-9} cm/s) and it acted as natural barrier.**

The soil samples collected from the upstream of the plant premises were found not to be contaminated with any of the suspected compounds or heavy metals.

Inside the UCIL premises, none of the surface soil samples had aldicarb. It was detected in subsurface soils samples at seven places inside the plant area. The concentrations varied between 3.713 and 923 ppm.

Carbaryl, however was found present in most of the samples taken from inside the plant premises. Its concentration varied between 0.038 and 10729 ppm. α – naphthol was also found present in most of the surface and subsurface samples with varying concentration between 0.511 and 1460 ppm.

Three isomers of HCH (lindane) were also detected in many of the soil samples. α – HCH varied between 0.148 and 19.82 ppm, β – HCH varied between 0.498 and 13.34 ppm and γ – HCH varied between 0.568 and 16.54 ppm.

Among others, few samples were detected with dichlorobenzene in concentration range of 0.000013 to 0.165 ppm and most of the samples were found to contain mercury between 0.01 and 4.17 ppm.

The results of the analysis of soil samples at different depth from the drilled bore-wells showed that the **contamination was found upto a maximum depth of 2 m.**

Among the four samples taken from downstream areas, a sample taken from near solar evaporation pond was found contaminated with aldicarb, carbaryl, α – naphthol, and β – HCH with concentrations of 8.15, 6.88, 3.51 and 2.55 ppm respectively. It also had 0.30 ppm of mercury.

Another sample taken from area adjacent to the secure land-fill near the solar evaporation pond was also found to be containing traces of β – HCH (0.40 ppm). The presence of contaminants in these samples was attributed to unscientific management of secure land-fill and solar evaporation pond. The study concluded that soil contamination was confined to the UCIL premises.

Findings: Water

None of the samples collected from within the UCIL premises were found to be contaminated with any of the chemicals tested for. **Few samples from the downstream areas were found to contain dichlorobenzene and aldicarb. A total of five wells in the downstream areas were found contaminated. The presence of these compounds was attributed to the surface runoff and any possibility of percolation of contaminants to the groundwater strata was ruled out.**

3	2010	Indian Institute of Chemical Technology	Technical and Tender Document for Detoxification, Decommissioning and Dismantling of Union Carbide Plant
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Indian Institute of Chemical technology was commissioned by the Madhya Pradesh government to develop technical and tender document for detoxification, dismantling and decommissioning of the UCIL plant. The sites and structures that needed to be dismantled and chemicals being used were studied and a detailed plan was proposed. The study spotted following areas under the scope of work

- MIC plant
- SEVIN plant
- SEVIN-product bagging area
- Tank farm storage areas- methyl isocyanate (MIC), alkali, monomethyl amine (MMA),
- Chloroform, chlorine and chlorine compressor room
- Utility block – Chilling plants
- Flare stack and adjacent areas
- Pipe rack and its structure

IICT has proposed the detoxification procedures for each of the above for the following chemicals which were being used in the plant

- Methyl isocyanate
- Mono methylamine
- Phosgene
- Hydrochloric acid
- Carbaryl (Sevin)
- Chloroform
- Alpha-naphthol
- Carbon monoxide
- Chlorine

In the study, samples were collected from all possible sites and identified using High Performance Liquid Chromatography (HPLC) and Nuclear Magnetic Resonance (NMR). Based on the results, the report suggested methods of detoxification and safe disposal of used chemicals. Following methods were suggested for detoxification:

- Hot air purging: Hot air is purged through the units until specified criteria are met. The used air is scrubbed with alkali before letting it out to the atmosphere.
- Steam Purging: In a similar manner, steam is purged through the units and the uncondensed steam is scrubbed with alkali and the condensate is further de-contaminated.
- Alkali Wash: The equipment and pipelines are subjected to thorough alkali solution wash, with specific criteria for the completion of the wash. The alkali solution used ranges from 5 to 10 percent NaOH.
- Dilute Acid wash: Some of the equipment and pipelines are specified with acid wash to detoxify them. Dilute HCl (5-10%) is suggested for this purpose. The procedure is similar to the alkali solution wash.
- Water wash: Finally a thorough water wash of the equipment and pipelines is recommended, before they are dismantled from their supports.
- Alkali Soak: After the water wash, the equipment and pipelines are dismantled and soaked in an alkali solution pit for a certain period. Then they are washed again with water to complete the detoxification procedure.

The report proposed dismantling after the in situ detoxification as above. The dismantling, as proposed, should start with pipelines followed by the equipments and finally the structure. Dismantling of the units should start with the top floor and proceed to the ground floor. The structure should be dismantled by suitably cutting the columns and beams into small sections. Broken and completely corroded equipment and pipelines should be removed from the place and directly soaked in an alkali pit for detoxification.

Decommissioning has also been proposed only after detoxification. As proposed, it should be done by cutting components into pieces to make them unfit for reuse and thus disposed off suitably.

4	2009	Centre for Science and Environment	Contamination of soil and water inside and outside the Union Carbide India Limited, Bhopal
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Sampling

A total of 12 water and 8 soil samples were collected for the study. The soil samples included one each from the waste storage shed in UCIL the solar evaporation pond and six others from various places inside the factory. The water samples included one from inside the factory (rain water collection ditch) and the other samples were from dugwells, borewells and hand pumps in the surrounding residential areas. All the soil and water samples were tested for five Chlorinated benzenes, four organochlorines, two carbamate pesticides and five heavy metals.

Findings: Soil

The sample collected from the waste storage shed was found to have maximum carbaryl contamination with 9858.61 ppm. It

contained four of the five heavy metals tested. The mercury content was as high as 1065 ppm. Chromium, arsenic and lead were detected at a concentration of 86.18, 0.73 and 23.22 ppm respectively.

Among the six soil samples collected from inside the plant area HCH and its isomers, HCB, 1,3 dichlorobenzene and 1,4 dichlorobenzene were detected in all soil samples. In five of the samples 1,2 dichlorobenzene and 1,2,3 trichlorobenzene were also found. The total pesticide and chlorinated benzene compounds ranged between 105 and 5674 ppm.

Among the carbamates highest concentration was detected in the soil sample collected from sevidol formulation plant. The concentrations of carbaryl and aldicarb were 7.47 ppm and 90.69 ppm respectively.

Arsenic and chromium were found in all soil samples. Mercury was found in two samples and lead in five out of the six samples. Cadmium was not detected in any sample. The chromium content ranged between 18 and 298 ppm. Mercury, which was found in just two of the samples, was present in very high concentrations.

The other sample from the solar evaporation pond was found to contain all chlorinated benzene compounds and organochlorine pesticides as well as four out of five heavy metals.

Findings: Water

The surface water sample collected from inside the plant premises was most contaminated among all the samples. It contained three Chlorinated benzenes, all organochlorines and both carbamate pesticides. HCH and its isomers were detected at a concentration of 0.0154 ppm. Carbaryl was detected at a concentration of 0.26 ppm.

The water samples collected from outside the plant premises were also found contaminated. **Four of the samples contained carbaryl in the range of 0.0002-0.028 ppm (2-280 times the individual pesticide limit). The total pesticide contamination in groundwater samples varied between 1.1 and 59.3 times the recommended limit by Bureau of Indian Standards (BIS) for drinking water.** The average concentration was 12 times the BIS standards.

5	2009	Central Pollution Control Board (CPCB)	Central Pollution Control Board (CPCB) study
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Sampling

CPCB had taken eight soil samples from the same spots as CSE as mentioned above. It also tested 14 groundwater samples from areas around the UCIL plant.

Findings: Soil

The findings of CPCB were much in agreement with the findings of CSE. Both the studies found same heavy metals and chemicals at most of the sampling spots.

CPCB detected arsenic, mercury and chromium in all the samples tested in higher amounts than CSE.

It detected carbaryl in 75 percent of the samples tested. Aldicarb and organochlorines were also detected in varying amounts while chlorinated benzenes were present in all soils samples.

Organochlorines (isomers of HCH) were also found in all the soil samples in quantities similar to what CSE found.

All the samples were found to contain dichlorobenzene.

Findings: Water

CPCB tested 14 samples of groundwater from around the plant premises and found evidence of contamination. CPCB HCH isomers, chlorinated benzenes, and zinc and copper among the metals at a number of places. Groundwater in Indira Nagar which is at a distance of 2.4 km from the site was also found contaminated with heavy metals and HCH.

6	2002	Greenpeace International	Chemical Stockpiles at Union Carbide India Limited in Bhopal: An Investigation
<p>Sampling</p> <p>Greenpeace studied the stockpile of chemicals at different places inside the UCIL premises. A total of 16 samples collected from seven different sites including four samples from solar evaporation ponds outside the plant premises were tested for carbaryl, HCH isomers, hexachlorobenzene and other possible organic constituents.</p> <p>Findings: Dump materials</p> <ul style="list-style-type: none"> • Four samples were collected from the first spot, the BHC store. All these samples contained carbaryl. HCH isomers and hexachlorobenzene were present in three and two of the samples. One of the samples had about 2 percent of HCH isomers. The stockpile at this spot was estimated to be about 100 tonnes. • All three samples collected from the formulation shed were found to contain carbaryl and HCH isomers with a highest of 10 percent HCH isomers in one of the samples. The estimated weight of stockpile at this spot was about 20 tonnes. • The only sample collected from the small shed, which had about between two and three tonnes of stockpile was found to contain carbaryl, alkyl benzenes and linear aliphatic hydrocarbons but no organochlorines. • The soapstone shed close to the formulation shed had about 20 tonnes of stockpiles. The only sample taken from this spot was found to contain 1.8 ppb carbaryl which was maximum among all samples. The sample was also found to contain 40 ppm of HCH isomers. • The cycle shed, in the north of the site near the formulation shed, had about 20 tonnes of stockpile, mainly sevin residues and a solid black tar in rusting barrels. A sample each from the sacks and the barrel was collected. Out of these, the sample collected from barrels did not contain carbaryl. However, both the samples were found to contain HCH isomers in the range of tens of ppm. The sample from the sacks also had 1900 ppb of hexachlorobenzene. The samples were also detected with chlorinated benzenes and aromatic and aliphatic hydrocarbons. • Four samples collected from the SEPs were found to contain one or more chlorobenzenes and aliphatic hydrocarbons. Two of the samples also contained phthalate esters, persistent toxic compounds used in many industrial applications. 			
7	2002	Fact Finding Mission & Shrishti	Surviving Bhopal: Toxic Present, Toxic Future
<p>Sampling</p> <p>Shrishti and Fact Finding Mission conducted study on chemical contamination in and around the UCIL plant in Bhopal. They tested 10 samples of soil with six samples from outside the factory premises and four from inside, three samples of vegetables being grown in the locality and eight samples of breast milk for presence of heavy metals, pesticides, volatile organic compounds (VOCs). Groundwater samples from in and around the plant were also tested which included 10 samples from outside and samples from four different sites inside the plant.</p> <p>Findings: Soil</p> <p>Among the six samples from outside, five showed presence of nickel. Chromium and mercury were present in three samples each and lead was found in two samples. Of the four samples collected from the plant premises; two had mercury in elevated concentrations. Nickel and chromium were also found in some samples.</p> <p>Lindane was found in most of the samples from inside and outside the premises. The samples from outside the premises had an average concentration of 1.6 ppm. The highest concentration of 5.038 ppm was found in the J. P. Nagar area. Among the soil samples from inside the premises, the maximum concentration found was 8 ppm near the sevin plant.</p> <p>Dichlorobenzene, 1,3,5-trichlorobenzene and tetrachlorobenzene were present in all the samples.</p> <p>Samples from outside the plant had between 0.082 and 0.170 ppm of dichloromethane with an average amounting to 0.103 ppm.</p>			

An average of 6.55 ppm of chloroform was found in soils.

Findings: Water

All the 10 groundwater samples collected from the localities around the UCIL plant had chromium and nickel with average concentrations of 0.026 and 1.099 ppm respectively. Mercury was present in six and lead in eight samples. The average concentrations of mercury and lead were 0.567 and 0.122 ppm respectively.

The average concentration of pesticide HCH in the samples collected from outside the plant area was 0.011 ppm. A sample collected from inside the plant premises showed on an average 10 times more HCH compared to outside samples.

The mean concentration of volatile organic compounds (VOCs) in the groundwater samples of the residential areas were found to be 0.050 ppm. Water samples from the factory premises contained 0.0331 mg/L of them.

All the eight groundwater samples contained both dichloromethane and chloroform. The average concentration of dichloromethane was 1.63 mg/L which about twice the average concentration of chloroform.

Findings: Breast milk

Lead was present in seven out of eight samples tested. Nickel and mercury were found in two and three samples respectively.

All the samples tested had HCH which ranges between 0.179 and 11.44 ppm. The average content was 2.39 ppm.

Among the VOCs, 1,3,5trichlorobenzene was predominant while the average concentration of VOCs was 2.85 ppm.

All the breast milk samples contained dichloromethane and chloroform. Their average concentrations were 0.359 and 1.154 mg/L respectively.

Findings: Vegetables

All the three samples tested showed presence of chromium and nickel, while palak showed chromium, nickel, mercury and lead.

HCH was found present in Brinjal and Palak samples tested. VOCs were also present in these two vegetables with an average concentration of 0.132 ppm. Among halo-organics, both dichloromethane and chloromethane were found present in all the three vegetable samples.

8	2001-02	Peoples Science Institute	Groundwater Contamination near the Union Carbide Plant at Bhopal
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Sampling

The investigation was based on assessing the concentration of mercury in the groundwater of the areas adjoining the Union Carbide plant. Mercury was chosen as an indicator of contamination levels in the groundwater. Samples were collected from 20 different places around the UCIL premises from hand-pumps and tube-wells. These samples were collected both during pre-monsoon and post-monsoon season. This was done in order to ascertain whether there were any fresh additions of contaminants in the absence of rainwater.

Findings: Water

The sample analysis reports showed a higher concentration of mercury near the Union Carbide Factory region. These included areas of Arif Nagar, New Arif Nagar and Atal Ayub Nagar. Other than Risaldar colony, all other areas near the factory showed high level of mercury contamination with an average contamination value of 55 µg /L.

The data also showed that the direction of this groundwater flow was towards the northeast and east regions of the Union Carbide factory. There was no contamination observed in the region south or west of the factory. This suggested that the contaminants were flowing away from the factory region in the particular northeast and north direction. This hypothesis is corroborated by data, which clearly shows higher concentration of mercury in sites towards the north and northeast direction. This hypothesis is based on the report on the hydro-geological framework of Bhopal city, which suggests that flow of groundwater is in the northeast direction.

The mercury pre-monsoon contamination levels were significantly lesser than those of post-monsoon, which suggest that in the absence of rainwater there is no further addition of contaminants. The data collected post- monsoon shows significantly lower concentration of mercury, which suggests no further addition of contaminants. These samples were mainly collected from areas near the plant and showed higher concentration of contaminants than those collected from areas away from it. High concentrations of chloroform (as high as 984 microgram/L) were observed in the area of Atal Ayub Nagar.

Various remedial solutions were suggested to counter the hazards of groundwater contamination. These included rapid and action-oriented clean-up operations to remove toxic hazardous wastes, proper disposal of hazardous wastes according to stipulated regulations, provision of alternative drinking water source for areas detected with high level of groundwater contamination as well as routine monitoring of area for further contamination threat.

9	1999	Greenpeace International	The Bhopal Legacy
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Sampling

A total of 31 samples of water, waste and soil were collected from in and around the UCIL plant site. From within the plant site, five samples of soil and waste and two samples of water were collected. From outside the compound, two samples of soil were collected from near the erstwhile solar evaporation ponds. A total of 21 water samples were collected from eleven private wells. The soil and waste samples were taken from a depth of about 20 – 30 cm while the water samples were collected generally from hand-pumps.

Findings: Soil

The contamination in soil samples varied from place to place. Sample collected near the Sevin plant was found to contain about 12 percent of free mercury. It also had lead, chromium, copper and nickel. Among organochlorines, hexachloroethane and hexachlorobutadiene were found. Another sample collected from a ditch near the Sevin plant had a mixture of organichlorines such as isomers of HCH, numerous chlorinated benzenes and DDT.

Samples from near south east corner of the plant were also found to contain mercury and a complex mixture of organochlorines at elevated levels. Samples from SEPs were less contaminated overall.

Findings: Water

VOCs including chloroform, carbon tetrachloride and chlorinated benzenes were detectable in groundwater samples from all three wells near the northern boundary of the UCIL plant. A little but still significantly elevated concentrations of VOCs were found in the samples collected near the south boundary of the plant. Samples from near north boundary were found to contain carbon tetrachloride as high as 3.4 mg/L and chloroform as high as 2.59 mg/L. Eight out of ten VOCs for which WHO has established guidelines could be found in the samples.

The report pointed out that the contamination levels in the locality varies between substantial to severe. It urged steps to be taken for remediation of groundwater and safeguarding the local communities from contaminated water and environment.

10	1997	NEERI	Assessment of Contaminated Areas due to Past Waste Disposal Practices by EIII, Bhopal
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Sampling

The study area included the complete area of Union Carbide India Limited (taken over by Eveready Industries India Limited (EIII) at the time of study) plant premises and adjoining open area north of the plant. Samples were collected from waste disposal areas, spilled areas and open area only. Samples of soil, groundwater and dump material were collected from different spots. The report divided the disposal area, which was found to be about 7 acres or 22.6 percent of the total plant area, into three different parts.

Findings: Soil

The study found soil in the premises of UCIL to be contaminated with sevin (carbaryl), temik (aldicarb), lindane, manganese, naphthol and chlorides.

Soil samples from Disposal Area I (DA I) were found to contain maximum concentrations of 356 ppm and 74 ppm for carbaryl and

aldicarb respectively. Lindane content of the samples varied between 0.5 ppm and 201.4 ppm.

Carbaryl was found in 50 percent of the samples from Disposal Area II with a maximum concentration of 7218 ppm. Aldicarb was found in 25 percent of the samples between 5.81 and 92.34 ppm. Lindane was found in some of the samples between 0.34 ppm and 2.8 ppm. The samples also had α – naphthol between 19.83 ppm and 1194 ppm in nearly 50 percent of the samples. A total of 36 samples from DA II were tested.

In rest of the area, very few samples were found to contain carbaryl and aldicarb. Out of 29 samples tested from the area, just three samples had carbaryl between 2.42 to 8.65 ppm. Aldicarb was found between 5.49 to 51.64 ppm in eight of the samples.

Samples collected near target and spill areas did not show the presence of contaminants except in traces in a few sites. Carbaryl was found present with concentrations of 65.6 ppm to 1226.7 ppm near sevin plant.

Findings: Water

Seventeen samples of groundwater were collected from in and around the plant premises. None of the samples was found contaminated. **The study noted that soil in and around the plant premises was mainly clayey with permeability rate as low as 1×10^{-5} , which would have taken 23 years for contaminants to reach groundwater level.**

Findings: Dump materials

Among the samples collected from dump materials, about 16 percent had more than 1000 ppm of carbaryl with a maximum content of 520003 ppm. Most of the other samples had carbaryl content between 100 and 500 ppm.

Aldicarb was between 4411 ppm to 5105 ppm near the temik neutralization pit. One sample was found to contain 7876 ppm of it. Aldicarb was not detected in about 40 percent of the samples. Alpha naphthol was recorded between 500 and 9914 ppm in seven out of 64 samples; 76 percent of the samples recorded α – naphthol below 348 ppm. Lindane content was found in traces in 50 percent of the samples.

***The study did not rule out possibility of presence of other chemicals. HPLC analysis showed certain peaks which could not be analysed at that time.**

11	1996	State Research Laboratory, Public Health Engineering Department, Government of Madhya Pradesh	Report of Chemicals found in Water for Communities around UCIL premises
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Sampling
Groundwater samples from 13 spots in the vicinity of the factory.

Findings: Water
The samples tested had Chemical Oxygen Demand (COD) values between 45 mg/l and 98 mg/l, 16 times higher than the limit set by the World Health Organization (WHO) which indicated severe chemical contamination.

12	1992	NEERI	Process Package for Disposal of SEP Contents at UCIL, Bhopal
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Sampling: Soil and groundwater samples from in and around the Union Carbide factory.

Findings: Groundwater within an area of radius 1 km met the drinking water quality standards.

Volatile and Semi-volatile organic chemicals were found present in soil samples.

Recommendations: The study recommended dilution of water in pond I to obtain a chloride level of 1000 mg/L before discharging it into nallah. In case that was not possible pumping pond water into landfill could be considered.

It also recommended converting pond III into secured landfill for storing the sediment in pond II. The proposed landfill was

supposed to have a flexible membrane liner, drainage layer and finally a clay cover to prevent leachate generation.

13	1990	Bhopal Group for Information and Action, Bhopal	Union Carbide in Bhopal, India-The lingering legacy
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Sampling: Soil sediments and waste stored inside the factory. Groundwater from adjacent communities.

Findings: High concentrations of toxic materials were found in the samples from the waste storage area. Dichlorobenzene was found in the community's drinking water. Polynuclear aromatic Hydrocarbons, were also found in the waste impoundment area. Phthalates were found in the surface soils in the waste pond.

14	1989	Union Carbide Corporation	Site Rehabilitation Project –Bhopal Plant
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Sampling: Nine soil/solid and eight water samples were collected from within the plant premises.

Findings: Soil

Soil samples had organic contamination ranging between 10 to 100 percent. Naphthol and Napthalene were found in most of the samples.

Findings: Water

Majority of the liquid samples 'contained naphthol and/or Sevin in quantities far more than permitted by ISI for onland disposal. **All samples showed 100 percent mortality to fish.**