The Bhopal Gas Tragedy Site : Amelioration and the Way Ahead

By
Raveena Chauhan

A Practicum submitted to the Faculty of Graduate Studies

of The University of Manitoba

in partial fulfilment of the requirements of the degree of

MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture

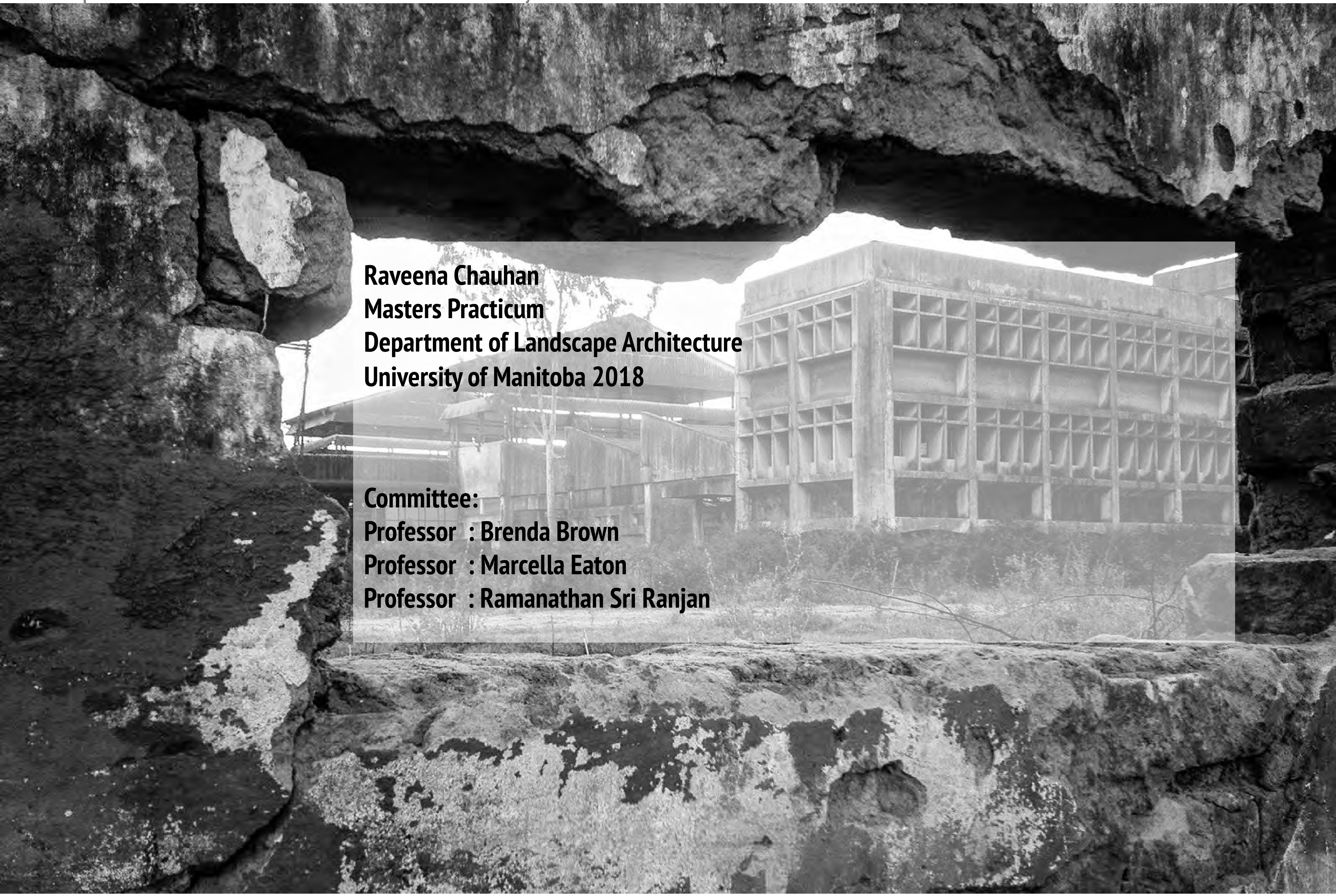
University of Manitoba

Winnipeg

The Bhopal Gas Tragedy Site : Amelioration and the Way Ahead

Raveena Chauhan

Bhopal still hasn't recovered from the worst industrial disaster in history



Raveena Chauhan
Masters Practicum
Department of Landscape Architecture
University of Manitoba 2018

Committee:
Professor : Brenda Brown
Professor : Marcella Eaton
Professor : Ramanathan Sri Ranjan

(Giles Clarke, 2012)

Acknowledgements

I am thankful to everyone who has supported me through the process of developing and successfully completing this practicum. Above all, I would like to pay regards to my advisor and chair, Brenda Brown for always guiding me in the right direction and enabling me to spearhead towards the completion of this practicum project in such a short time- frame. You have helped me in improving my skills throughout my Masters in Landscape Architecture.
I would also like to thank Dr. Marcella Eaton for always motivating and helping me in shaping my ideas in the best possible way. Your advice has helped me explore new dimensions of learning and develop an insightful vision with respect to landscape.
Dr. Ramanathan Sri Ranjan, I cannot thank you enough for your immense help and involvement throughout this practicum. Your expert advice has helped me in keeping my spirits high while completing this practicum.

I would also like to thank Mom and Dad, for always supporting and encouraging me throughout my education. Dad, without you it would not have been possible.
Lastly, I would like to thank my family and friends back home for supporting me throughout my journey of Masters in Landscape Architecture.

The hope to live

(Montse Argerich Oró and Jordi Ferrando i Arrufat, 2017)

Abstract

Bhopal has witnessed one of the greatest industrial disasters in the history of mankind. The gas tragedy had widespread implications on the society, culture, environment, and health of the residents of the city. For decades government and non- government organizations have tried to mitigate the impact of the disaster of 1984.
These attempts have at the most proved to be marginally successful. The aim of this practicum is to take these attempts a step further. The practicum provides a more thorough assessment of the environmental conditions of the former Union Carbide factory site and proposes an action plan to remediate the factory area through the use of technologies such as phytoremediation and electro- kinetic remediation. Further, the practicum presents a design for an area for community engagement on the site, an area where neighbourhood people can gather, play, share feelings and engage themselves in restructuring their lives and non- residents can learn about the history of the site.

Contents

Introduction

This practicum aims to develop a design strategy that could render the former Union Carbide factory site useful for the neighbourhood residents. The major challenge in proposing a design for the factory site is the contamination in the soil and groundwater. So, the practicum proposes a detailed procedure, to remediate the factory site as well as the creation of a community engagement area in a part of the site that does not put the health of the residents at risk.

I propose integrated use of technologies such as phytoremediation, electro-kinetic remediation and soil replacement to deal with the soil contamination of the factory site. Further, efforts are made to design the community engagement area in such a manner that it serves as a place where people can share, play, learn and relax.

Union Carbide factory in Bhopal…………………………………

Beginning of a new life for the people of Bhopal

The advent of Green Revolution in the late 60s fueled the need for large quantities of pesticides and fertilizers in India. Morehouse and Subramaniam reported that the government of India approved the establishment of pesticide and fertilizer plants in many parts of the country to cater to the needs of agriculture (Nair, 2005). The Union Carbide factory was established in 1969 in Bhopal, Madhya Pradesh as part of this effort.

Soldiers guard the entrance of union carbide factory in Bhopal after a deadly poison gas leak

(Bhopal Medical Appeal, 2013)

Expectations of the people and government

The initial response from the local population was very positive. People saw the factory as a medium for good employment opportunity and infrastructure development for the city. During the operation of the factory, people from all classes came to Bhopal in search of better livelihood. The factory provided not only high-paying technical and managerial jobs but also daily wages and permanent employment for workers. People from nearby districts and even other states flocked to the city. The population of Bhopal expanded from around 300000 in 1969 to more than 900,000 in less than the three decades after the arrival of the Union Carbide factory (Peterson, 2009, p. 3).

Chemical leak kills thousands in Bhopal

(writeopinions.com)

Unawareness in people

While people's initial response to the Union Carbide factory was very positive, there was a dark side due to the sheer negligence of the authorities regarding the follow-up on safety standards and procedures. Also, the community was never informed about the dangers posed by the materials used in the plant. Several neighbors thought that the plant made medicines (India's Enviornment, 1984-1985, p. 215). Thus it can be concluded that residents were unaware of how the factory was putting their lives and health at risk.

What happened on 2nd December 1984

On the night of 2nd December 1984, approximately 40 tonnes of poisonous Methyl Isocyanate gas leaked from the Union Carbide factory, triggering one of the reasons for the greatest industrial disasters ever witnessed by humankind which came to be known as 'Bhopal Gas Tragedy'. The official report by Kumar, et al in 1994 estimated that more than 2000 people died immediately and another 200,000-600,000 people were left with severe injuries (The Bhopal Legacy, n.d, pg.6).

A tragedy and travesty of justice

(wordpress, 2015)

What circumstances led to the event

The Union Carbide factory produced the pesticide Carbaryl, also called Sevin (Nair, 2005, pg. 4). The first intermediate product in this process is Phosgene, which is produced by the reaction of Carbon Monoxide with Chlorine. Further, Phosgene reacted with Mono Methylamine to produce Methyl Isocyanate (MIC), the dangerous gas that leaked in the Bhopal gas tragedy. "MIC reacted with Alpha- Naphthol to produce Carbaryl" (Nair, 2005, pg.4) . It was kept under a blanket of nitrogen in two storage tanks in the factory because it is highly combustible.

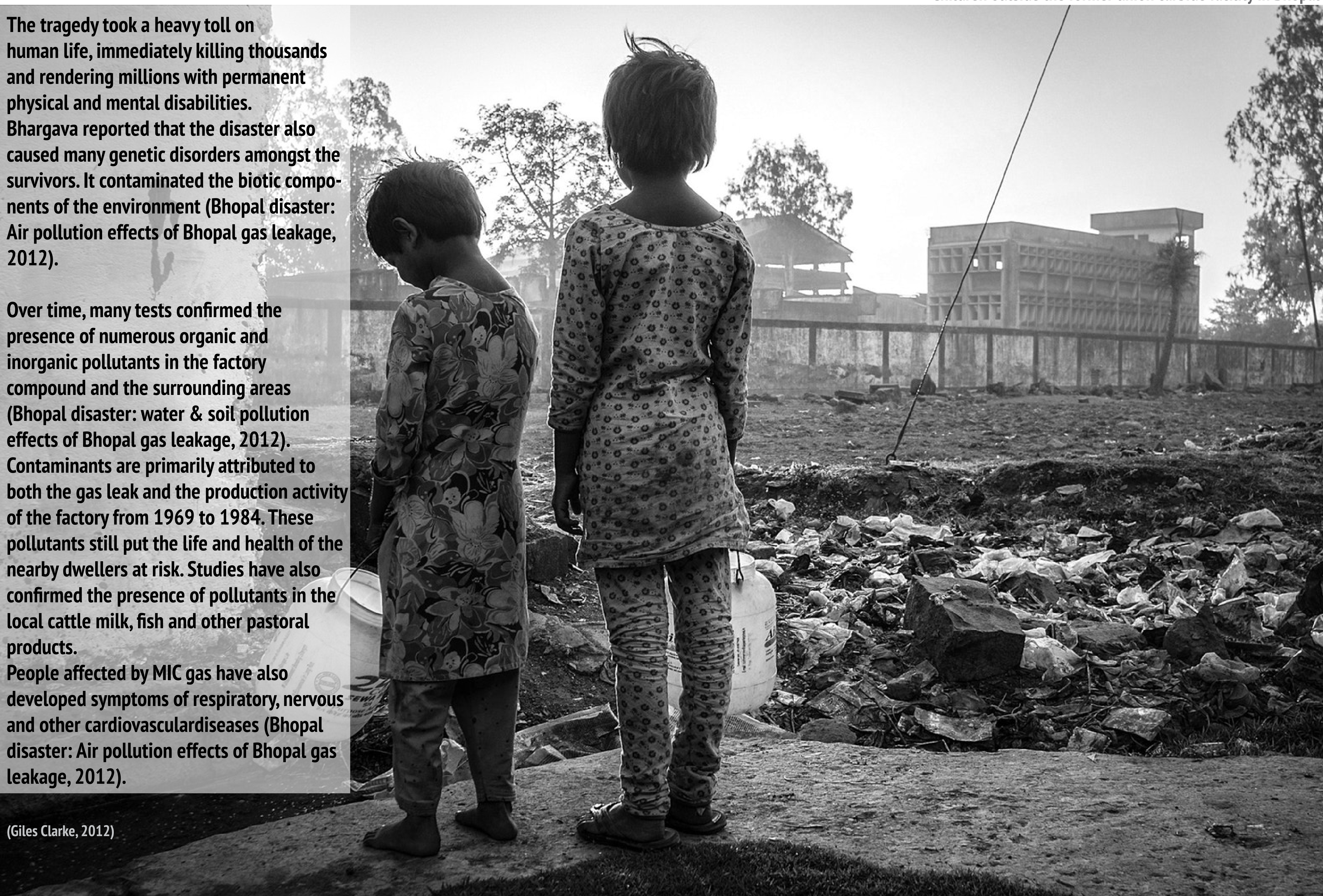
Morehouse and Subramaniam reported that this storage location on site of the factory was ill-advised since the factory was located among densely crowded areas. "Due to malfunctioning of the valve on the night of December 2nd, 1984, resulted in water getting into the storage tanks and reacted with nitrogen, thus the nitorgen blanket gone, MIC leaked out" (Nair, 2005, pg. 4) .

Tank 610 in 2010

(Julian Nitzsche, 2010)

Immediate and long term consequences of the event

Children outside the former union carbide facility in Bhopal



The tragedy took a heavy toll on human life, immediately killing thousands and rendering millions with permanent physical and mental disabilities. Bhargava reported that the disaster also caused many genetic disorders amongst the survivors. It contaminated the biotic components of the environment (Bhopal disaster: Air pollution effects of Bhopal gas leakage, 2012).

Over time, many tests confirmed the presence of numerous organic and inorganic pollutants in the factory compound and the surrounding areas (Bhopal disaster: water & soil pollution effects of Bhopal gas leakage, 2012). Contaminants are primarily attributed to both the gas leak and the production activity of the factory from 1969 to 1984. These pollutants still put the life and health of the nearby dwellers at risk. Studies have also confirmed the presence of pollutants in the local cattle milk, fish and other pastoral products.
People affected by MIC gas have also developed symptoms of respiratory, nervous and other cardiovasculardiseases (Bhopal disaster: Air pollution effects of Bhopal gas leakage, 2012).

(Giles Clarke, 2012)

What could be and has been done till now

People of Bhopal outraged by the disaster

(Obi, 2006)

This accident created a rift in Bhopal society ostracizing the victims from the mainstream (Nair, 2005). Post- disaster, many government and non-government organizations have actively worked to provide relief through many rehabilitation programs. The governments of Madhya Pradesh and India have created a chain of super specialty hospitals that provide free treatment to the gas tragedy victims. Many non- government organizations have also opened medical clinics.

However, the most disappointing aspect of the rehabilitation and relief program was the inefficiency and corruption in the distribution machinery of government. Nair states that the Indian Supreme Court ordered Union Carbide to pay $470 million to the Indian Government, as compensation to the victims. But most of those affected by the disaster have not received any money for compensation. Moreover, this court order did not include money for site cleanup or any liability for medical treatment to the victims.

Timeline 1969-2010

Trail of events...

1969
Union Carbide India Limited (UCIL) develops up plant to manufacture pesticide Sevin.

1973
Methyl isocyanate (MIC) is used in the manufacture of Sevin, and is imported from US.

1979
UCIL begins production of (MIC) on the site.

1980-1982
In 1981, a worker killed in phosgene gas leak. Another gas leak killed 28 people in 1982.

1984
(MIC) leaks from tank no. 619 after a series of safety and technical lapses. The gas affects people residing within 20 sq. km.

1985
Indian government files claim for $3 billion (US) from UCIL in a US court.

1986
UCIL succeeds in pursuading the US court to send the case back to the Indian judiciary where compensation liability is much lower.

1989
Indian government and UCIL strike an out of court settlement. Compensation is $470 million (US).

1992
Indian courts declares Warren Anderson (CEO Union Carbide) a fugitive from law.

1994
Indian supreme court allows UCIL to sell off its assets, technically wiping out the company's physical presence in India.

2001
Union Carbide corporation and Dow chemical company merge.

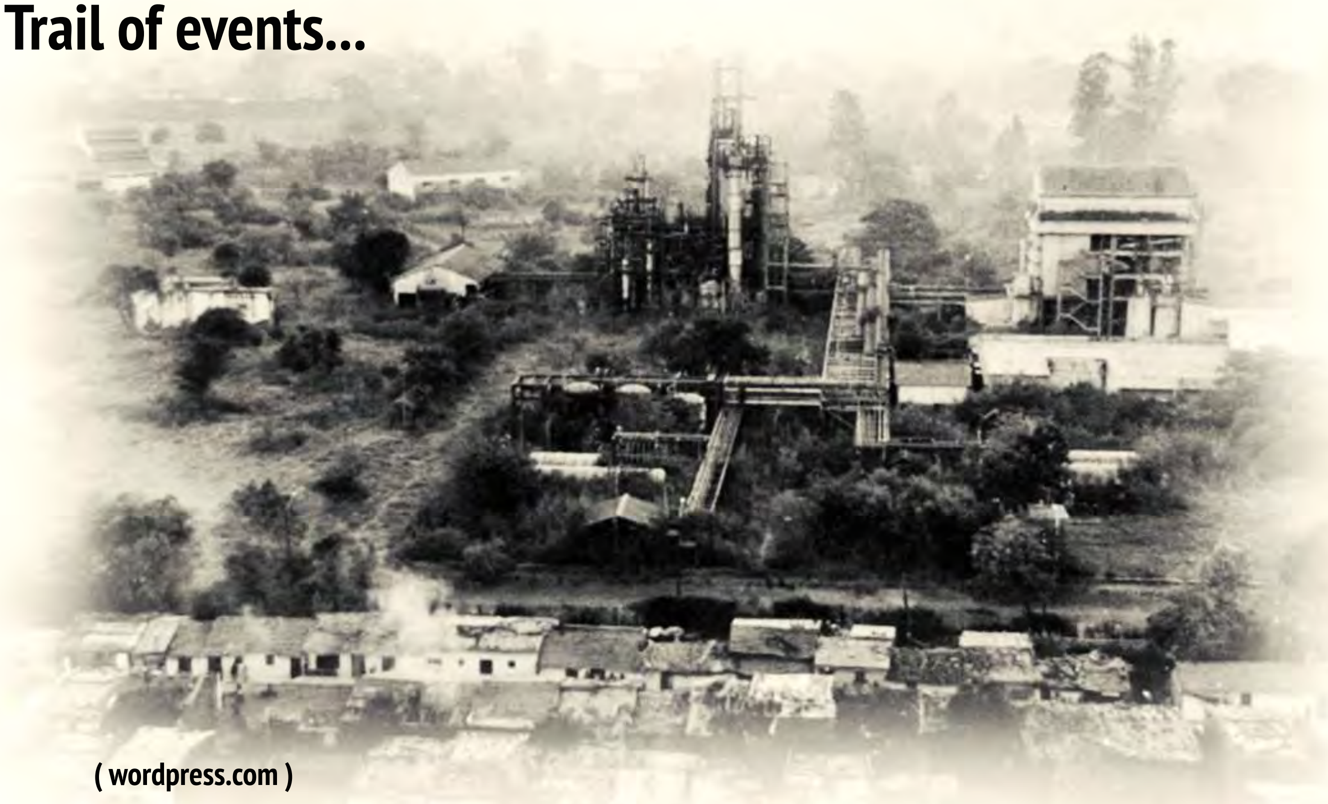
2002
Madhya Pradesh (M.P) government announces that it will petition the US Supreme Court to compel Dow chemical company to clean up the contaminated soil and groundwater at the factory site.

2005
Task force to remove toxic waste is set up under the Ministry of Chemicals and Fertilizers.

2007
(M.P) high court orders 350 tonnes of waste recovered from the site to be sent for incineration in Gujarat.

2008
Gujarat government rejects the order at first. But then (M.P) high court reinstates the order to the Gujarat government to accept the waste.

2010
Group of ministers recommends joint task force of the federal and state government for clean up operation.



(wordpress.com)

(www. indiaenvironmentportal.org)

The site and situation today..

A victim from the Bhopal gas disaster

(Montse Argerich Oró and Jordi Ferrando i Arrufat, 2017)

Implications of tragedy on..............................

Society and Culture

Bhopal has an ancient culture with unique norms and traditions. The caste system prevails there and divides people into sub-castes wherein a number of people belonged to lower castes (Nair, 2005, pg.6). The untouchables are the most downtrodden of all. When the factory started in Bhopal, people of the lower castes migrated from villages towards the factory. The unique social system of Bhopal contributed to the challenges in the relief and rehabilitation operations. The affected section of the society had a low level of awareness of politics and was economically weak. They could not afford lawyers against the Union Carbide factory in the Supreme Court of India.

Irregular supply triggers water crisis in parts of Bhopal

(Bhopal Medical Appeal, 2013)

Politics

30 years after Bhopal disaster, Indians demand punishment

(Stéphane Bouillet, 2009)

The MIC leakage did not do as much harm as the political apathy toward the people harmed by it (Livemint, 2016). Even decades after the gas tragedy, people have not received fair compensation and justice for the misdeeds of the giant corporation. They have been suffering from economic, medical and environmental calamities to which there is no cure yet. Survivors still largely blame the corrupt governance and greed of corporation as the reason for this tragedy.

Abandoned solar evaporation pond

The Bhopal pesticide factory ceased normal operations after the disaster leaving behind warehouses, buildings, and chemical waste. The gas leak caused extensive damage to the environment surrounding the Union Carbide factory. The impacts were both immediate and long-term. Union Carbide industry and Madhya Pradesh (M.P) government did not bother to remediate the soil and groundwater of the factory site. Sahu, observed that improper cleanup led to water contamination with heavy metals and organic pollutants which adversely affected crop growth, fisheries and also potable drinking water availability. (International Environmental Law Research Centre, 2014, p.8).

(necrotravel / wordpress, 2012)

Vegetation

All broad-leafed trees on site suffered severe damage. The worse affected were Neem (*Azadirachta indica*) and Peepal (*Ficus religiosa*) both of which showed total defoliation within one kilometer radius of the factory. The trees less affected were Karanj (*Millettia pinnata*) and Chora neem (*Ailanthus excelsa*). Shrubs showed the same pattern: it was observed that small stems suffered the least when they were located close to the lakes and ponds. This shows the effect of water on the MIC. MIC reacts readily with water and forms a stable liquid compound that prevents the immediate threat of inhalation by organisms.
Further, the damage to trees was due to the reaction of the MIC with the leaf surface parts, whereas stems and other parts were hardly affected. So, it was concluded that the respiration through leaves of the plants led to the damage. (Ghosh and Singh, 1987, p.21).

Factory site

(Author)

Domestic animals

The animal death count due to MIC was also large 1087 in total including 240 cows, 280 buffaloes, 18 bullocks, 84 calves, 288 goats, 60 pigs, 12 horses, 99 dogs, 2 cats, and 3 chickens while another 7334 animals were also reported to be affected and were treated with the same drugs as humans (Ghosh and Singh, 1987, p.22).

Ghosh and Singh reported that autopsies of animals showed swollen livers and lymph glands and bloated digestive tracks and enlarged blood vessels. Necrosis and clots of blood were observed in lungs and hearts and kidneys were found to be congested.

A lady sits next to her dead cattle

(Danish Siddiqui and Kapoor Baldev, 198

The aftermath of the Bhopal disaster

(David Graham)

Human Health

Immediate disaster relief focused on medical emergencies and recovery. Methyl isocyanate caused damage to lung tissue and respiratory functions. Victims suffered from breathlessness, cough, nausea, vomiting, chest pains, dry eyes, poor sight, photophobia, and loss of appetite They also manifested psychological trauma symptoms: anxiety, depression, phobias, and nightmares. The government aimed to provide world-class healthcare amenities to the affected population and to the generations that would follow by creating chains of specialized hospitals and Medical Research centers in Bhopal (Shrivastava, 1987).

Contribution of Non-governmental organizations (NGOs)

The role of some of the major non-governmental organisations (NGOs) such as Sambhavna, Srishti, GreenPeace and Bhopal Medical Appeal (Eckerman, 2004) working in this domain has been commendable. Apart from fighting for proper compensation and amenities from the government, the (NGOs) have done substantial work in providing:

- Accessible medical advice and services to tragedy victims
- Awareness regarding the political, medical, environmental and legal rights of the victims and the survivors
- Capacity and morale building
- Knowledge of technology in medical and environmental science
- Knowledge related to disaster mitigation and preparedness

People protesting against Dow Chemicals

(Yann Forget, 2010)

NEIGHBOURHOOD AREAS

Neighbourhood street beside the Union Carbide factory

(Bhopal Medical Appeal, 2013)

Development in neighbourhood areas

2002

Site

2016

Development in connectivity, residential and industrial sector took place at a large scale in last 14 years

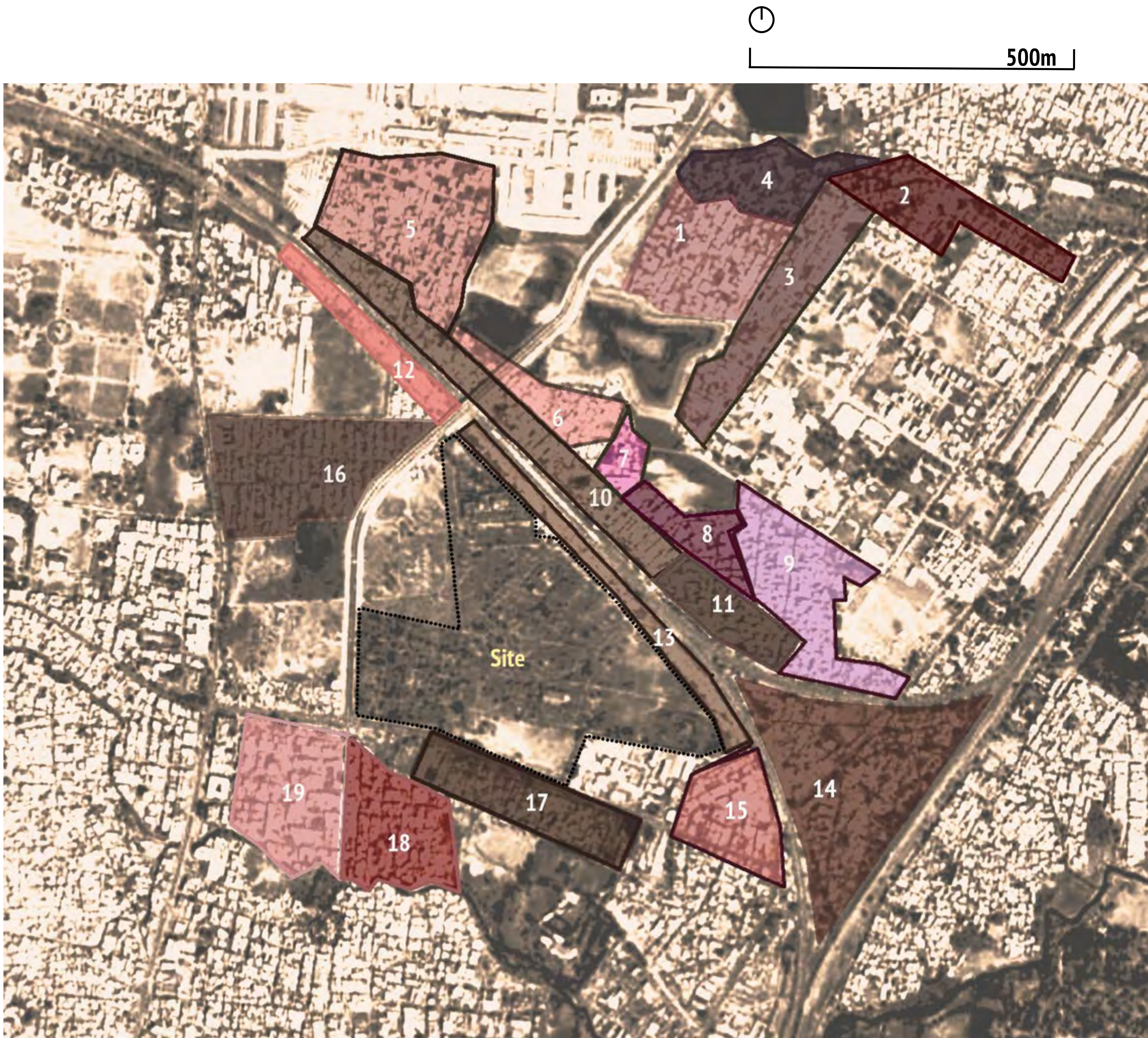
Land use around the former Union Carbide factory site

- Former Union Carbide Factory Site
- Residential use
- Temporary shelter (originally constructed by factory workers)
- Commercial use
- Solar evaporation pond
- Brownfield

400m

Affected neighbourhood areas

1. Shivshakti Nagar
2. Chandabdi
3. Garib Nagar
4. Preet Nagar
5. Nawab Colony
6. Blue Moon Colony
7. Sundar Nagar
8. Prem Nagar
9. Navjeevan Colony
10. Annu Nagar
11. Shri Ram Nagar
12. New Arif Nagar
13. Atal Ayub Nagar
14. Kainchi Chola
15. Shakti Nagar
16. Arif Nagar
17. Jp Nagar
18. Rambha Nagar
19. Chowksey Nagar



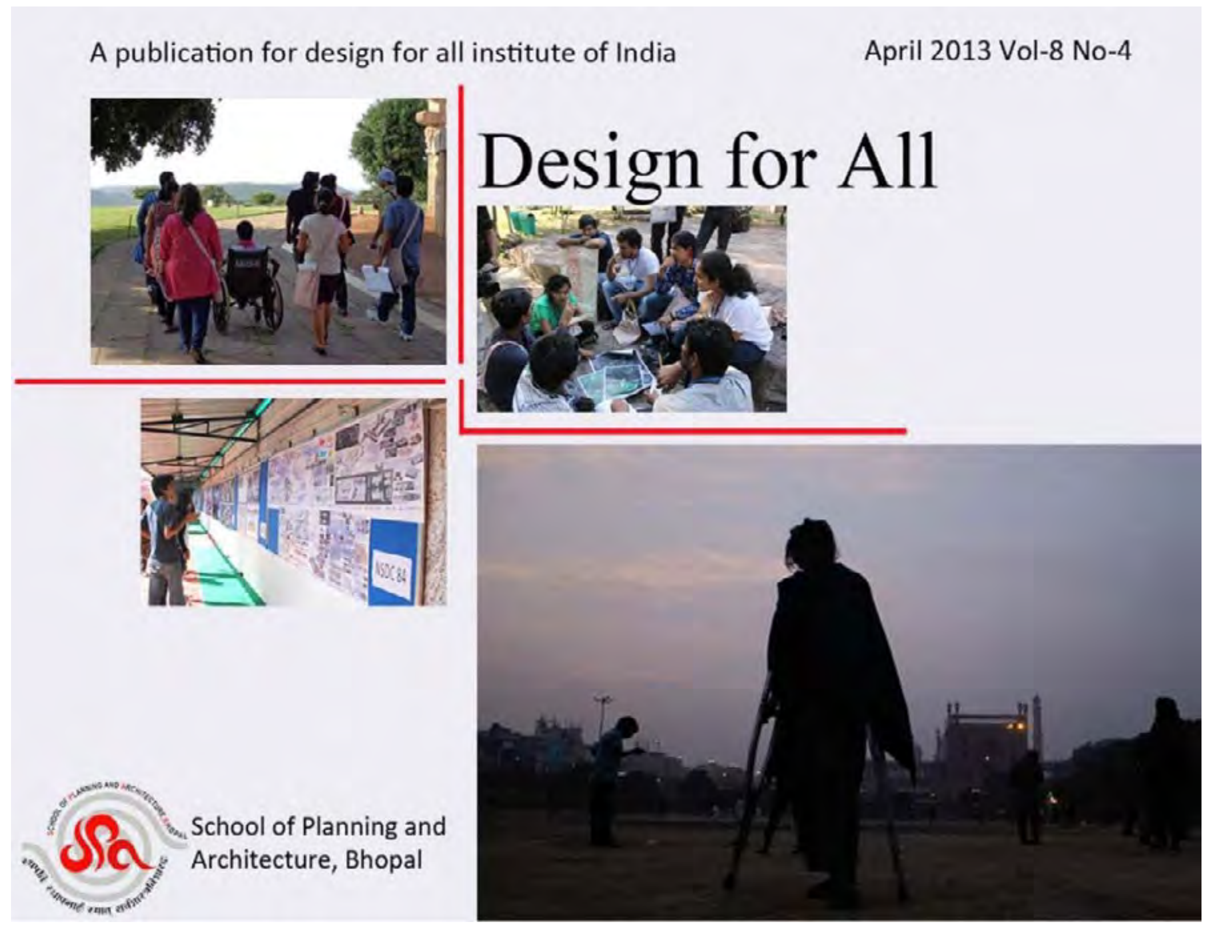
My connection with Bhopal and my insipiration.......................................

How I am connected to the city and tragedy

I pursued an undergraduate degree in Architecture from the School of Planning and Architecture in Bhopal. Throughout the coursework, many case studies, field surveys and site visits helped me to learn about the history, geography, and demographics of Bhopal. The city has a rich cultural heritage, beautiful landscapes and a prudent economic and political base.

The gas tragedy has garnered attention of the media, public and educational communities worldwide for decades now. Research has been conducted to assess the ramifications of the disaster on the city and people.
However my interest in the event stemmed from my emotional connection to the city. I was previously quite unaware of the media frenzy and public agitation that surrounded the tragedy.

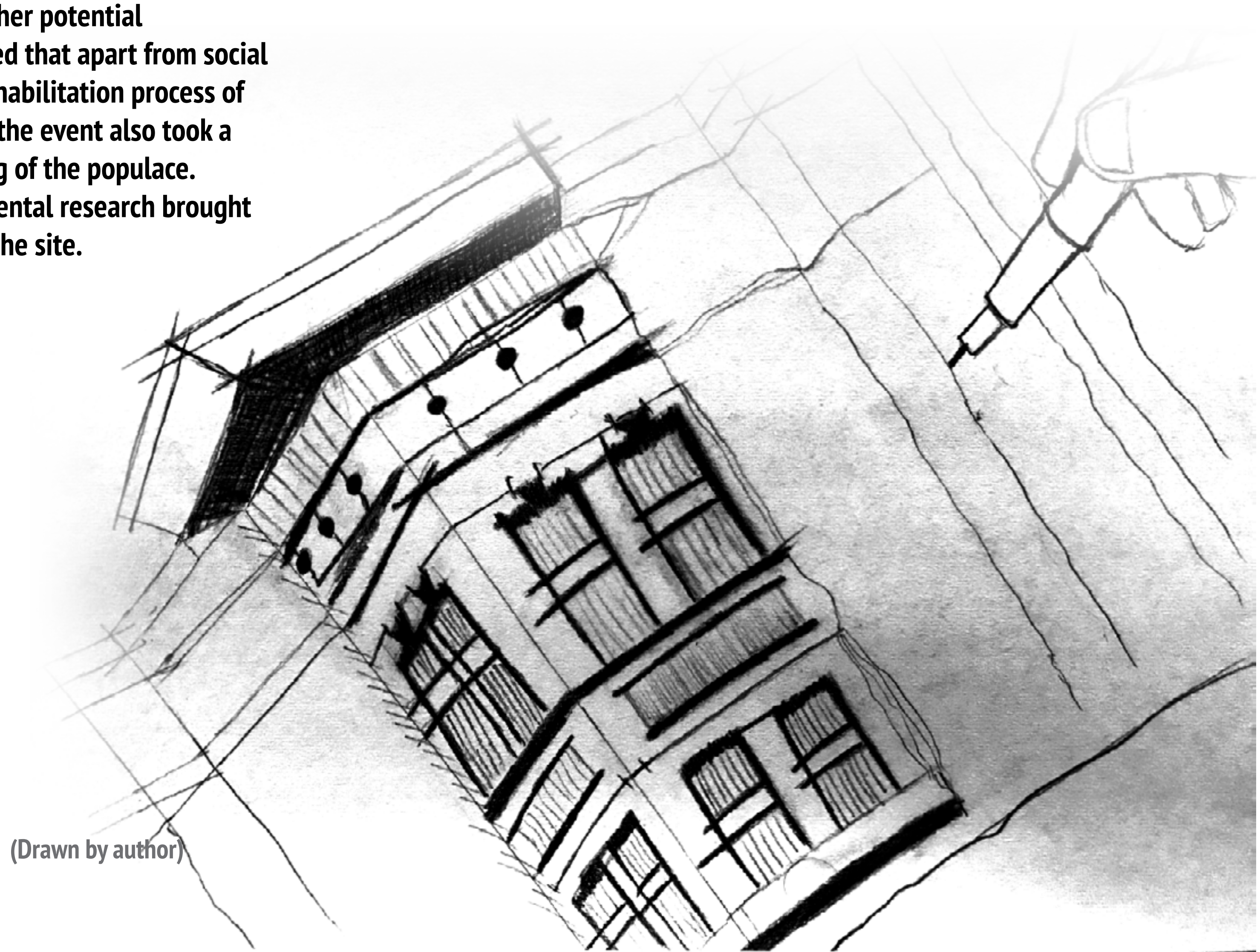
Universal design workshop



(School of planning and architecture, Bhopal magazine)

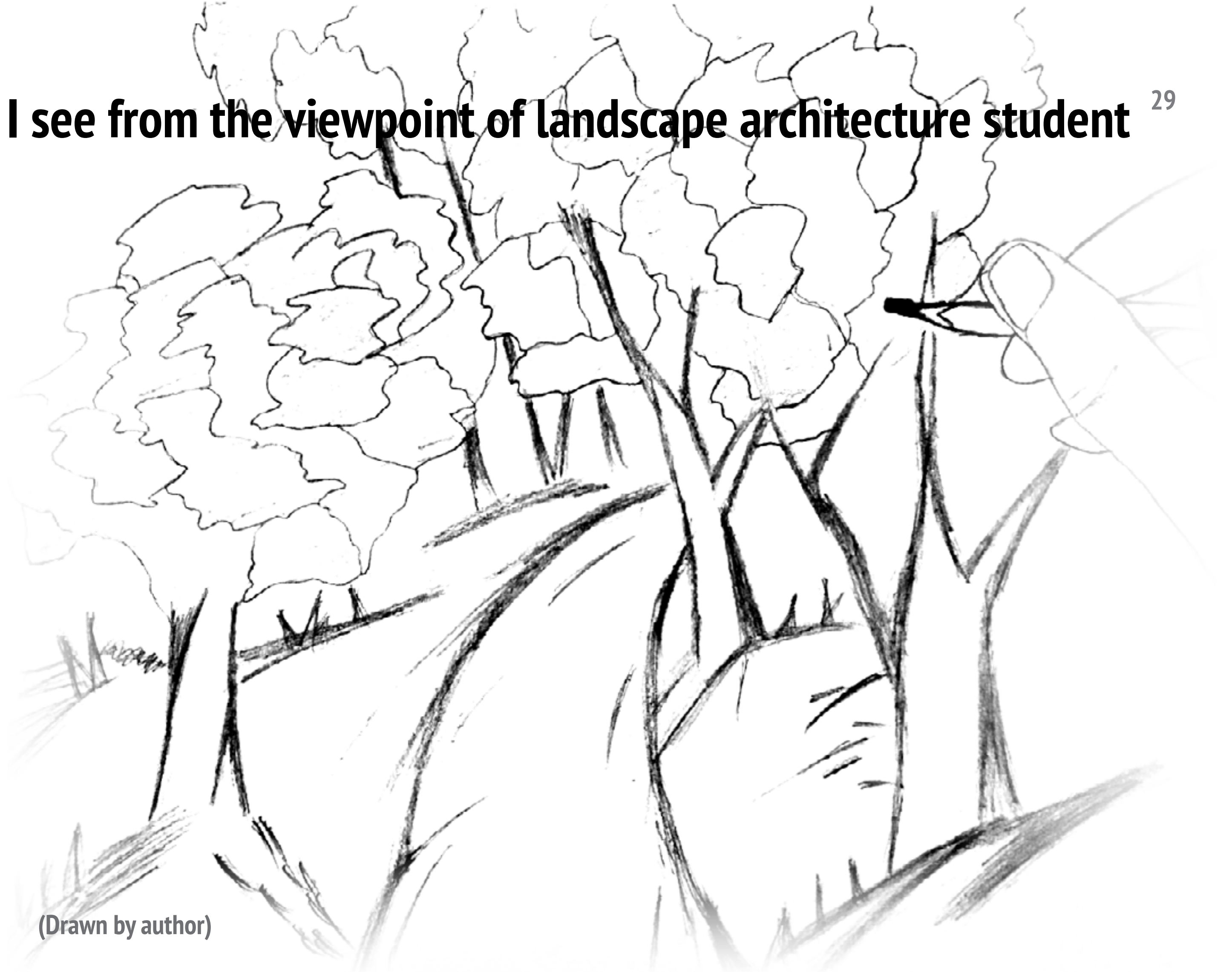
How studies in architecture helped me understand the situation

During my undergraduate studies, I worked extensively on the subject of 'Universal design'. In my course of research, I came to know that Bhopal has the highest disabled population in the entire state of Madhya Pradesh (Hindustan Times, 2015). This fact helped me understand the catastrophic impact the gas tragedy had on the demography of Bhopal. Soon I delved further into research related to other potential ramifications of the tragedy has created. I realized that apart from social and legal challenges that have hampered the rehabilitation process of the victims, environmental problems created by the event also took a very heavy toll on the life, health, and well-being of the populace. While there has been much social and environmental research brought forward, very little has been done to remediate the site.



(Drawn by author)

What did I see from the viewpoint of landscape architecture student



(Drawn by author)

In my Masters in Landscape Architecture studies, I decided to choose this topic for my practicum, so I could explore and understand the social and environmental aspects of the disaster. I travelled to Bhopal in December 2016, to conduct a site study of the former Union Carbide factory. I was able to map, document and evaluate the existing condition of the landscape, flora, and fauna of the factory site and better understand social conditions in the area.

Studies by scientific organizations such as National Environmental Engineering Research Institute (NEERI) and National Geophysical Research Institute (NGRI) have substantiated the presence of both organic and inorganic pollutants in the factory area and the surroundings. Studies have also revealed serious ecological and biological damage to the local flora and fauna.

Analysis of former Union Carbide Factory site................

Location of Former Union Carbide Factory site

Madhya Pradesh (MP) is a state in central India. Its capital is Bhopal. It is also called the "heart of India" due to its geographical location. Madhya Pradesh is the second-largest state in the country by area (308,252 km2(119,017 sq mi).

Population : 75 million

3 % land area comapared to Canada

Twice population of Canada

Bhopal is the capital city of Madhya Pradesh. It is an ancient city and was the capital city of many rulers in the medieval period (10th to 18th century). It is famous for the artificial lake upon which it is situated.

Arif Nagar is a district located to the North of the Old Bhopal City and railway Station, it is adjacent to 'Berasia road.' which connects the area to the old city (Hamidia road'). Most of the area of Arif Nagar is occupied by the Union Carbide factory, the rest is filled with slums that are adjacent to the factory .

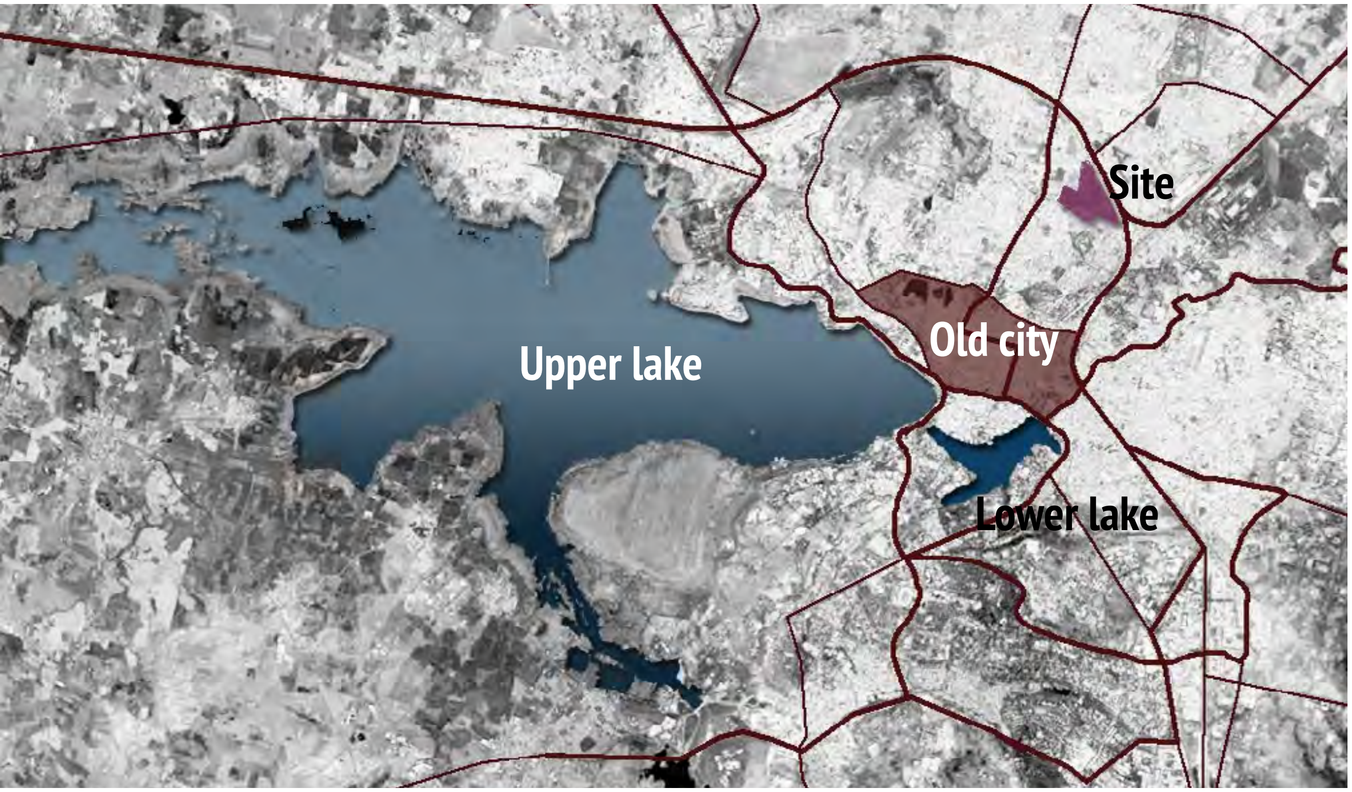
About Bhopal

Bhopal is known as the City of Lakes because of its various natural as well as artificial lakes; it is also one of the greenest cities in India. Bhopal has rich tropical deciduous vegetation (Sal and Teak trees). It is located on the Malwa plateau which is higher than the north Indian plains and the land rises towards the Vindhya range. The city has uneven elevation and small hills along its boundaries. Some common birds found in the region are the Oriental white eye (Zosterops palpebrosus), Sunbird (Leptocoma zeylonica), and Pied cuckoo (Clamator jacobinus) (Bhopal birds, 2013).

Taj-ul-Masjid, Bhopal

(Shiwam Dwivedi, 2012)

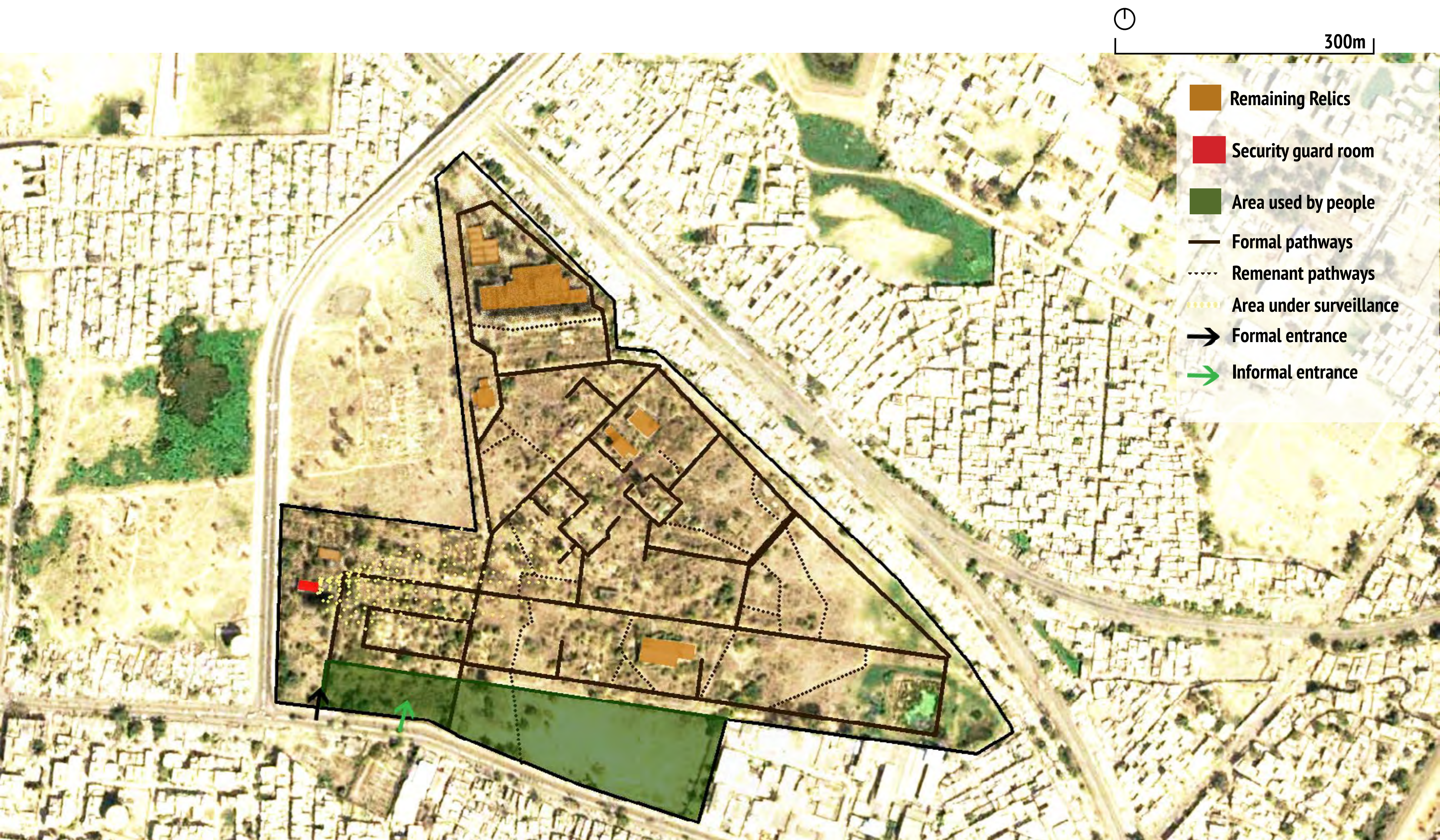
Former Union Carbide Factory site context



The designation of the site to Union Carbide in Arif Nagar was initially rejected by the state government and municipality, owing to the hazardous nature of the factory's operations. The site was adjacent to a major railway route (Delhi-CST) and a major highway (Bhopal-Vidisha bypass). Also, the proximity of the site to the old city and good connectivity made the site suitable for future urban growth. But the central government gave approval to the site allocation. When Union Carbide constructed part of its factory in 1968-69, large portions of the area next to the factory were still uninhabited though it was only two miles from the center of the old city and even nearer to some established neighborhoods with hospitals and a railway station (Peterson, 2009, p.3). Many poor migrants located their temporary dwelling huts along the periphery of the factory compund as the land around the site was owned by the Government.

Remaining relics, traces of pathways and accessibility

The current state of the factory buildings is dreadful. Maintenance is entirely neglected by the state and the central government. Most of the machinery is damaged, rusted or stolen and the site is full of wild animals and shrubs. The site becomes highly inaccessible for the guards during monsoons when wild shrubs grow and reptiles and insects come out. The cement concrete and mortar pathways constructed during the course of operation of the factory have deteriorated.



Formal entrance

Informal entrance

Roadside view of the entrance boundary wall

condition

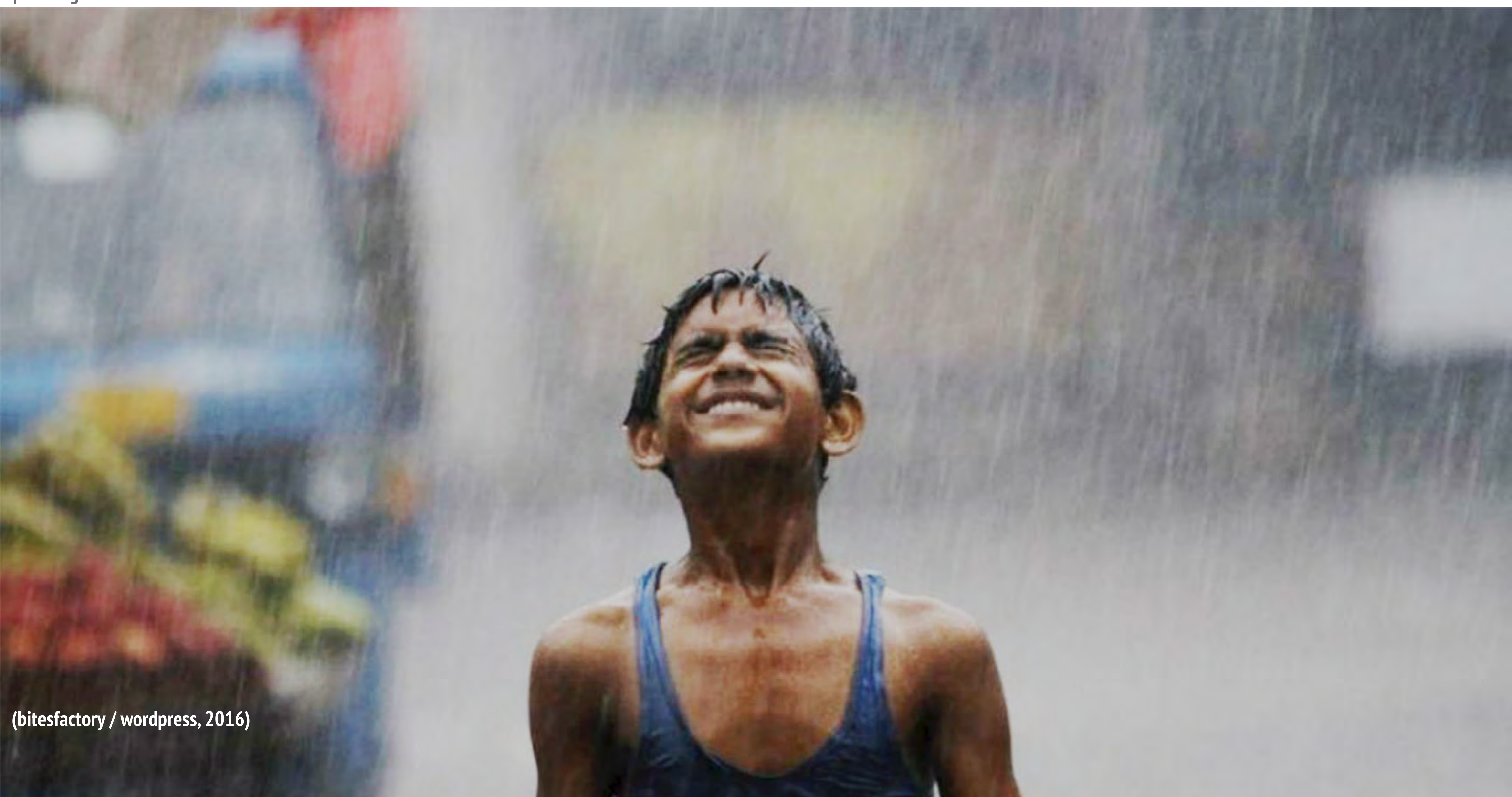
Treated as dumpyard

Railway track and dwellings

Solar evaporation pond

Climate

Spreading smiles all over



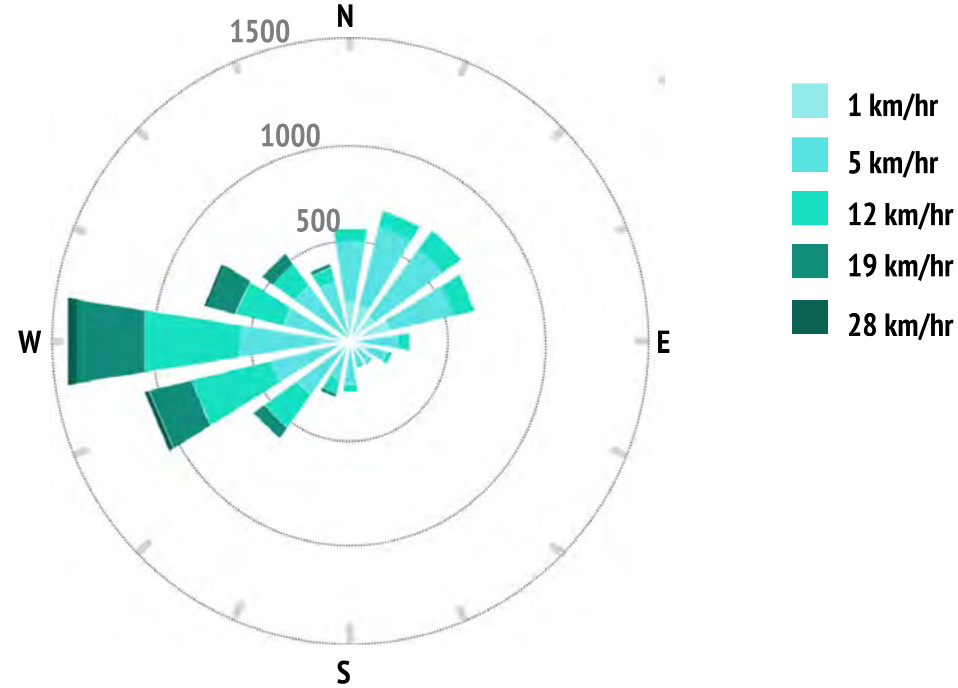
Temperature

Maximum (April- June) - 40^c - 30^c

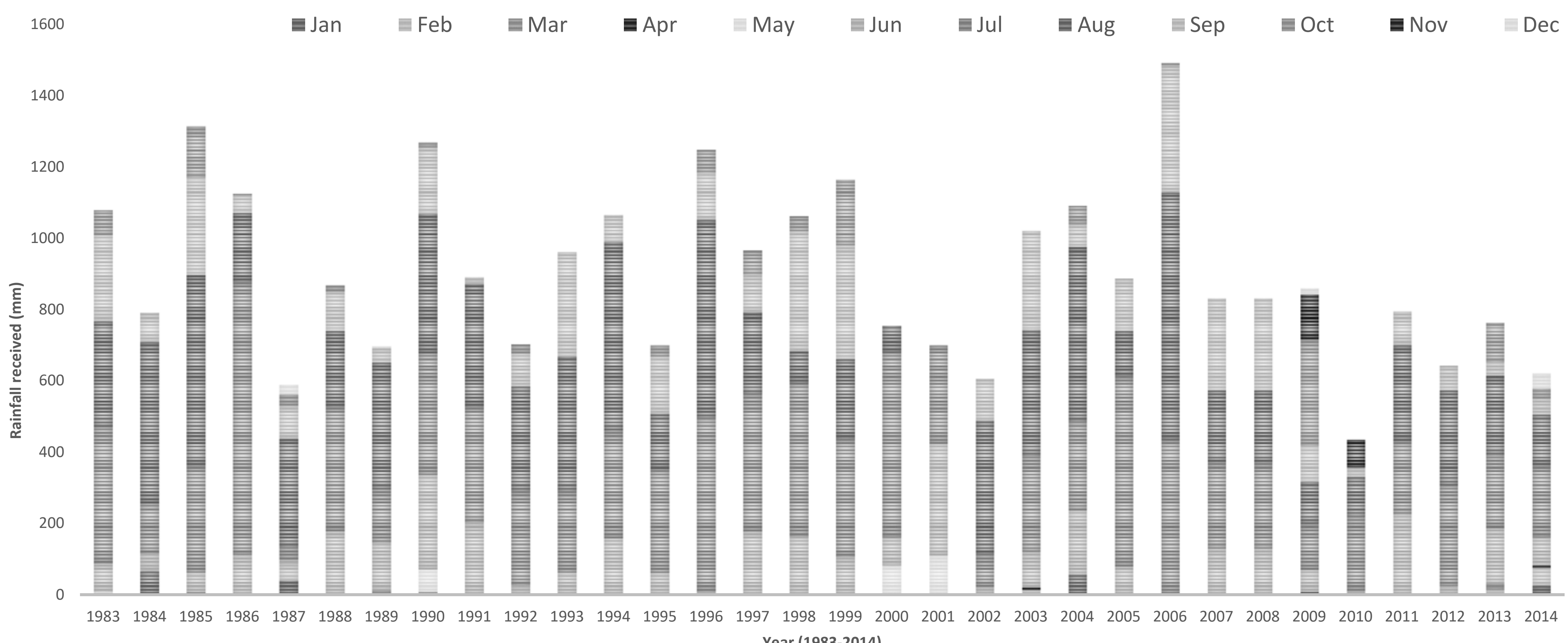
Average (January-December) - 20^c - 25^c

Minimum (December-January) - 20^c - 15^c

Wind Direction



Rainfall



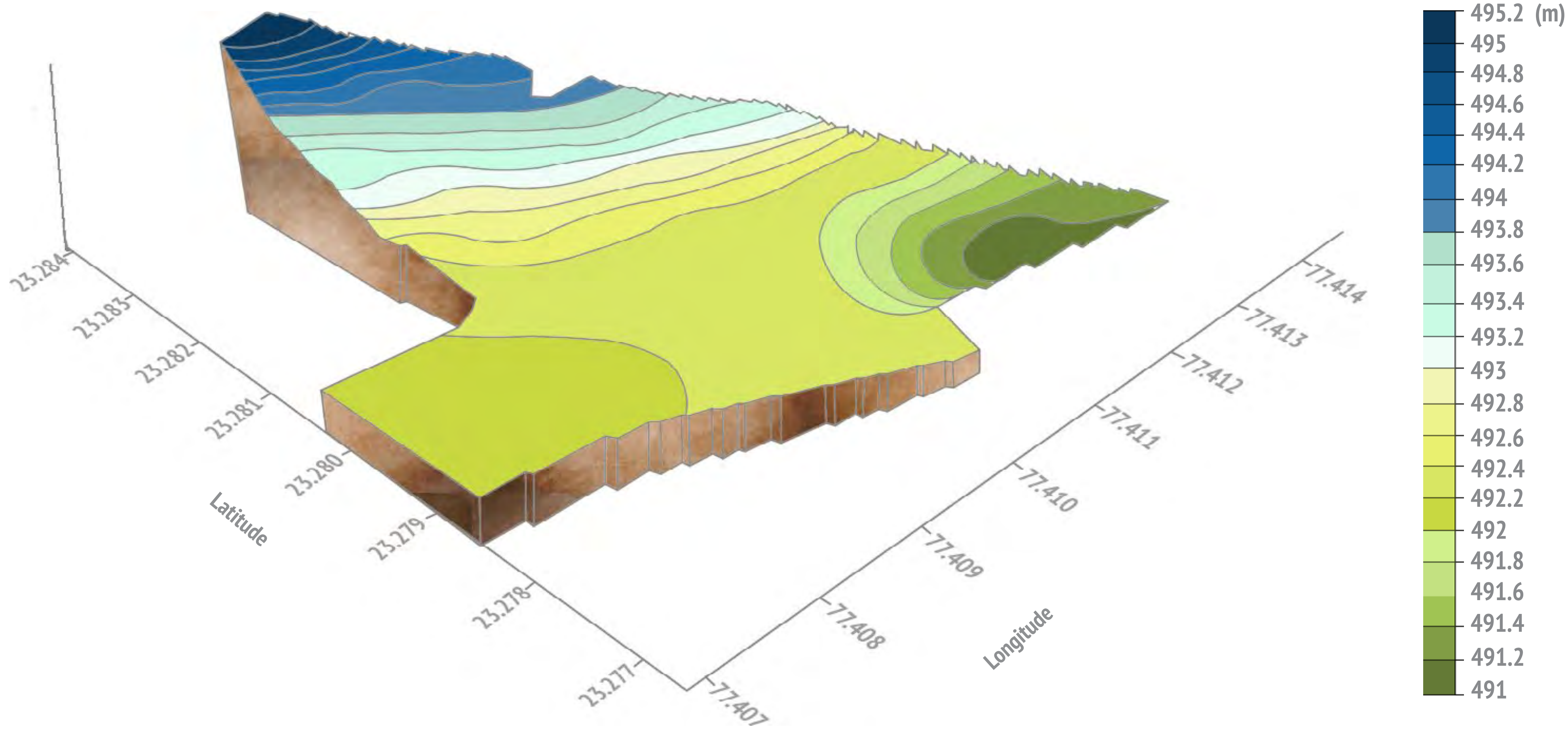
Source: Water resource department, Madhya Pradesh

Groundwater flow
(Neighbourhood)

The hydrogeological map shows the local and general groundwater flow in the area around the solar evaporation pond (SEP) and Union Carbide factory site. National Environmental Engineering Research Institute (NEERI 1990) found that the general groundwater flow is in a northerly to north- easterly direction, towards the river Patra. The water follows the drainage channel of the Lower lake, Bhopal. It drains into the Patra river which joins Halali river, a small tributary of the Betwa river.

Groundwater elevation
(Former Union Carbide Factory site)

It can be seen that shallow groundwater exists in the southwestern section of the site whereas deep water level is recorded in the eastern section.
It is maximum in the southeastern part which is also in the vicinity of residential area. The knowledge of this groundwater level helps to understand the surface drainage patterns. This groundwater would be used for electro- kinetic and phytoremediation that is proposed for the site. Also, understanding the contamination in the groundwater aids in understanding what ion- mobilizers must be used during electro- kinetic remediation.

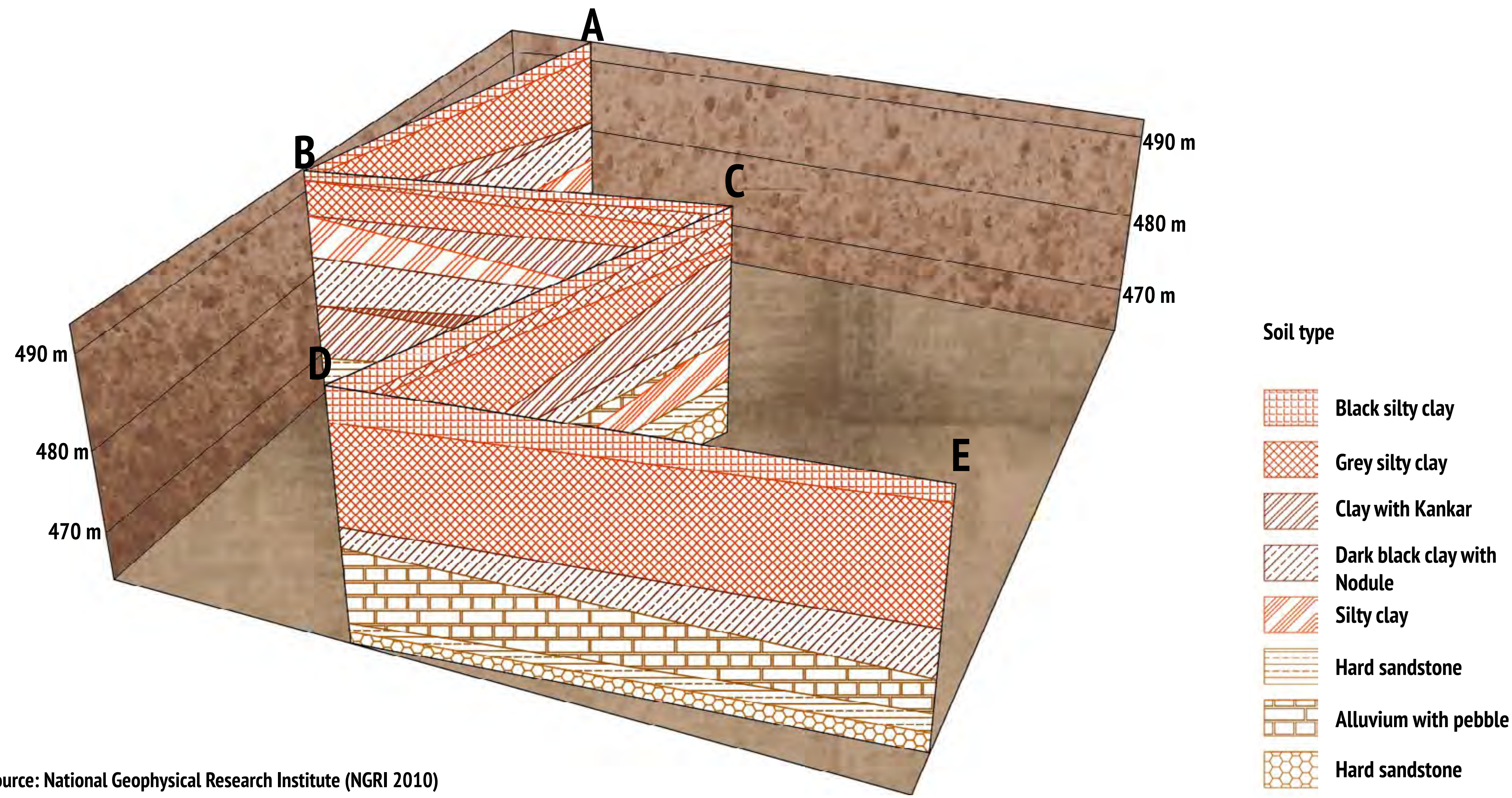


Source: National Geophysical Research Institute (NGRI 2010)

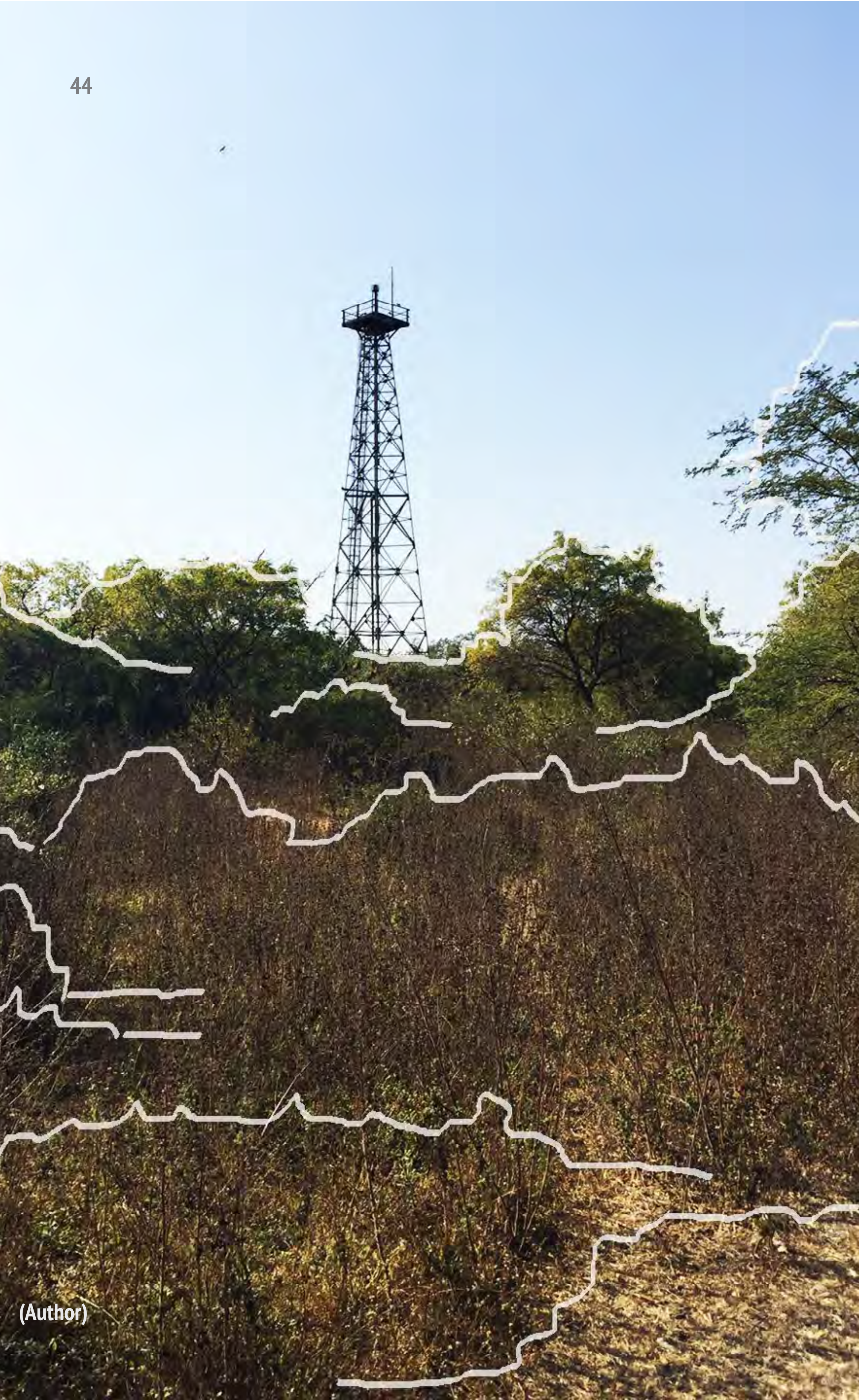
Soil analysis
(Sectional points)

A National Geophysical Research Institute, India (NGRI) study was conducted in 2010 to determine soil conditions in the site by drilling in five different spots.
The next diagram shows different soil layers.

Bhopal city has black silty clay soil. The soil has very little permeability and very high density. The soil is rich in calcium but low in humid content and phosphorus.



Source: National Geophysical Research Institute (NGRI 2010)

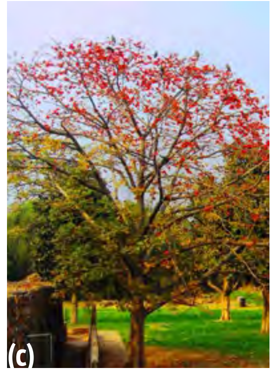


(Author)

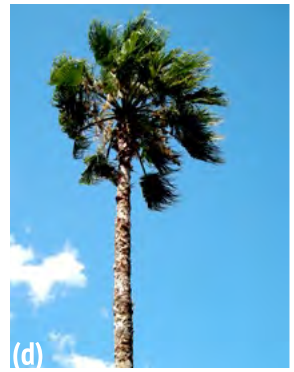
Existing plant species

Azadirachta indica

Eucalyptus



Bombax ceiba



Phoenix dactylifera

Leucaena leucocephala

Acacia nilotica

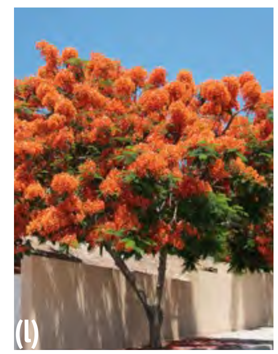
Ziziphus mauritiana

Hibiscus

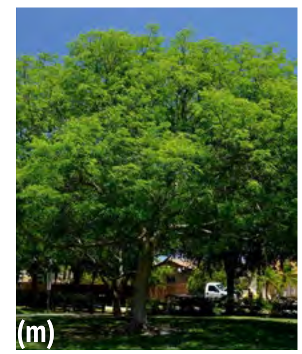
Dalbergia sisso

Cascabela thevetia

Saraca asoca



Delonix regia



Tamarindus indica

Santalum

Psidium guajava

Mangifera

Ficus religiosa

F. benghalensis

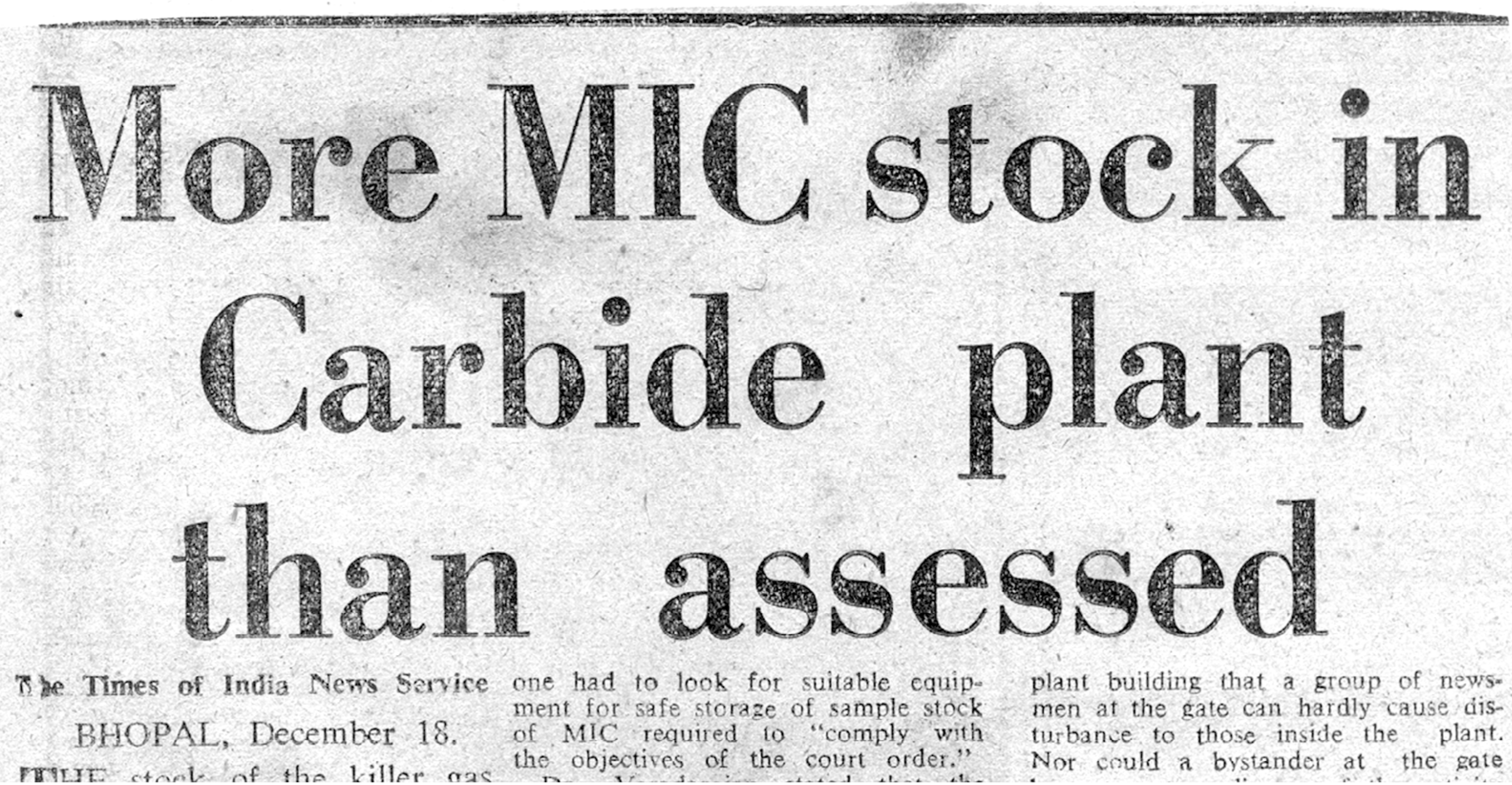
Prosopis cineraria

Butea monosperma

(Author)

Contamination (1969- present)

Tale of contamination



More MIC stock in Carbide plant than assessed

The Times of India News Service

BHOPAL, December 18.

THE stock of the killer gas

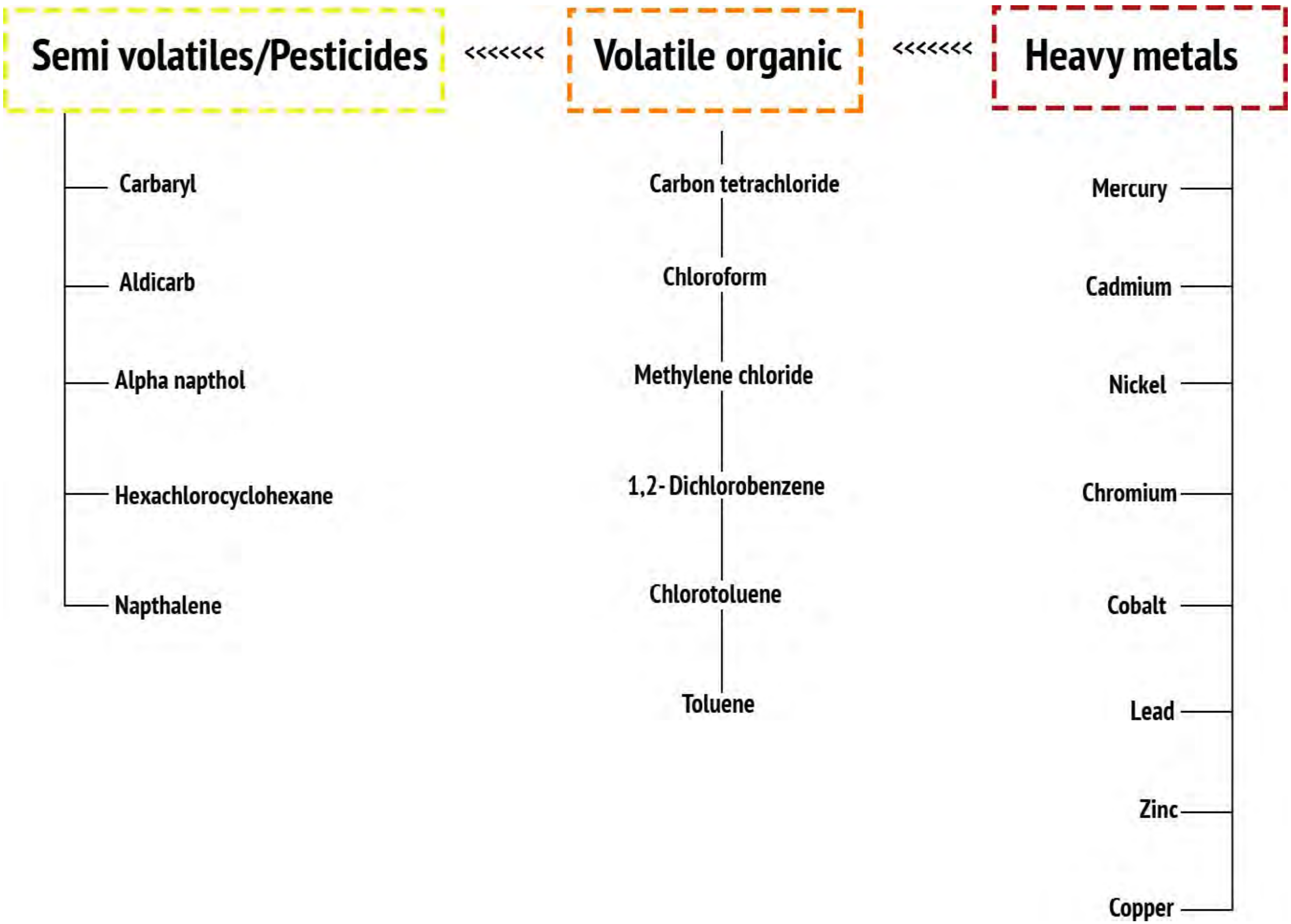
one had to look for suitable equipment for safe storage of sample stock of MIC required to "comply with the objectives of the court order."

plant building that a group of newsmen at the gate can hardly cause disturbance to those inside the plant. Nor could a bystander at the gate

Dated: 19 December 1984

(wordpress, 2009)

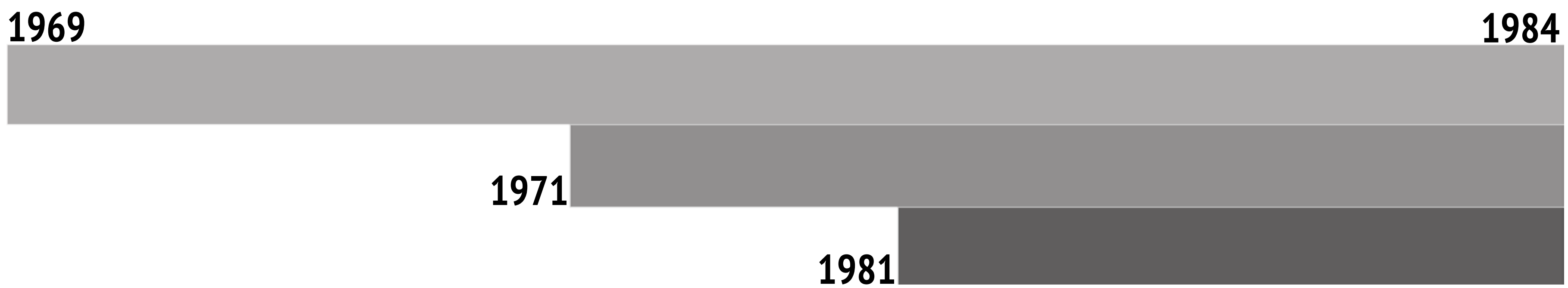
Contaminants found in and around the former Union Carbide factory



Source: National Environmental Engineering Research Institute, (NEERI, 1990)

Location of dumping areas before the tragedy

Contamination during the operation of Union Carbide factory (1969-1984)



Solids, semi-solids, liquid and tarry wastes generated during
the manufacture of pesticides and associated chemicals were dumped.

Manufacture of phosgene, monomethylamine, methylisocyanate and
carbaryl.

Production rate increased of Sevin and MIC:
Sevin-2658 mt/year
MIC- 864 mt/year

approximately 25,000 tons of contaminated solid material may exist at the site.

Source: National Environmental Engineering Research Institute, (NEERI, 1990)

Soil sampling inside the site

National Geophysical Research Institute, India (NGRI) drilled 30 boreholes (S1-S27, As-Es) in 2010 at the surface (30 cm) and the subsurface (60 cm) level, samples were collected from the suspected contaminated hot spots.

India has not developed standards to measure the permissible chemical and metal levels for soil. So, to analyze the concentration levels, United States Environmental Protection Agency (US EPA) standards are used.
The red values indicate that the concentration of the contaminant exceeds the (US EPA) standards.

Contaminants exceeding the safety levels:

Cadmium
Mercury
Aldicarb
Carbaryl
a,b,g-HcH

Source: National Environmental Engineering Research Institute (NEERI 1990)

Location	GPS coordinates	Level	Zinc (mg/kg)	Lead (mg/kg)	Cadium (mg/kg)	Nickel (mg/kg)	Cobalt (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Mercury (mg/kg)	Aldicarb (mg/kg)	Carbaryl (mg/kg)	Alpha napthol (mg/kg)	a-HCH (mg/kg)	beta HCH (mg/kg)	gamma HCH (mg/kg)	Dichlorobenzene (mg/kg)
		USEPA Stnd (mg/kg)	100-300	2-200	0.01-0.7	5-500	24	11	2-100	0.01-0.3	620	62000	31000	0.27	0.96	2.1	9800
S8	N:23.283144	Surface	3.48	3.18	0.58	3.06	8.56	2.22	0.94	n/a	n/a	24.3	42.7	13.96	n/a	n/a	n/a
	E:77.408424	Sub-Surface	3.56	4.3	0.54	3.04	7.34	1.98	1.01	n/a	923	14.2	n/a	19.82	n/a	16.54	0.000097
S7	N:23.282792	Surface	3.42	4.29	0.41	2.84	15.53	2.32	2.93	1.29	n/a	1.3	1.9	6.37	6.17	5.52	n/a
	E:77.409095	Sub-surface	2.57	2.37	0.18	2.39	4.68	1.65	1.82	1.29	n/a	n/a	n/a	n/a	0.584	0.568	0.000013
S10	N:23.281628	Surface	3.42	5.21	0.76	3.81	10.23	2.97	2.01	2.1	n/a	n/a	n/a	5.02	0.48	n/a	n/a
	E:77.409203	Sub-surface	2.46	5.64	6.56	2.06	2.23	2.46	2	0.34	n/a	24.6	14.94	0.24	0.36	0.16	n/a
S11	N:23.281357	Surface	4.42	6.64	1.32	3.84	3.24	1.83	3.81	n/a	n/a	n/a	n/a	n/a	0.38	n/a	n/a
	E:77.410308	Sub-surface	6.72	5.94	0.74	3.44	9.38	1.48	3.16	n/a	n/a	0.126	0.54	0.43	0.26	0.08	0.000017
S19	N:23.280026	Surface	2.81	0.89	0.54	1.26	7.86	3.04	2.31	0.1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	E:77.410115	Sub-surface	2.41	0.98	0.56	1.84	8.24	2.82	2.61	n/a	n/a	18.3	2.3	n/a	0.27	n/a	n/a
S20	N:23.279494	Surface	4.12	0.96	0.63	3.41	8.42	2.61	2.09	0.41	n/a	n/a	n/a	0.21	0.62	0.41	n/a
	E:77.409734	Sub-surface	3.89	1.02	0.81	3.06	7.93	3.8	2.01	n/a	n/a	n/a	n/a	n/a	0.31	0.16	n/a
S12	N:23.279878	Surface	6.36	4.62	1.02	2.06	9.72	2.41	2.16	0.41	n/a	n/a	n/a	n/a	0.15	n/a	n/a
	E:77.410936	Sub-surface	7.36	1.22	0.63	3.02	7.8	2.3	2.08	0.21	n/a	0.174	0.511	0.31	0.34	0.15	n/a
S6	N:23.279371	Surface	4.32	5.99	1.79	1.18	11.78	3.02	2.11	4.17	n/a	2.48	1.55	n/a	n/a	n/a	n/a
	E:77.410952	Sub-surface	4.03	5.66	1.59	1.84	12.35	2.08	1.76	0.19	n/a	n/a	n/a	n/a	0.498	n/a	n/a
S13	N:23.279302	Surface	4.6	2.14	0.58	2.72	7.61	1.67	2.17	0.36	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	E:77.412674	Sub-surface	4.28	2.31	0.72	2.2	8.41	1.42	2.08	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S14	N:23.278972	Surface	3.64	2.81	0.78	3.61	8.76	2.97	1.94	0.81	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	E:77.413034	Sub-surface	3.04	1.67	1.18	1.26	7.93	2.08	1.82	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S15	N:23.278567	Surface	3.48	3.18	0.65	3.21	6.21	1.1	2.46	0.14	n/a	0.273	1.507	2.08	3.14	1.83	0.165
	E:77.413377	Sub-surface	1.26	2.16	0.58	3.1	5.89	2.1	2.16	n/a	n/a	1.577	2.995	1.82	2.06	2.48	0.0001
S16	N:23.278114	Surface	2.7	3.08	0.76	3.12	6.02	2.06	1.94	0.63	n/a	n/a	n/a	4.21	3.58	2.06	n/a
	E:77.41386	Sub-surface	3.41	2.62	0.82	3.4	6.01	2.31	2.34	n/a	n/a	n/a	n/a	2.64	2.89	3.41	n/a
S17	N:23.277991	Surface	4.06	1.22	1.34	2.06	7.23	2.18	2.86	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.108
	E:77.413388	Sub-surface	4.13	1.46	1.62	2.41	7.41	2.04	2.65	n/a	n/a	2.728	1.037	n/a	0.2	n/a	n/a
S18	N:23.278144	Surface	3.64	2.13	0.82	2.72	3.32	2.12	1.89	0.61	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	E:77.412696	Sub-surface	2.84	2.36	0.76	2.2	9.21	3.1	1.95	0.21	n/a	n/a	n/a	0.53	0.63	n/a	n/a
S4	N:23.278868	Surface	3.96	5.34	1.55	1.39	10.08	2.4	1.25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	E:77.411982	Sub-surface	3.66	5.42	1.03	2.6	10.41	1.13	0.34	0.76	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S5	N:23.278937	Surface	3.58	6.87	1.6	2.95	10.14	2.88	1.96	0.43	n/a	1.06	0.721	n/a	n/a	n/a	n/a
	E:77.411161	Sub-surface	4.31	2.49	1.27	2.03	11.43	1.35	1.08	0.36	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S3	N:23.278533	Surface	5.6	5.73	1.03	2.62	10.38	1.28	0.17	n/a	n/a	5493	1460	n/a	6.93	5.59	n/a
	E:77.410754	Sub-surface	3.57	4.96	1.75	1.75	10.72	2.09	1.9	n/a	n/a	233	297.2	n/a	n/a	n/a	n/a
S2	N:23.277656	Surface	6.76	5.24	1.97	2.63	9.9	2.59	1.74	n/a	n/a	10729	1208	n/a	n/a	n/a	n/a
	E:77.410233	Sub-surface	5.24	7.58	1.46	1.91	13.61	1.67	1.87	n/a	n/a	n/a	n/a	n/a	13.34	n/a	n/a
S1	N:23.277326	Surface	3.7	4.51	0.76	2.74	7.72	3.97	2.87	3.07	n/a	1.25	13.02	n/a	n/a	n/a	n/a
	E:77.409096	Sub-surface	4.82	5.37	1.76	2.14	5.8	1.92	1.61	0.519	n/a	3.883	6.877	0.313	n/a	n/a	n/a
S21	N:23.279318	Surface	1.84	1.23	0.91	2.07	6.42	2.91	2.87	n/a	n/a	n/a	n/a	n/a	0.8	n/a	n/a
	E:77.408728	Sub-surface	1.86	2.03	0.87	2.14	6.73	2.04	2.96	n/a	n/a	7.68	24.23	0.64	0.53	n/a	0.0001
S22	N:23.278668	Surface	2.18	2.41	1.84	2.06	7.81	1.98	1.94	n/a	n/a	n/a	n/a	0.21	0.18	n/a	n/a
	E:77.407451	Sub-surface	2.06	2.08	1.26	2.73	8.46	1.75	1.68	n/a	n/a	10.77	37.9	n/a	0.31	n/a	0.11
S9	N:23.278698	Surface	1.26	2.62	0.48	3.37	7.66	2.05	1.85	1.04	n/a	251.3	n/a	n/a	n/a	n/a	n/a
	E:77.406679	Sub-surface	1.22	3.08	0.5	3.04	10.21	2.46	1.23	0	596	486	n/a	n/a	n/a	n/a	n/a
As	N:23.282953	Surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.673	0.415	0.66	0.637	n/a
	E:77.408903	Sub-surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.73	0.038	0.86	0.395	0.597	n/a	n/a
Bs	N: 23.28111	Surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.754	0.423	0.614	n/a	n/a
	E: 77.410754	Sub-surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.78	0.304	0.267	0.407	0.549	n/a	0.000013
Cs	N: 23.278638	Surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.392	0.635	n/a	n/a
	E: 77.412462	Sub-surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.77	3.708	3.594	0.286	n/a	n/a	n/a
Ds	N: 23.27852	Surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	E: 77.408651	Sub-surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.884	n/a	n/a	0.148	n/a	n/a	n/a
Es	N: 23.27852	Surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.82	0.408	n/a	0.614	n/a
	E: 77.408651	Sub-surface	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.713	0.288	0.077	0.362	n/a	n/a	0.00009

Soil sampling outside the site

Soil samples were also collected from eight different locations outside the factory. Four locations were upstream (south-west) and four locations were downstream (north-east) considering the north-east direction of groundwater. The soil samples at these locations were collected at three different levels (surface, 30 cm deep and 60 cm deep).

Contaminants exceeding the safety levels:

Cadmium
Mercury
b-HcH

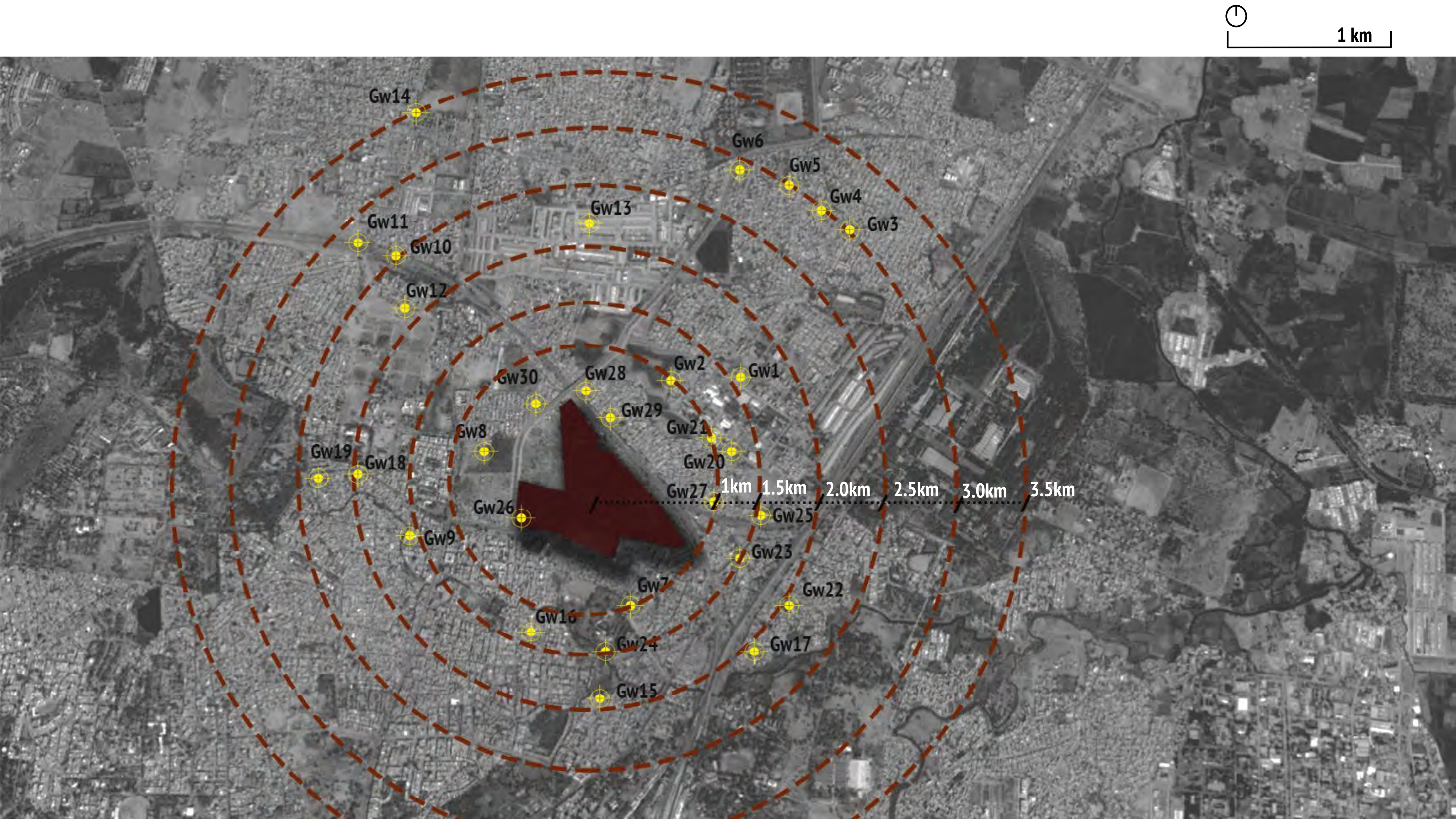
Again, to analyze the concentration levels, United States Environmental Protection Agency (US EPA) standards are employed.
The red values indicate that the concentration of the contaminant is exceeding the United States Environmental Protection Agency (US EPA) standards.

Source: National Environmental Engineering Research Institute (NEERI 1990)

Location	GPS coordinates	Level	Zinc (mg/kg)	Lead (mg/kg)	Cadmium (mg/kg)	Nickel (mg/kg)	Cobalt (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Mercury (mg/kg)	Aldicarb (mg/kg)	Carbaryl (mg/kg)	a-naphthol (mg/kg)	b-hch (mg/kg)
		USEPA Stnd .in mg/kg	100-300	2-200	0.01-0.7	5-500	24	11	2-100	0.01-0.3	620	62000	31000	0.96
US1	N:23.2763184087	Surface	8.06	1.62	0.21	3.32	2.48	nd	4.17	nd	nd	nd	nd	nd
	E:77.4104704	Sub- surface	6.7	1.64	1.21	3.45	7	nd	2.93	nd	nd	nd	nd	nd
US2	N:23.2756088026	Surface	8.11	1.23	nd	3.43	2.37	nd	4.12	nd	nd	nd	nd	nd
	E:77.4082818031	Sub- surface	6.1	1.83	nd	3.2	4.47	nd	3.65	nd	nd	nd	nd	nd
US3	N:23.2798466717	Surface	7.69	2.23	5.08	3.51	2.54	1.45	1.02	nd	nd	nd	nd	nd
	E:77.4039044380	Sub- surface	2.5	1.29	nd	4.06	5.87	nd	nd	nd	nd	nd	nd	nd
US4	N:23.2840646959	Surface	9.02	2.49	10.88	3.51	1.54	10.66	2.36	nd	nd	nd	nd	nd
	E:77.4034752844	Sub- surface	9.08	2.84	3.64	4.4	1.66	n.d	3.1	nd	nd	nd	nd	nd
DS1	N:23.2856612041	Surface	6.27	3.53	1.4	5.05	1.35	5.21	0.3	nd	8.158	6.888	3.516	2.55
	E:77.4106636046	Sub- surface	6.08	1.59	1.14	2.81	2.74	2.09	nd	nd	nd	nd	nd	nd
DS2	N:23.2879081074	Surface	7.8	1.18	2.86	3.87	3.27	6.16	3.39	0.33	nd	nd	nd	0.403
	E:77.4084749221	Sub- surface	6.47	1.73	1.4	2.75	2.98	1.11	3.22	nd	nd	nd	nd	nd
DS3	N:23.2888344513	Surface	7.76	2.11	1.49	2.76	1.5	3.87	3.2	nd	nd	nd	nd	nd
	E:77.4034752846	Sub- surface	5.63	2.52	nd	3.15	2	2.45	3.72	nd	nd	nd	nd	nd
DS4	N:23.2916922799	Surface	6.59	1.29	0.22	3.86	3.79	nd	2.25	nd	nd	nd	nd	nd
	E:77.4157919884	Sub- surface	7.58	2.86	2.74	2.35	3.01	2.47	3.04	nd	nd	nd	nd	nd

Groundwater sampling outside the site

From existing dug wells, bore wells and hand pumps, 27 groundwater samples were collected around the factory site.



The red values indicate that the concentration of the contaminant is exceeding the United States Environmental Protection Agency (US EPA) and Indian standards.

Contaminants exceeding the safety levels:

Nickel
Cobalt
Aldicarb

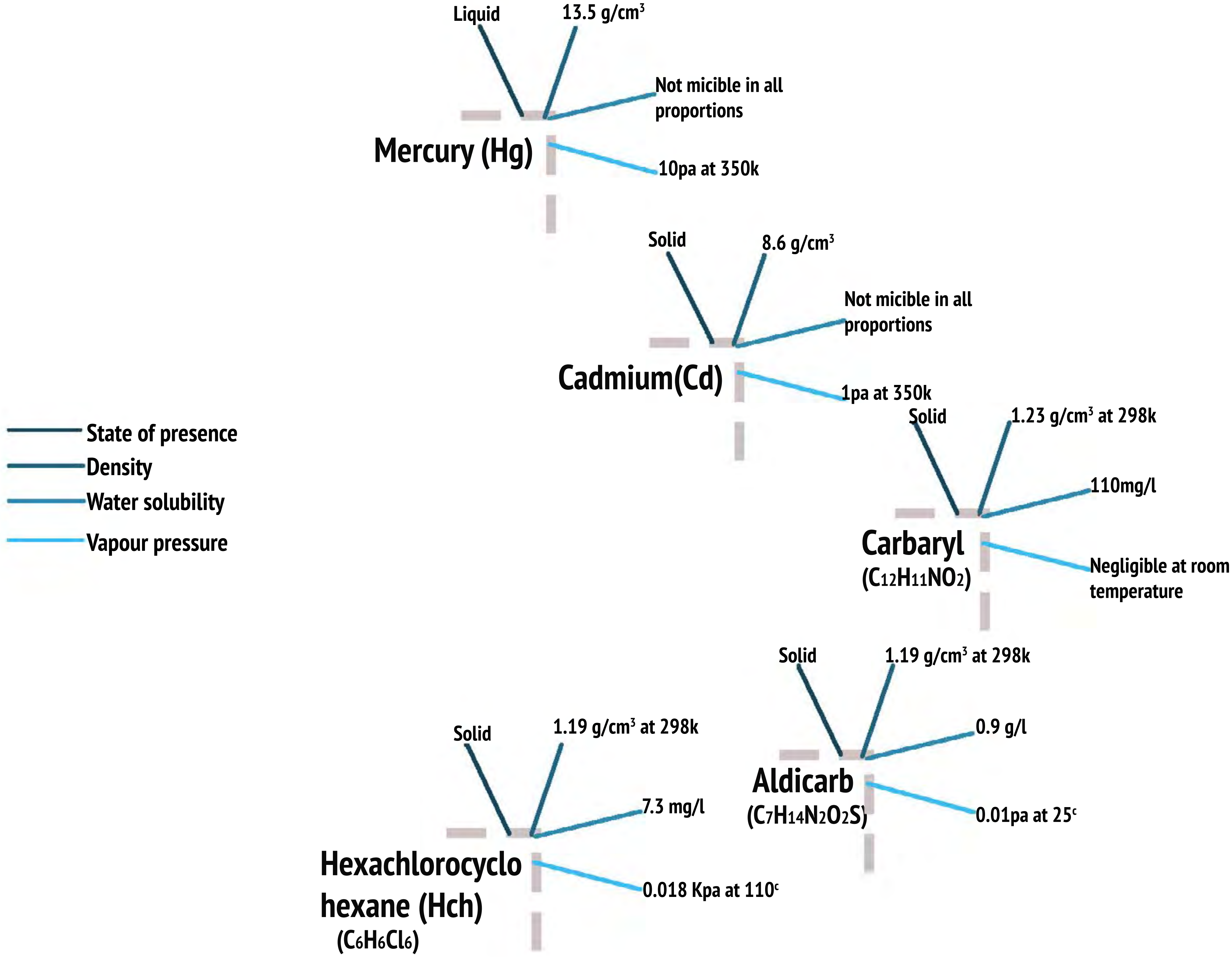
Location	Latitude	Longitude	Zinc (mg/kg)	Cadmium (mg/kg)	Nickel (mg/kg)	Cobalt (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Aldicarb (mg/kg)	Dichlorobenzene(mg/kg)
USEPA Stnd.-mg/kg			5	0.005	0.02	0.005	0.05	1	0.09	0.36
Indian stnd.-mg/kg			15	0.01	0.02	nd	0.05	1.5	0.01	1
GW1	23.283848	77.41569328	0.048	nd	0.014	nd	0.019/0.05	0.012/0.05	nd	nd
GW2	23.284557	77.41307545	0.407	nd	nd	nd	0.017/0.05	nd	nd	nd
GW3	23.292086	77.42238808	0.634	nd	0.013	0.011	0.02/0.05	0.008/0.05	nd	nd
GW4	23.292796	77.42114353	0.062	0.005/0.01	0.013	0.013	0.021/0.05	nd	nd	nd
GW5	23.293624	77.41904068	0.001	nd	0.016	0.012	0.028/0.05	nd	nd	nd
GW6	23.293978	77.41590786	0.027	0.006	0.018	0.011	0.03/0.05	0.02/0.05	nd	nd
GW7	23.275766	77.41170216	0.001	0.007/0.01	nd	0.013	0.029/0.05	nd	nd	nd
GW8	23.281759	77.40492153	0.032	0.006/0.01	0.024	0.016	0.038/0.05	nd	nd	nd
GW9	23.278171	77.4020462	nd	0.006/0.01	nd	0.014	0.028/0.05	nd	nd	0.0002
GW10	23.289524	77.40135956	0.17	0.007/0.01	0.015	0.013	0.03/0.05	nd	nd	0.0002
GW11	23.290076	77.3995142	nd	nd	0.015	nd	0.011/0.05	0.005/0.05	nd	nd
GW12	23.287474	77.4011879	0.566	0.006/0.01	nd	0.027	0.013/0.05	0.045/0.05	nd	nd
GW13	23.291692	77.4092989	0.018	nd	0.015	0.013	0.015/0.05	0.008/0.05	nd	nd
GW14	23.296107	77.40080166	0.141	0.003/0.01	0.012	nd	0.012/0.05	0.004/0.05	nd	nd
GW15	23.272061	77.41088676	nd	0.005/0.01	0.012	nd	0.018/0.05	0.005/0.05	nd	nd
GW16	23.274505	77.4070673	0.565	nd	0.015	0.01	0.02/0.05	0.009/0.05	nd	nd
GW17	23.274071	77.41728115	0.029	0.007/0.01	nd	0.016	0.027/0.05	0.007/0.05	nd	nd
GW18	23.280537	77.39985752	0.098	0.006/0.01	nd	0.016	0.023/0.05	0.012/0.05	nd	nd
GW19	23.280418	77.39852715	1.389	nd	nd	0.047	0.028/0.05	0.02/0.05	nd	nd
GW20	23.281877	77.41530704	1.099	0.008/0.01	nd	0.033	0.024/0.05	nd	nd	nd
GW21	23.282192	77.41457748	0.071	0.003/0.01	0.012	nd	0.016/0.05	0.004/0.05	nd	nd
GW22	23.275885	77.41891193	0.034	0.001/0.01	0.007	nd	0.006/0.05	0.002/0.05	nd	nd
GW23	23.277619	77.41676617	0.055	0.004/0.01	0.007	nd	0.005/0.05	0.006/0.05	nd	nd
GW24	23.273717	77.41045761	0.004	0.004/0.01	0.004	nd	0.008/0.05	0.002/0.05	nd	nd
GW25	23.279472	77.41719532	1.257	0.004/0.01	0.014	0.007/0.005	0.009/0.05	0.002/0.05	nd	nd
GW27	23.279866	77.41492081	0.101	0.003/0.01	0.011	0.012	0.013/0.05	0.009/0.05	3.4	0.0003
GW28	23.284203	77.4092989	0.262	0.004/0.01	0.012	0.013	0.019/0.05	0.006/0.05	3.7	nd
GW29	23.283178	77.41020012	0.046	0.002/0.01	0.007	0.014	0.01/0.05	0.01/0.05	3.4	0.0001
GW30	23.283611	77.40715313	0.089	0.006/0.01	nd	nd	0.036/0.05	0.016/0.05	nd	nd

Source: National Environmental Engineering Research Institute (NEERI 1990)

Challenging contaminants

(Properties of the contaminants)

These contaminants in the former Union Carbide factory site exceed the US EPA standards of safety and are therefore of concern.



Health issues

Immediate

Long term

Vomiting, nausea
Diarrhea, dizziness
Loss of memory
Extreme excitability
Depression, Insomnia
Irritability, numbness
Inflammation of gums

Mercury

Increased blood pressure
Increased heart rate
Pulmonary edema
Corrosive bronchitis and pneumonitis
Damage to the kidneys
Tremors and spasms

Emphysema
Dyspnoea
Respiratory issues

Cadmium

Fatal lung damage
Lung cancer
Tracheobronchitis
Pulmonary edema

Vomiting, nausea
Diarrhea, dizziness
Tightness in chest
Involuntary urination
Abdominal cramps
Fatigue, weakness
Increased bronchial secretions
Miosis

Aldicarb

Increased blood pressure
Hyperglycaemia

Vomiting, nausea
Diarrhea, dizziness
Loss of memory
Extreme excitability
Stomach cramps
Irritability
Muscle weakness
Blurred vision
Coma, headaches

Carbaryl

Respiratory problems

Vomiting, nausea
Diarrhea, dizziness
Decreased appetite
Vertig, headache

HCH

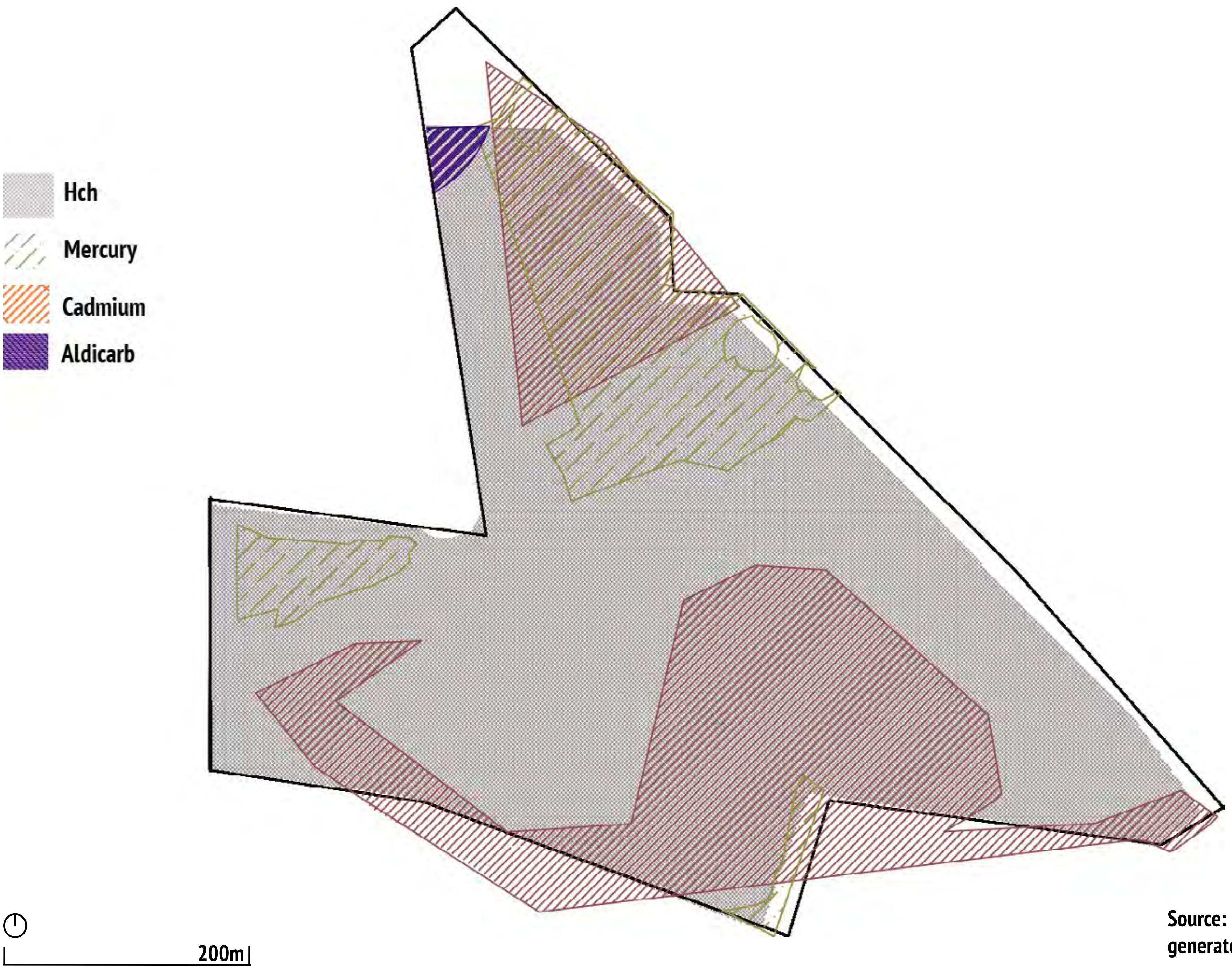
Neurological imbalance
Harmonal effect

Source: Contamination of soil and water inside and outside the Union Carbide India Limited, Bhopal , 2009

Dangerous concentration levels

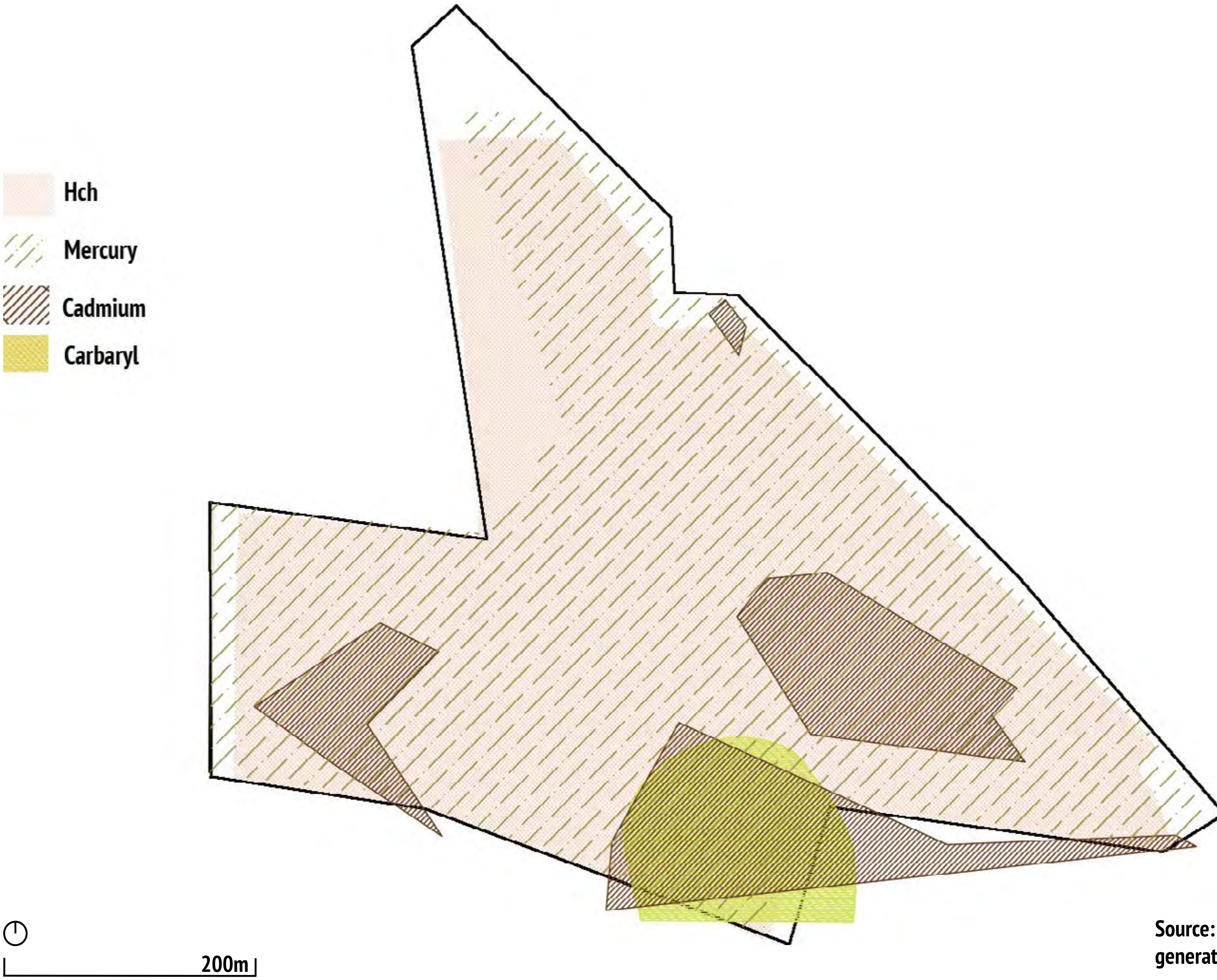
(Subsurface level up to 30-60 cm)

For my practicum, I will only address the contamination in the factory site with remediation strategies and design.



Source: Initial concentration maps were generated in ArcGis by Jerrold Rentz

Dangerous concentration levels
(Surface level)



Source: Initial concentration maps were generated in ArcGis by Jerrold Rentz

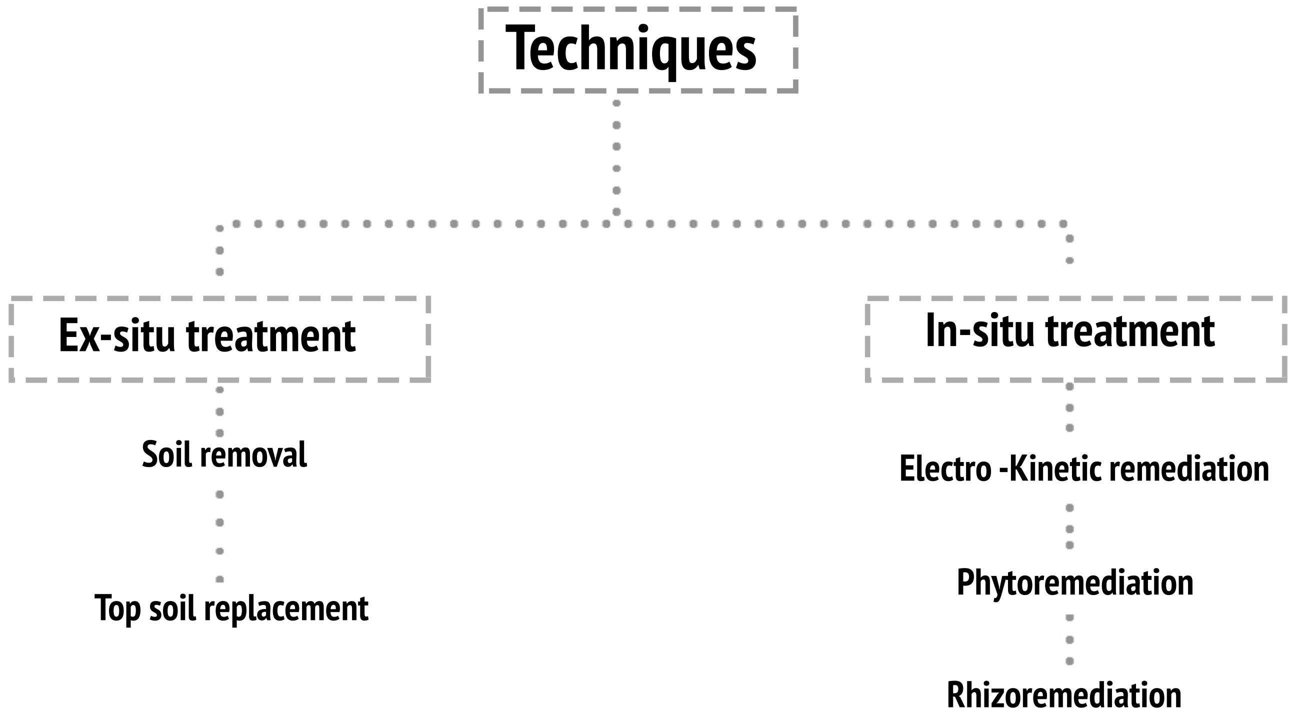
Dangerous concentration levels
(Subsurface and Surface level)

Overlapping contaminants
(Subsurface and Surface level)

Darker color represents greater concentrations of contaminants at different levels.

Amelioration techniques

Of the five contaminants, mercury and cadmium are heavy metals while the other three are organic pesticides. All five are found (at different concentration levels across) most of the site. So, a specific remediation strategy for a particular contaminant cannot be devised. The remediation strategies selected should deal with multiple contaminants in the same area. Also, it must be noted that the factory site is surrounded by densely populated areas so the remediation measures should be fast and should not have any a side effects to the adjoining population. Therefore, a holistic approach for the remediation has been proposed which would include soil removal, electro-kinetic remediation, phytoremediation and rhizoremediation, in the respective order.


Techniques
Ex-situ treatment
Soil removal
Top soil replacement
In-situ treatment
Electro -Kinetic remediation
Phytoremediation
Rhizoremediation

Top soil replacement

In this remediation technique we dig out the contaminated soil and take it, dump it at other wasteland, where it does not come in contact with people. In the second stage the uncontaminated soil is filled in to the excavated area. Soil to a depth of 30 cm would be removed and replaced with uncontaminated soil.

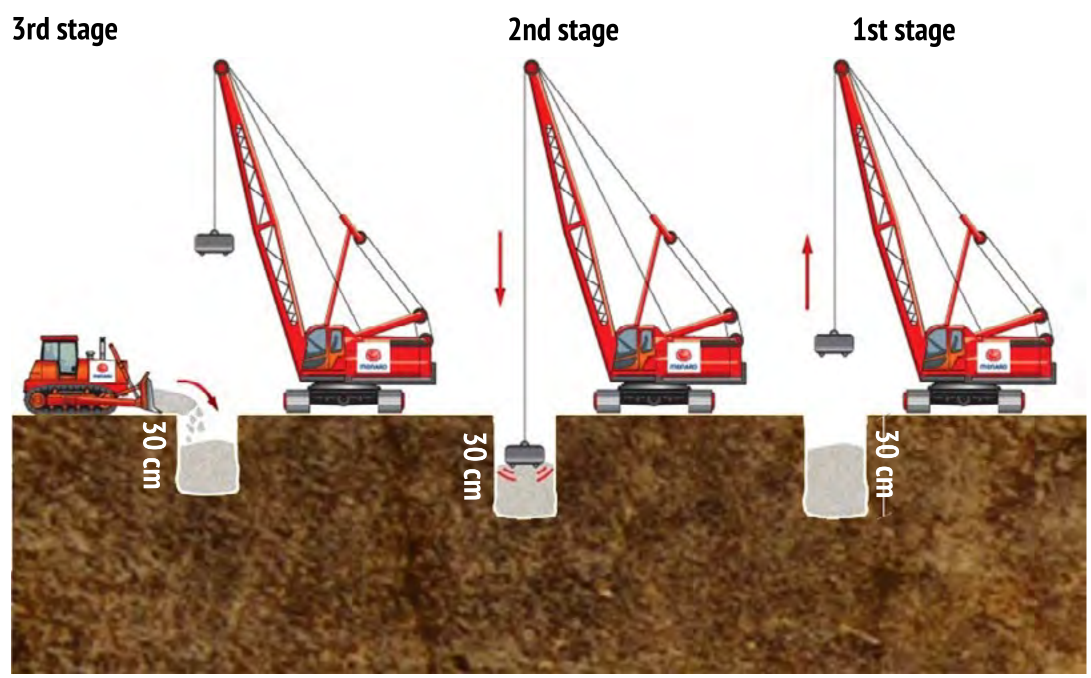
Advantages:

It is a very time efficient strategy.

It is not that expensive in India.

Disadvantages:

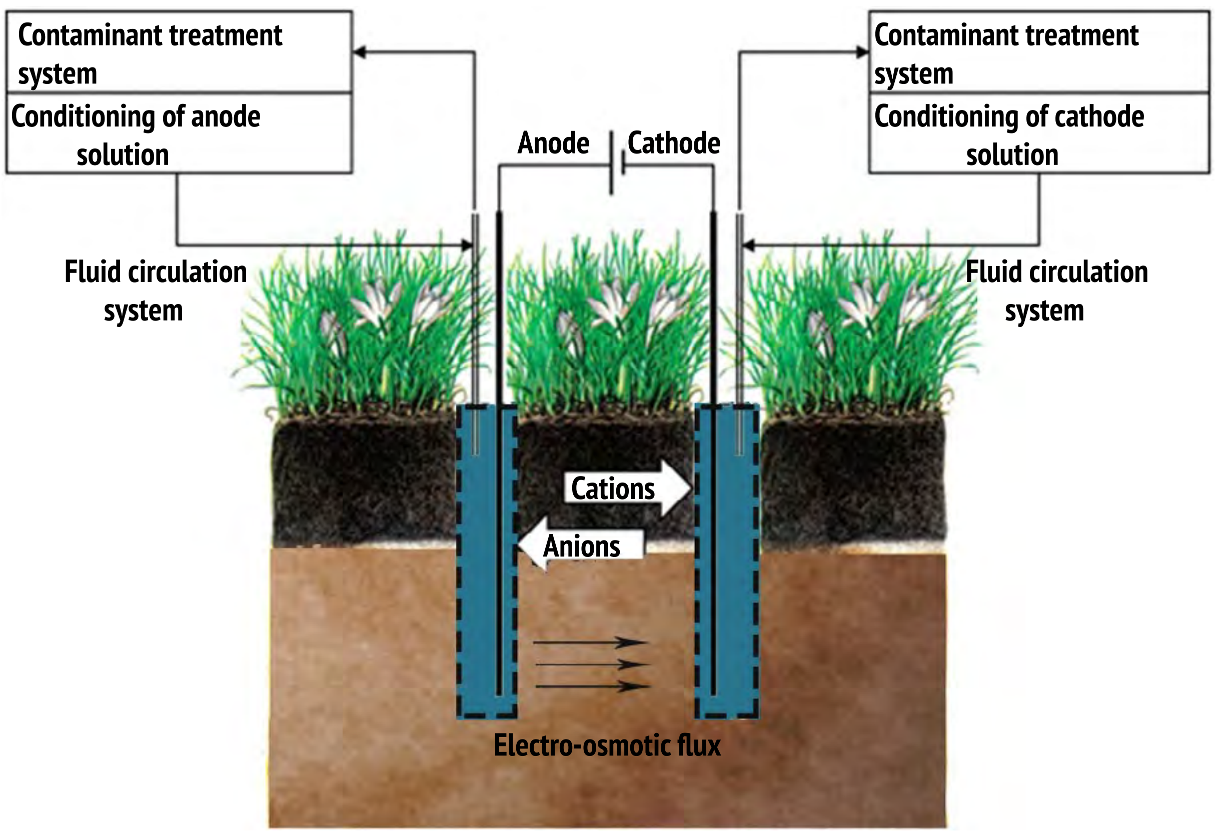
The removed soil needs a remote location where it can be dumped.



Process of soil replacement

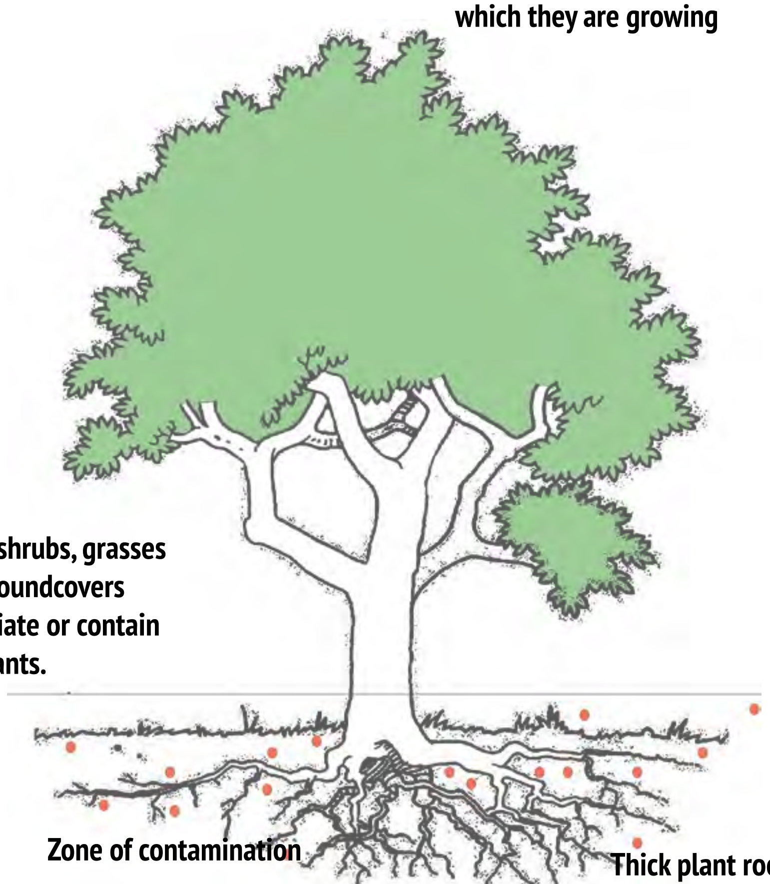
(Wordpress.com) image edited by author

Electro-kinetic remediation



(Cameselle et al., 2013) image edited by author

"This method involves the application of an electric direct current of low density to the contaminated site. An electric field is created by inserting electrodes in the contaminated site and passing low- density DC, which makes the contaminant particles mobile in the soil medium. The contaminants get transported towards the electrodes and they are pumped out. This technique is usually used for removing inorganic contaminants" (Ramalingam, 2013).

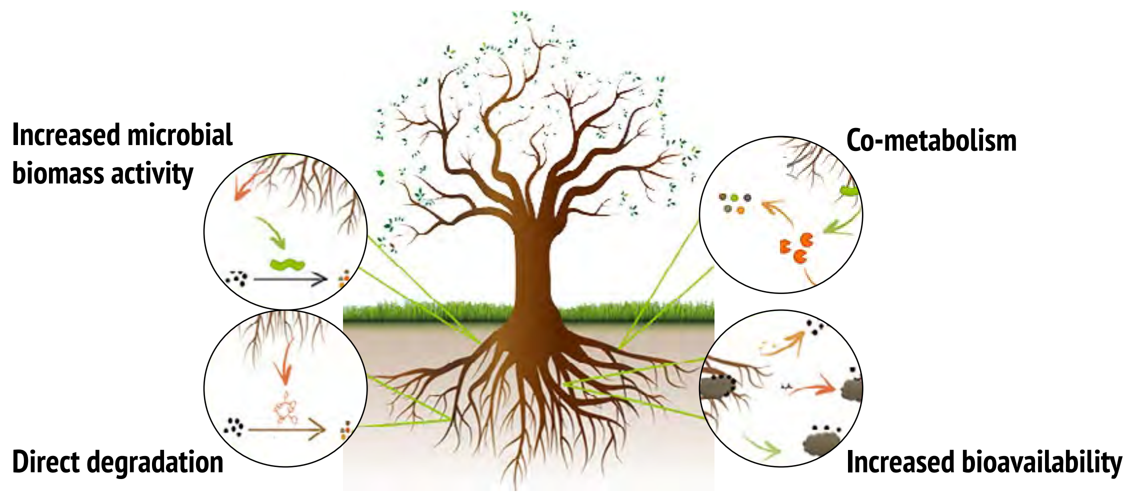


(Phyto: principles and resources for site remediation and landscape design) image edited by author

"Phytoremediation helps in the removal of particular contaminant on polluted site with a specific plant group. It also includes techniques such as the stabilization of pollutants within the surrounding soil or root structure of a plant" (Kennen and Kirkwood, 2015, p. 4).

Rhizoremediation

"Rhizoremediation is a process where microorganisms degrade soil contaminants in the rhizosphere. Contaminants that are remediated by this method are generally organic compounds that cannot enter the plant because of their high hydrophobicity. Plants are generally not considered as the major role player of remediation in this technique. Moreover, the plant creates a niche for rhizosphere microorganisms to do the degradation. Rhizosphere microorganisms are served by the plant acting as a solar-powered pump that pulls in water and the contaminant while producing substrates that benefit microbial survival and growth. Root exudates and root turnover can serve as substrates for microorganisms that perform contaminant degradation" (Child et al., 2007).



(Fanny Rohrbacher and Marc St-Arnaud, 2016) image edited by author

How these technologies can be useful in treating contaminants in Bhopal

Two major in-situ strategies are proposed to decontaminate the soils of the Union Carbide factory area, namely electro-kinetic remediation and phytoremediation. As per the analysis, organic contaminants (Aldicarb, Carbaryl, and HCH) and inorganic contaminants (Mercury and Cadmium) are found on the surface and subsurface level in the soil. The above-mentioned strategies are used to decontaminate the soil from the found contaminants. In the electro-kinetic remediation the addition of ion mobilizers such as Ethylene diaminetetraacetic acid (EDTA) and Sodium chloride (NaCl) is proposed to speed up the remediation process. For the phytoremediation, the species proposed for the crop cycles are suitable and adaptable to the site's black clay existing soils and the humid subtropical climate (mild, dry winters, a hot summer and a humid monsoon season).

Design proposal for former Union Carbide factory site................

सम्सारा पार्क

Samsara park

sam·sa·ra-(the cycle of death and rebirth to which life in the material world is bound)

Total factory area = 77 acres
Total designed area = 8 acres

Design Challenges

Contamination
Union Carbide factory site is contaminated by heavy metals and pesticides (dumped on site) in the soil and groundwater. A major challenge for the design is to provide a safe area on site for the people working on site remediation and for the health and safety of the people who will visit the site's community area .

Accessibility
The main gate to the site is currently at the south-west corner. The asphalt road connecting the main gate and factory buildings has deteriorated . The site is covered with thorny shrubs and trees, making it highly inaccessible and dangerous. Numerous insects and animals in the factory buildings and open areas make the site unsafe for people. The new design must ensure that the pathways do not interfere with future remediation strategies.

Identity
The Union Carbide factory at Bhopal can be marked as one of the most important events in the history of modern Bhopal. The urban panorama of the city quickly changed after the arrival of the factory. Huge inward migration of workers and other skilled and educated people led to the exponential rise in population and development of the city. The vacant lands of the surrounding areas of the factory were transformed into overcrowded slums. But what now remains of the factory now is in stark contrast to its former glory and prestige. Moreover, the survivors of the gas tragedy and their families see the factory as a symbol of their oppression, a manifestation of denial of the right to live, and as the representation of an ongoing struggle for justice they have been denied. The design for the site must respect these emotions and sentiments.

Concerns

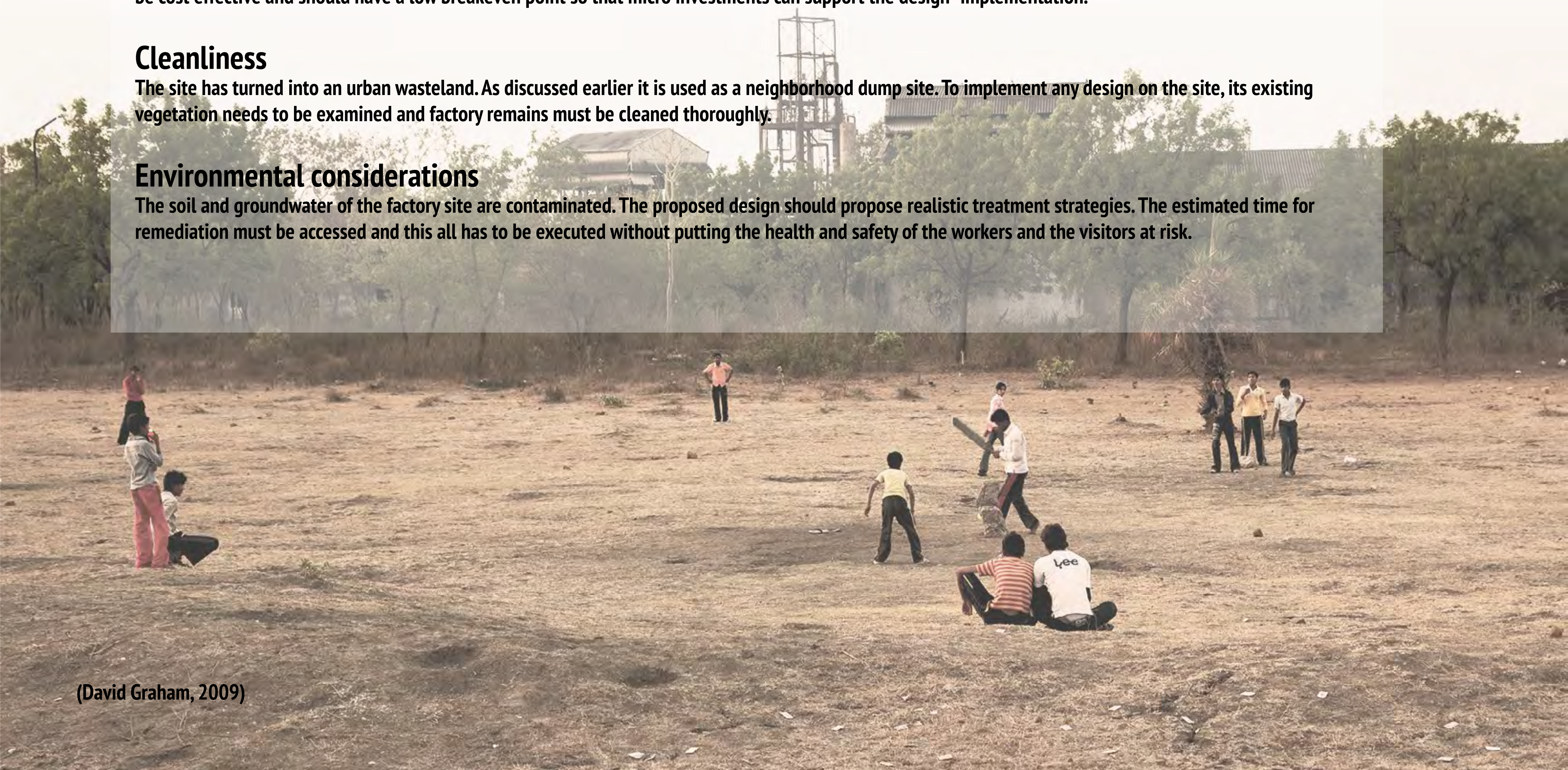
Ownership and responsibility
The land is owned by the federal government which is responsible for waste disposal, security, and maintenance. The government has provided security forces for the protection of factory site and for the people who might enter it. The site wall is punctured at a few points, which undermines these protective gestures. Also, the surrounding areas are crowded with slums that are centres of illegal activities. The security of the site is a major concern for the future design.

Infrastructural constraints
There is currently no water and electricity on the site. The essential infrastructure and amenities required for the proposed remediation are not currently available.

Cost to benefit ratio
None of the government or public organizations have thus to demonstrate a willingness to try to remediate the factory site. The proposed design should be cost effective and should have a low breakeven point so that micro investments can support the design's implementation.

Cleanliness
The site has turned into an urban wasteland. As discussed earlier it is used as a neighborhood dump site. To implement any design on the site, its existing vegetation needs to be examined and factory remains must be cleaned thoroughly.

Environmental considerations
The soil and groundwater of the factory site are contaminated. The proposed design should propose realistic treatment strategies. The estimated time for remediation must be accessed and this all has to be executed without putting the health and safety of the workers and the visitors at risk.



(David Graham, 2009)

Objectives

Increase height of the boundary wall.

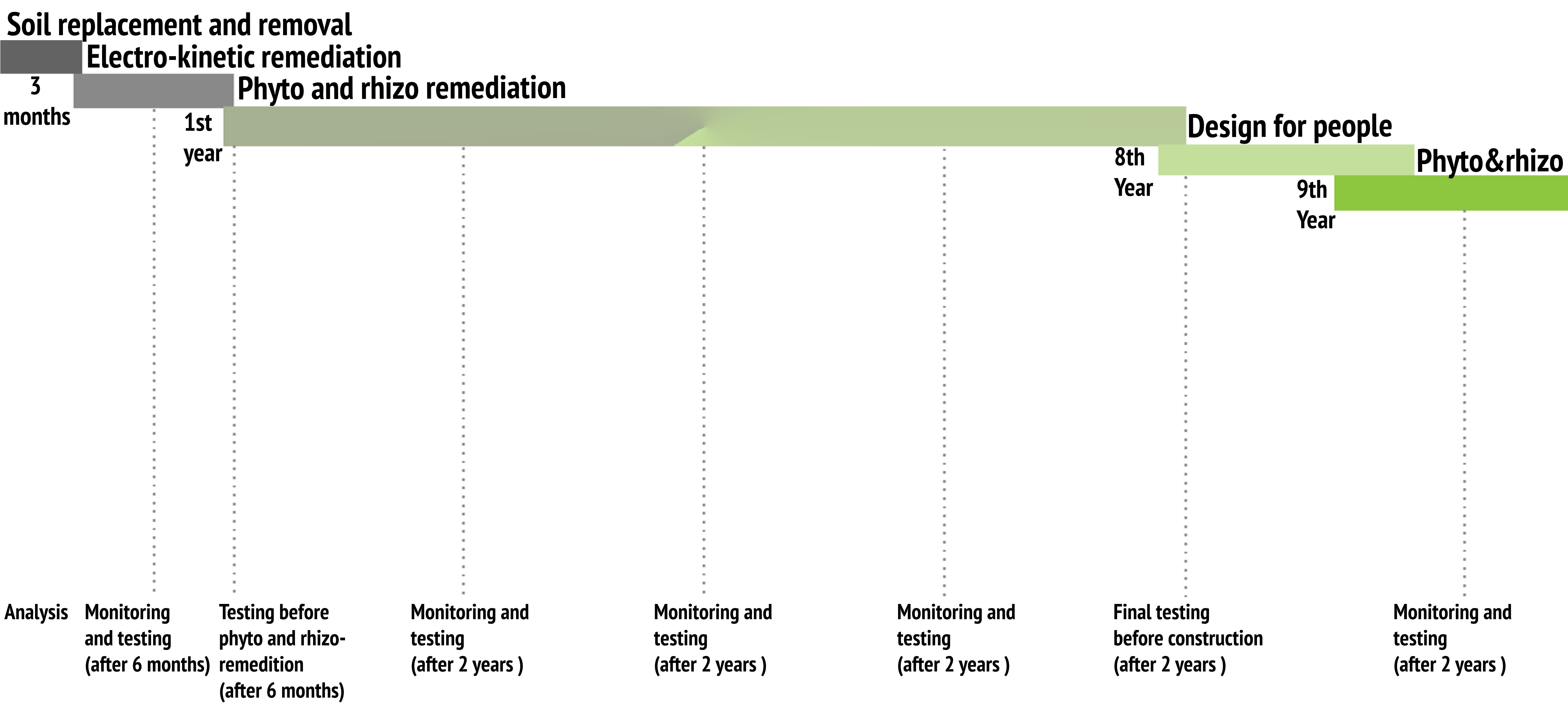
Undertake proper cleanup and analysis of the existing vegetation and remediation of contaminants from the soil.

Keep the remaining factory buildings.

Create community engagement areas in which people can play, relax, share and learn.

Planning and time management

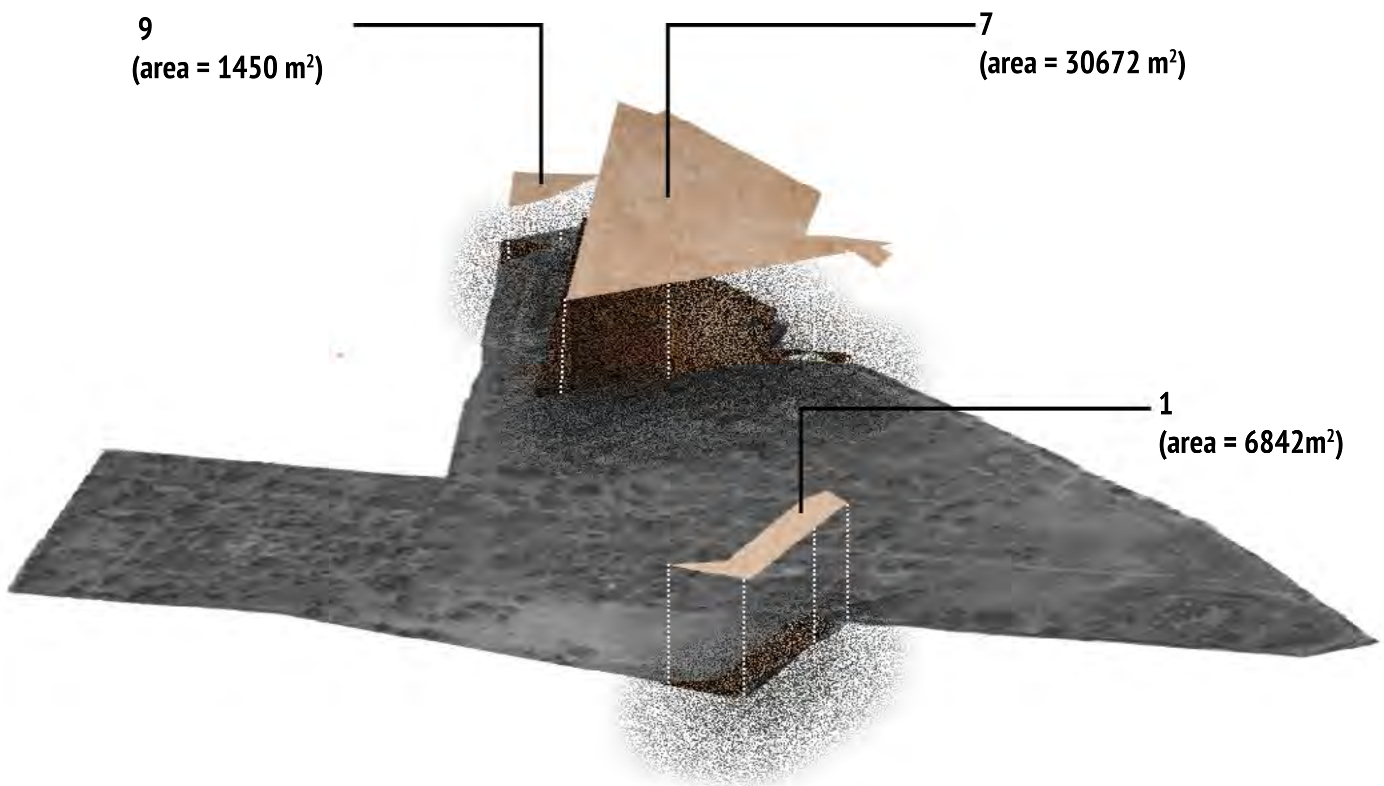
This is a pilot project, for the remediation of contaminants present in the soil samples of the factory site. A combination of four technologies: soil replacement, electro-kinetic remediation, phytoremediation, and rhizoremediation are used to remediate the contaminated soils of the factory site. Owing to the specifics of the site related to location, population, and contamination. The strategy developed is itself unique in the context of India. The species selected for the phytoremediation and rhizoremediation are suitable for the environmental conditions of the given area. But the uptake of the contaminant by different plant species is highly variable and is subject to ph, acidity, humus, nitrogen, phosphorus and micronutrient content of the soil. Further, the presence of essential bacteria and fungi in the soil and the temperature, irrigation frequency, and humidity also play a determinant role in the uptake process. Although all necessary amendments to the soil would be made in this regard, still the exact duration of remediation process is hard to predict. Moreover, research on phytoremediation with these particular plants in this particular environment and pollutants is lacking, therefore, there is uncertainty and monitoring is important for this project as well as future ones. Therefore the proposed timeline is tentative and consistent monitoring would be a very important aspect of the project. After the uptake, if the concentration level falls below the permissible levels then the site would be deemed fit for future development prospects.

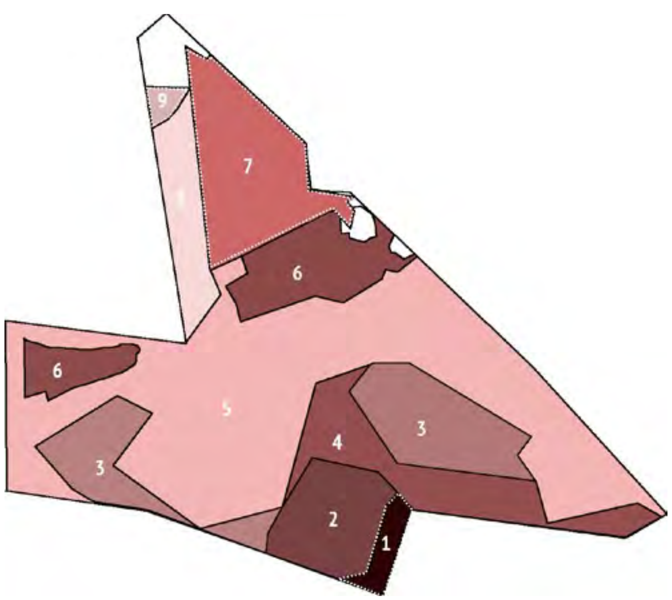


Remediation design

Top soil replacement

(ex- situ treatment)





This remediation technique is used in the site areas demarcated as patch 7, 9 and 1. Soil up to the depth of 30 cm would be removed and replaced with fresh soil. The rationale behind removing soils from these areas follows:

The area demarcated as 1 is the most contaminated area of the site. It was used as a dump site and the soil samples contain high levels of Carbaryl, HCH, Mercury and Cadmium. So, if this area is not decontaminated, it may pose threat to the health of the people who would be working on-site remediation.

Area demarcated as 7 is contaminated with Mercury, Cadmium and HCH and area demarcated as 9 is contaminated with Aldicarb, Mercury, and HCH. In large part, because these areas are less contaminated than the other areas of the site, they are where the community engagement area is proposed. Though less contaminated than other areas, current contamination levels are nevertheless dangerously high. Therefore, soil replacement is proposed in this area.

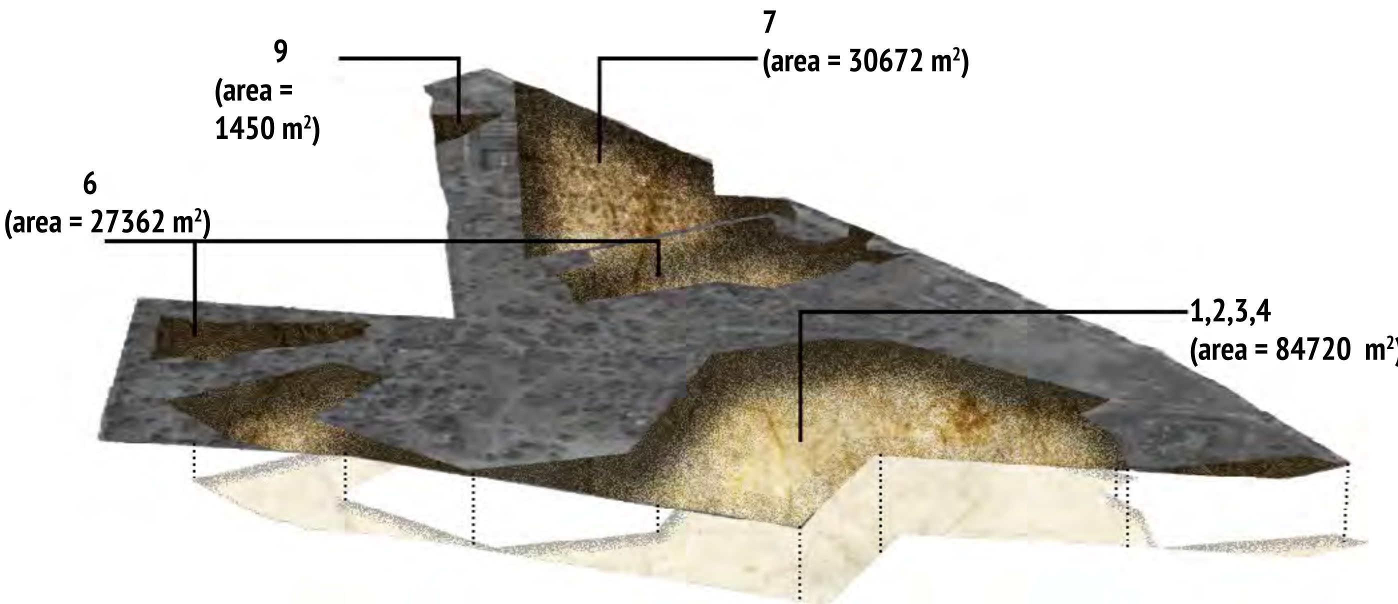
The density of black clay soil at site = 1660 kg/m3

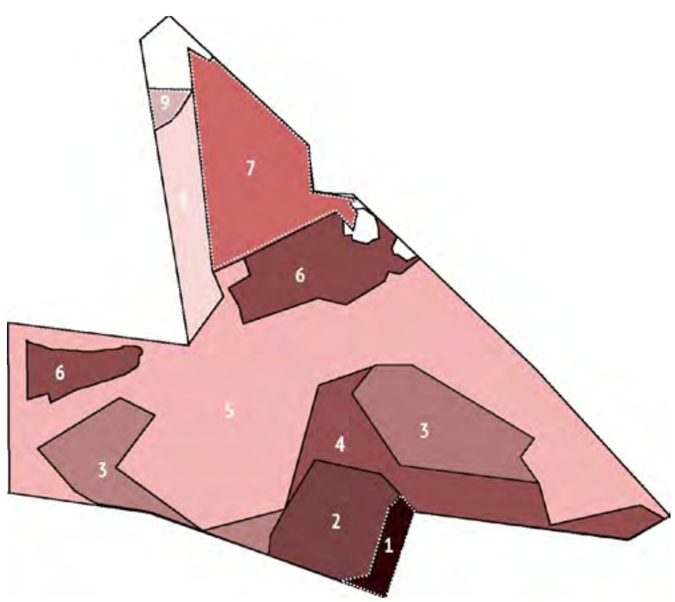
Volume of contaminated soil to be removed
= (1450 + 30672 + 6842) x 0.3 m3

= 11689.2≈ 11689 m3

Electro-Kinetic remediation

(in-situ treatment)





Two transport contaminant mechanisms are followed in electro-kinetic remediation : electro-migration and electrophoresis. Electro-migration is adopted for areas which are severely contaminated with Mercury and Cadmium (heavy metals).

In this process a voltage gradient is created between the electrodes in the soil media and ions migrate due to this gradient pressure. The carbon electrodes would be inserted up to the depth of 60 cm. Voltage and current are expected to be 240 V and 15 A. Electrode to electrode distance would have to be altered at regular intervals to increase the efficacy of remediation.

Chemical enhancement of the soil would be done by using chemicals such as Ethylene diamine tetra acetic acid (EDTA), citrate and carbonate salts, sodium chloride and citric acids for enhanced and effective remediation of Hg and Cd (Kornilovich et al., 2005). Due to the presence of contaminants in the groundwater of factory site. Groundwater cannot be used for electro-kinetic remediation. So, clean water would be sourced from outside the site. For this technique to work, clean water with suitable amendments would be added to soil to increase the ion mobility of the contaminants present in the soil.

The formulae to calculate the velocity of the ions in the soil medium could be calculated as (Ramalingam, 2013):

$$v = I v_i P_w / AtO$$

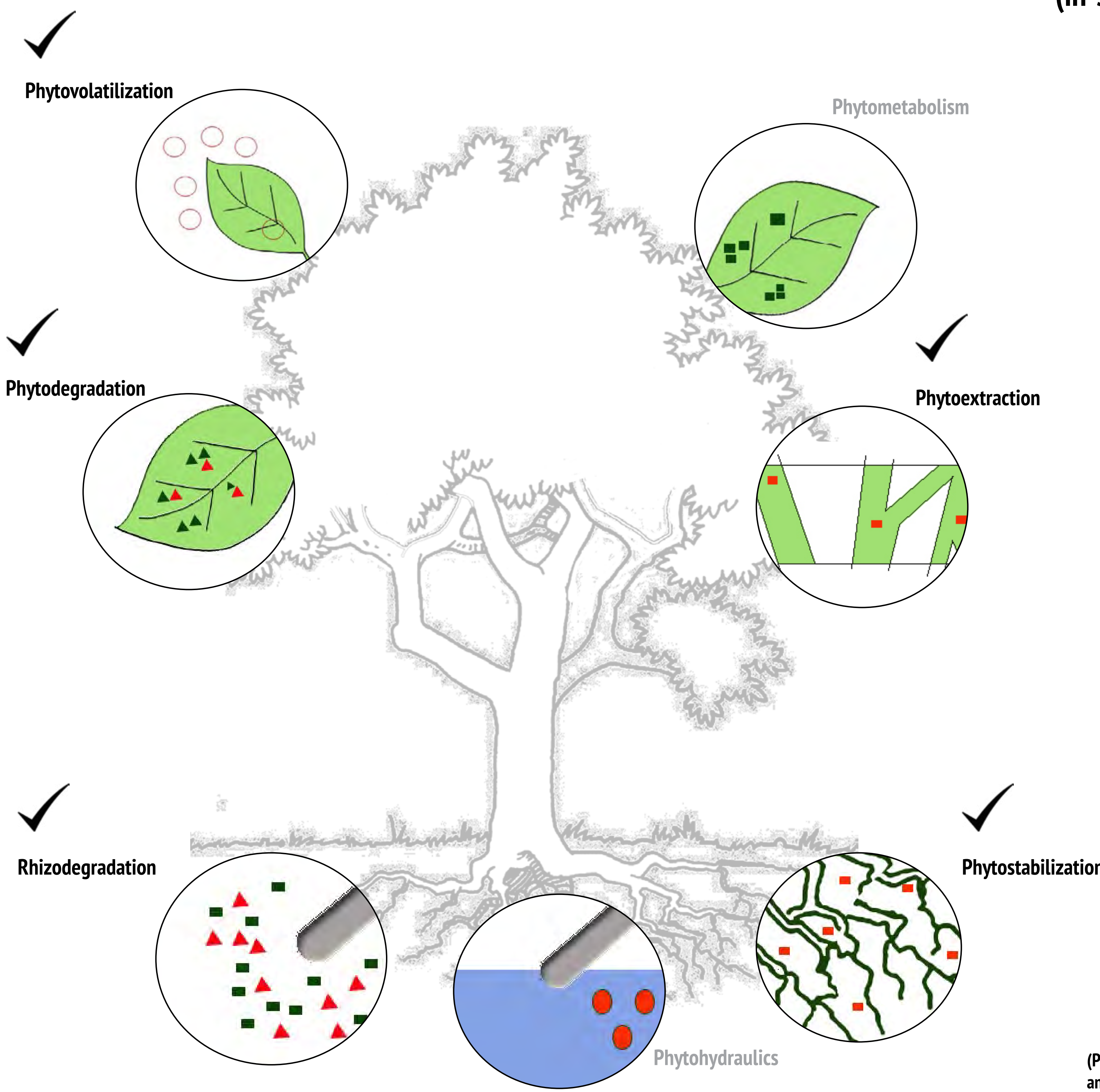
Where,

- I - Applied current
- v_i - Ion velocity
- A - Cross sectional area
- P_w - Pore water resistivity
- t - Tortuosity
- O - Volumetric moisture content

Mechanisms used

Phytoremediation

(in-situ treatment)



(Phyto: principles and resources for site remediation and landscape design) image edited by author

Phytoremediation

(in-situ treatment)

■ Mechanisms applied

■ Mechanisms unapplied

These mechanisms are used by the plants to treat the inorganic and organic contaminants found in the factory site.

Phytovolatilization: Plant takes up the pollutant in either form and transpires it to the atmosphere as gas.

Phytodegradation: Contaminant is taken up by the plant and broken down into smaller parts.

Rhizodegradation: Root exudates released by the plant and the soil microbiology around the roots break down the contaminant.

Phytoextraction: Phytoextraction is the ability of the plant to take up a pollutant from soils and water move it into plant parts.

Phytostabilization: Plant holds the contaminant in place so that it does not move off site.

Phytohydraulics: Plant pulls up water, and the contaminant may come with it.

Rhizofiltration: Roots and soil filter water.

Phytometabolism: Plant uses it in growth, incorporates it into biomass.

Phytoremediation will be implemented based on India's three planting seasons. The three seasons are Rabi (July- October), Kharif (October-March) and Zaid (March- July). The first map describes the species that will continue to remain on the site throughout the remediation process. The following three maps that these species would be harvested every season.

Source: Phyto: principles and resources for site remediation and landscape design

Perennial species

These are two perennial species proposed for the phytoremediation of the factory site. First, is Poplar tree which grows up to 8 ft per annum. For an optimal yield of wood and uptake of contaminants, Poplars would be harvested after every 2-4 years. The second is Morning Glory which is a perennial flowering plant. It has a prolific growth rate and would require extensive trimming to save space and promote contamination uptake. The old plants would be replaced after a cycle of 2 years.

Populus deltoides

Ipomea cornea
(Morning glory)

200m

Species	Type	Life cycle	Quantity	Mechanism Used	Planting steps	Soil amendments and fertigation	Addition of Chelating agents	After growing
 (a) *Populus deltoides* (Poplar)	Tree	Biennial	8000 per hectare	Phytovolatilization Phytostabilization Phytodegradation	1. Digging pits . 2. Filling pits with mixture of manure, spent mushroom substrate (sms)and fertilizers. 3. Planting.	Year 1 -Farm yard manure 8kg/plant. -Spent mushroom substrate 1kg/plant. -Urea/ single superphosphate(ssp) 50 gms/ plant. Year 2 -Farm yard manure 10kg/ plant. -Spent mushroom substrate 1.5kg/plant. -Urea/ single superphosphate 80 gms/plant.	Amino acid chelates 7gm /tree. Micronutrient chelates Foliar application 5gm/liter in spray after each month.	Harvesting , selling of wood.
 (b) *Ipomea cornea* (Morning glory)	Shrub	Perennial	Varies	Phytoextraction Phytovolatilization Phytostabilization Rhizofiltration Phytodegradation	1. Heavy ploughing. 2. Application of manure, spent mushroom substrate (sms), and fertilizers. 3. Broadcasting seeds.	-Addition of decomposed Farm yard manure 15 ton/hectare. -Spent mushroom substrate 2.5 ton/hectare.	Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Uprooting , disposing .

First season

Rabi (July - October)

Holcus lanatus
(Common velvet grass)

Zea mays
(Maize)

Populus deltoides
(Poplar)

Ipomea cornea
(Morning glory)

200m

Species	Type	Life cycle	Quantity	Mechanism Used	Planting steps	Soil amendments and fertigation	Addition of Chelating agents	After growing
 (c) *Holcus lanatus* (Common velvet grass)	Crop	Perennial	8 kg/hectare	Phytoextraction Phytostabilization	1. Site clearing. 2. Raised bed preperation. 3. Application of manure, spent mushroom substrate and fertilizers. 4. Broadcasting seeds.	Addition of decomposed arm yard manure 15 t/h. -Spent mushroom substrate 2.5 t/h.	Micronutrient chelates Foliar application of 5gm/liter in spray and soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and disposing.
 (d) *Zea mays* (Maize)	Crop	Seasonal	20 kg/hectare	Phytoextraction Phytovolatilization	1. Heavy ploughing 2. Application of manure, spent mushroom substrate and fertilizers. 3. Seeding through seedrill.	-Farm yard manure 12t/ha. -Spent mushroom substrate 3t/ha. -Urea/single superphosphate 200kg/ha. -Potash 180kg/ha. Top dressing : -Urea 60-80kg/ha. -Potash 50 kg/ha potash.	Micronutrient chelates Foliar application of 5gm/liter in spray and soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and threshing.

Second season

Kharif (October - March)

Species	Type	Life cycle	Quantity	Mechanism Used	Planting steps	Soil amendments and fertigation	Addition of Chelating agents	After growing
 *Medicago sativa* (Alfalfa)	Crop	Seasonal	20-40 kg/hectare	Phytoextraction Rhizofiltration Phytodegradation	1. Site clearing. 2. Raised bed preperation. 3. Application of manure,spent mushroom substrate (sms), and fertilizers. 4. Broadcasting seeds.	-Farm yard manure 8t/ha. -Spent mushroom substrate 1.5 t/ha. -Nitrogen 20-25 kg/ha -Potash 40-45 kg/ha. Top dressing : -Nitrogen 15 kg/ha	Micronutrient chelates Foliar application at 5gm/l in spray, Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and disposing.
 *Coriandrum sativum* (Coriander)	Crop	Seasonal	10-12 kg/hectare	Phytoextraction Phytovolatilization Phytodegradation	1. Site clearing. 2. Raised bed preperation. 3. Application of manure,spent mushroom substrate (sms), and fertilizers. 4. Broadcasting seeds.	-Farm yard manure 10t/ha, -Spent mushroom substrate 2t/ha, -Nitrogen 20kg/ha -Potash 40kg/ha. Top dressing : -Nitrogen 10 kg/ha.	Micronutrient chelates Foliar application at 7gm/l Amino Acid Chelates of micronutrients foliar spray at 7mg/l Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and disposing.
 *Triticum* (Wheat)	Crop	Seasonal	100-125 kg/hectare	Phytoextraction Phytodegradation	1. Heavy ploughing. 2. Application of manure,spent mushroom substrate (sms), and fertilizers. 3. Sedding through seedrill.	-Farm yard manure 12 t/ha. -Spent mushroom substrate 2.5 t/ha. -Azotobacter 2.5 kg and Phosphetica culture 2.5 kg -Diammonium Phospate at the time of sowing at 100 kg/h and dose of Urea after 15 -45 days at 100 kg/ha.	Micronutrient chelates Foliar application at 5gm/l in spray, Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and threshing.
 *Brassica juncea* (Indian Mustard)	Crop	Seasonal	4-6 kg/hectare	Phytoextraction Phytovolatilization Phytostabilization Rhizofiltration	1. Site clearing. 2. Raised bed preperation. 3. Application of manure,spent mushroom substrate (sms), and fertilizers. 4. Broadcasting seeds.	-Farm yard manure (fym) 12 t/ha. -Spent mushroom substrate (sms) 2.5 t/ha. -Nitrogen 40-45 kg/ha -Potash 30-35 kg/ha. Top dressing : -Nitrogen 25 kg/ha after	Micronutrient chelates Foliar application at 9 gm/l Amino Acid Chelates of micronutrients foliar spray at 7mg/l Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and threshing.
 *Capsicum annuum* (chilli)	Crop	Seasonal	42000 plants/ hectare	Phytoextraction Phytovolatilization Phytostabilization Phytodegradation	1. Heavy ploughing. 2. Creating furrows and ridges . 3. Application of manure,spent mushroom substrate (sms), and fertilizers. 4. Transplanting.	-Farm yard manure 15 t/ha. -Spent mushroom substrate 3 t/ha. -Nitrogen (N) 80 kg/ha -Potash (P) 150 kg/ha. Top dressing : -(N) and (P) at 2.5-4 gm/ sqm.	Micronutrient chelates Foliar application at 7 gm/l. Amino Acid Chelates of micronutrients foliar spray at 7mg/l. Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting fruits and disposing plant biomass.

Third season

Zaid (March - July)

Holcus lanatus
(Common velvet grass)

Coriandrum sativum
(Coriander)

Pennisetum glaucum
(Pearl millet)

Populus deltoides
(Poplar)

Ipomea cornea
(Morning glory)

200m

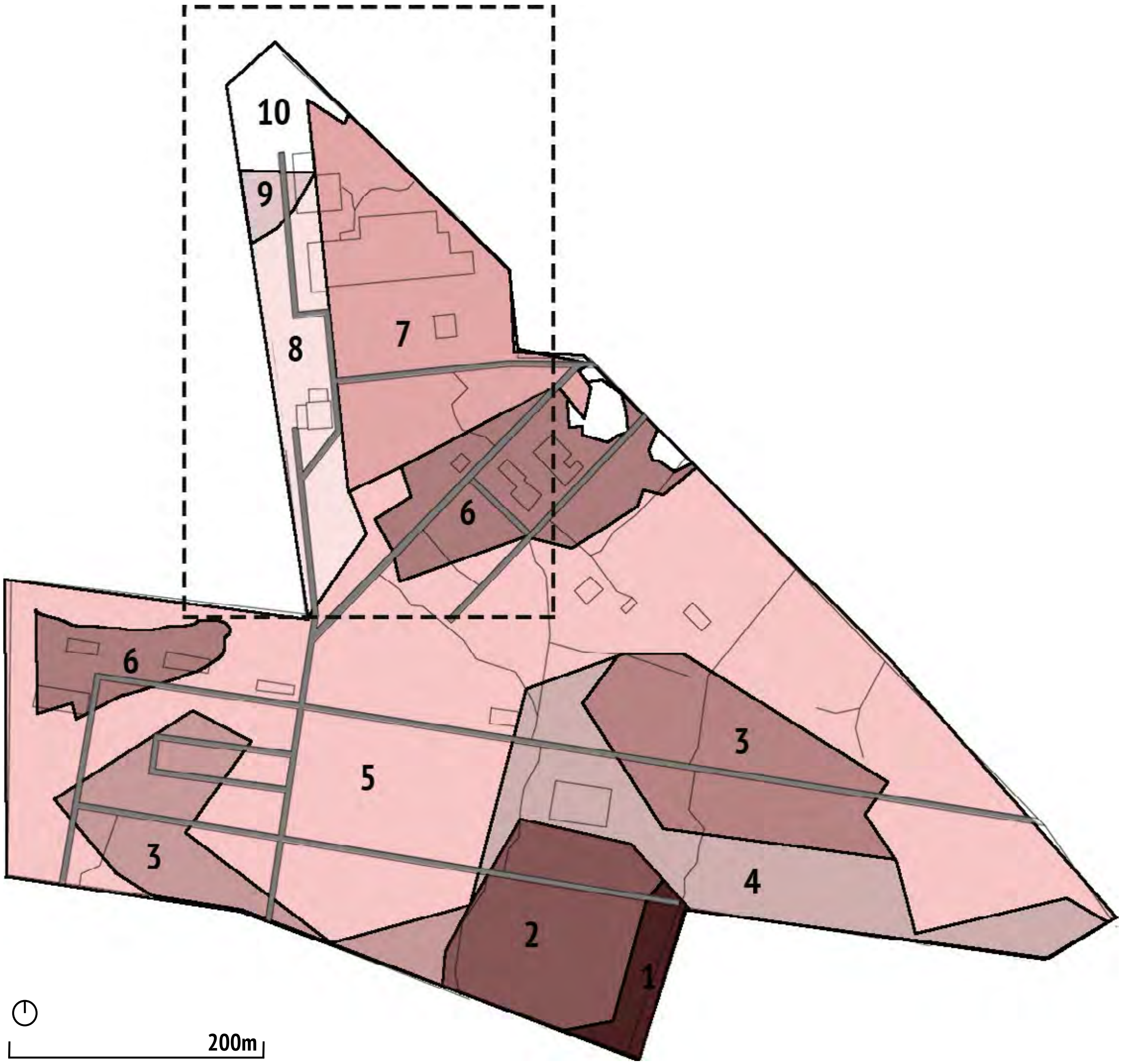
Species	Type	Life cycle	Quantity	Mechanism Used	Planting steps	Soil amendments and fertigation	Addition of Chelating agents	After growing
 *Pennisetum glaucum* (Pearl millet)	Crop	Seasonal	5 kg/ha	Phytoextraction Phytostabilization	1. Site clearing. 2. Raised bed preperation. 3. Application of manure,spent mushroom substrate (sms), and fertilizers. 4. Broadcasting seeds.	-Farm yard manure 5 t/ha, -Spent mushroom substrate 1t/ha, -Nitrogen (N) 50-60 kg/ha -Potash (P) 50-60 kg/ha. Top dressing : -Nitrogen at25 kg/ha.	Micronutrient chelates Foliar application at 5gm/l in spray, Soil application of 1kg of chelates mixed with 20 kg fine soil and sprinkled after last ploughing.	Harvesting and threshing.

Design for people

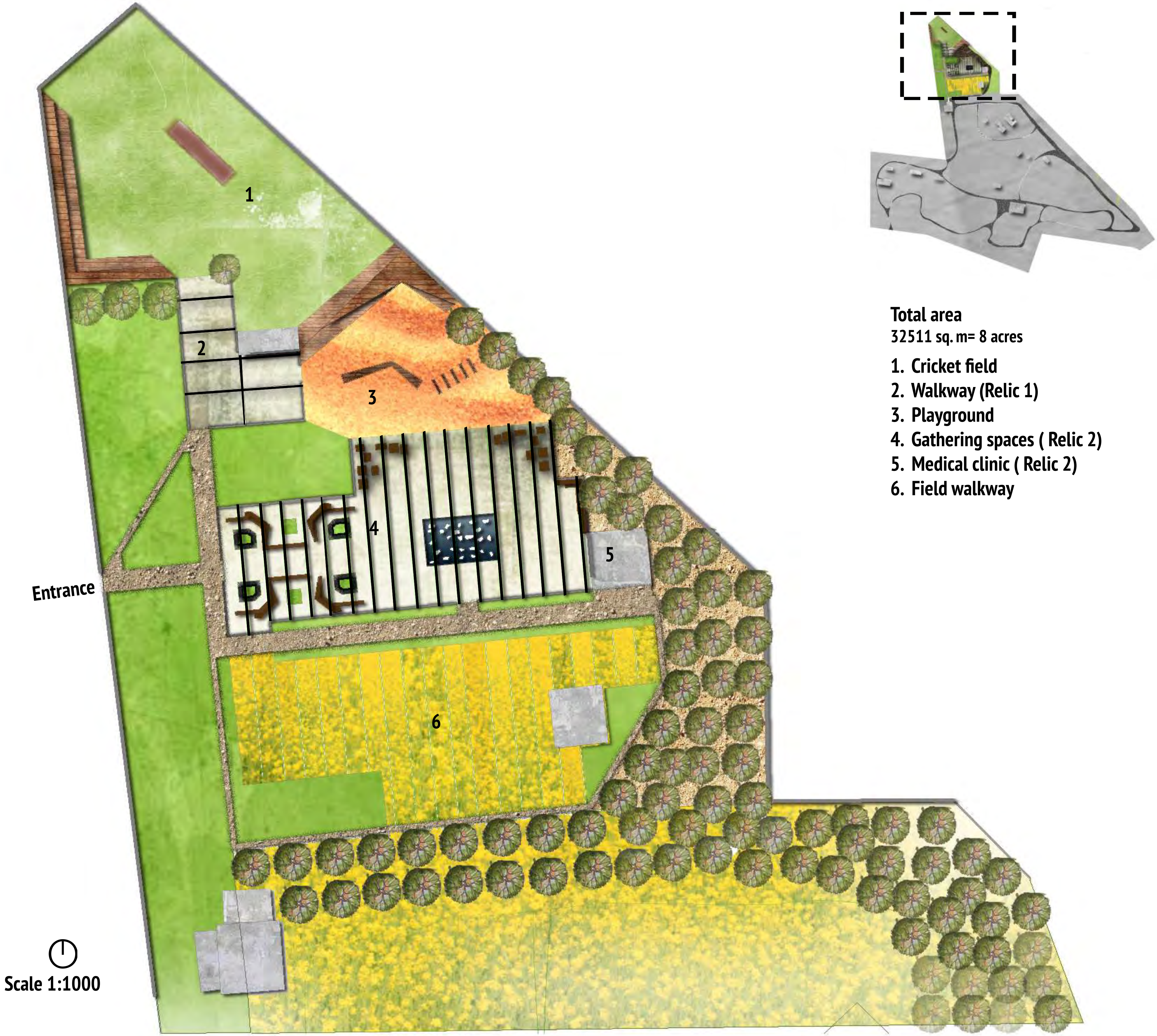
The residents of the slums adjoining the factory site are primarily survivors of the gas tragedy. The residents share a feeling of hatred for the site because of the loss suffered by them due to the tragedy and its aftermath. However, the area lacks public amenities and spaces for play and recreation. Therefore, developing the site with such amenities would establish a new relationship with the residents. It would help foster positive association of the residents with the factory site.

Patches:

1,7,9	- Top soil replacement
1,2,3,4,5,7,9	-Electro-kinetic remediation
All	-Phyto and rhizo remediation
7,8,9	-Design interventions



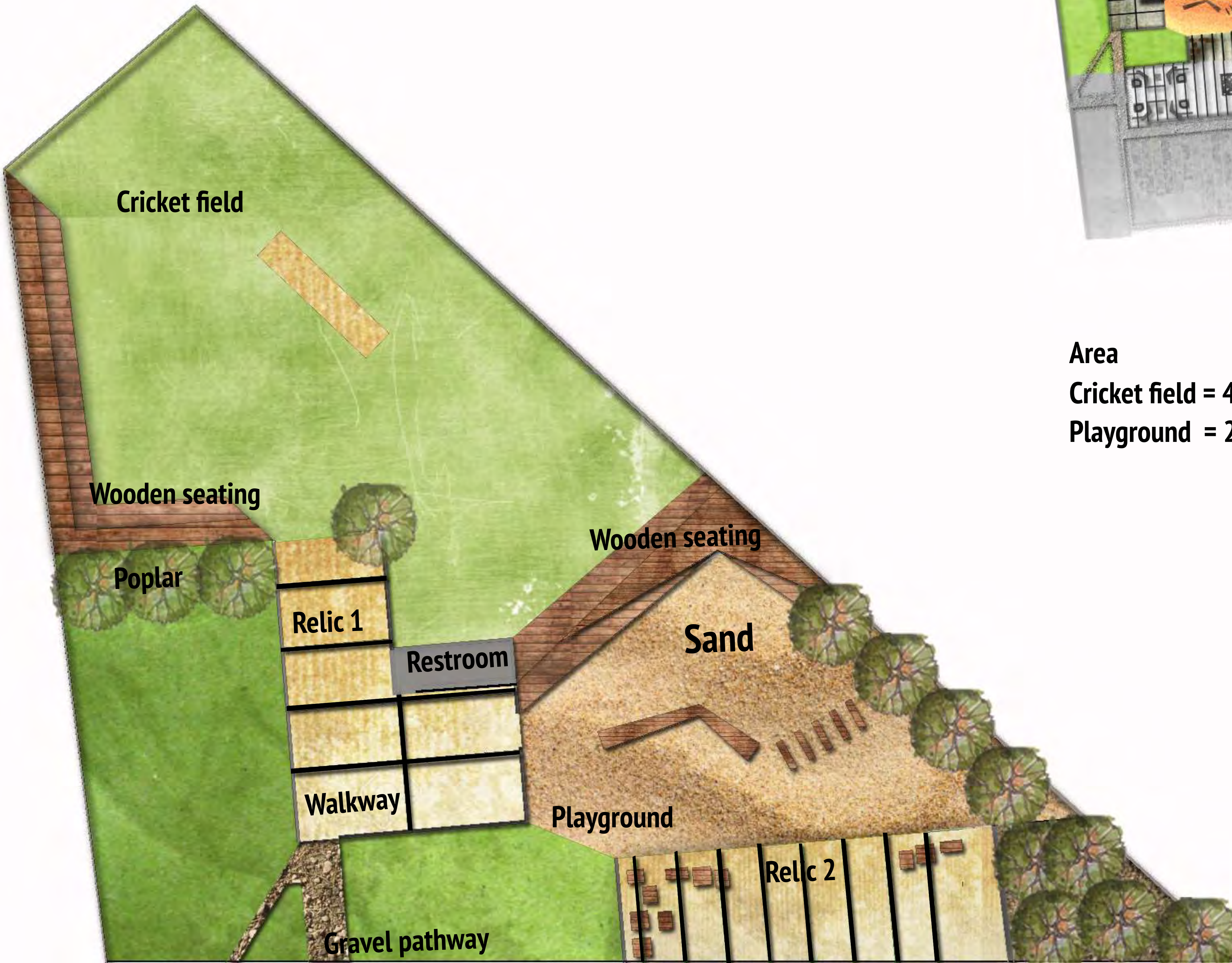

Remediation
Design for people
Total site area=77 acres
Remediation
Kharif
(October-March)
Railway track
Bhanpur bridge road
Berasia road
Scale 1:3500

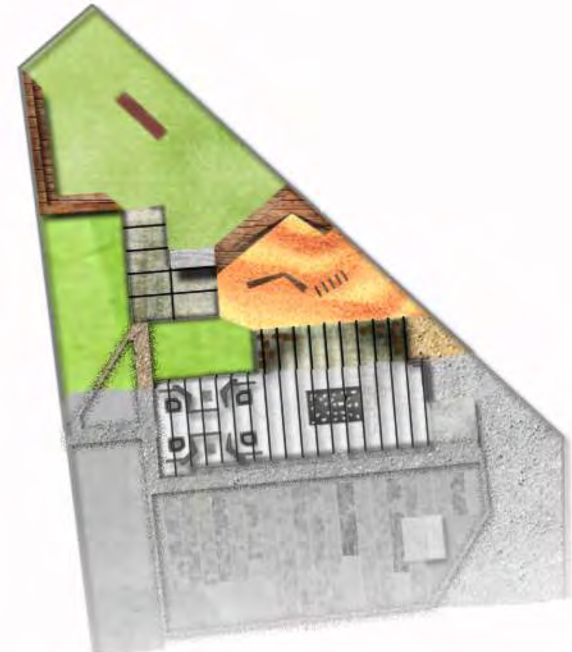


Total area
32511 sq. m= 8 acres

1. Cricket field
2. Walkway (Relic 1)
3. Playground
4. Gathering spaces (Relic 2)
5. Medical clinic (Relic 2)
6. Field walkway

Detail part 1

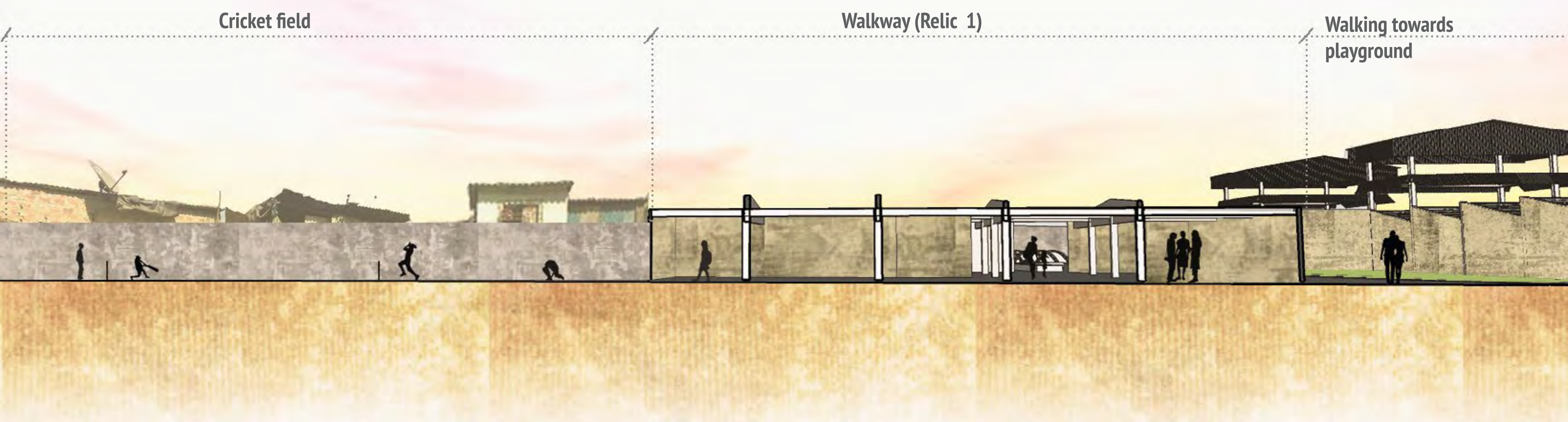




Area
Cricket field = 4821 sq.m
Playground = 2250 sq.m

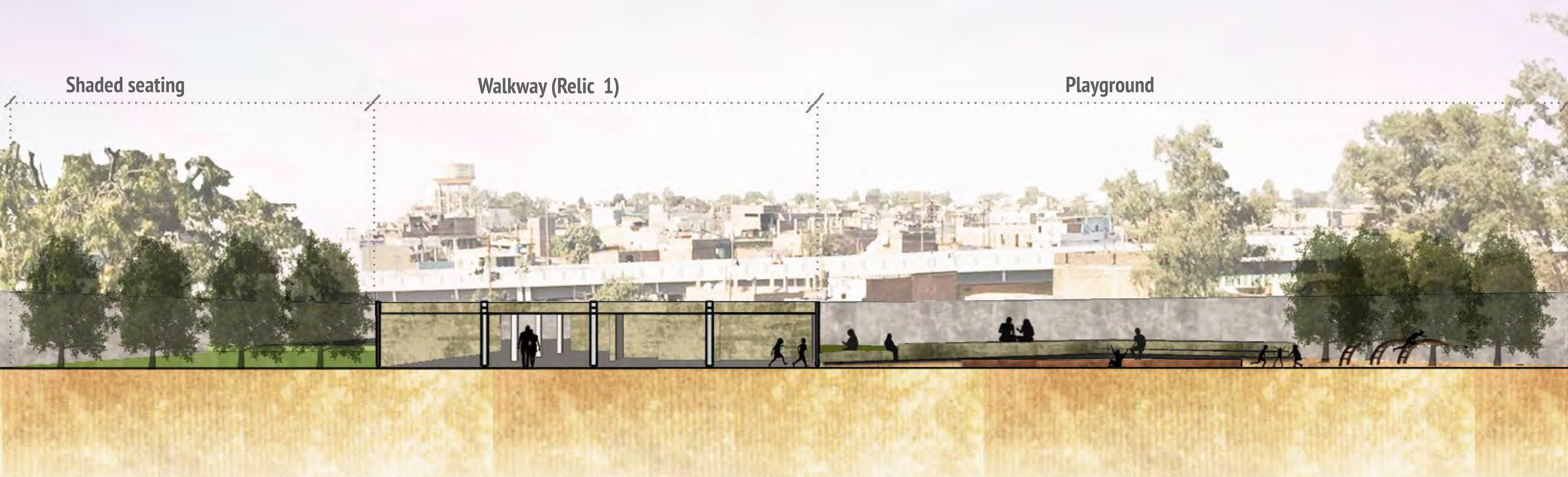
Scale 1:700

This section shows the cricket field, the old factory complex that has been designed as a shaded walkway and the open walkway. The users enter the site and walk through the open pathway to reach the shaded walkway area. A new entrance is created for this area and this is a transitional space and provides access to the cricket playground and the open play area. This area would also be used to document the history of the site and the tragedy associated with it, it would also have public amenities and sitting spaces.

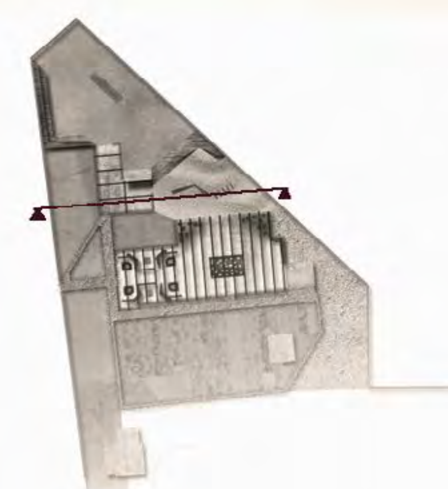


Scale 1:250

This section shows the open green area to the left of the walkway, the shaded walkway, and the playground. The playground could be directly accessed from the shaded walkway area. It is made up of soft landscape material and includes sitting spaces and swings, so parents can watch while their kids play. Also, the playground provides a view that connects to the in-use built infrastructure of the factory site.



Scale 1:250



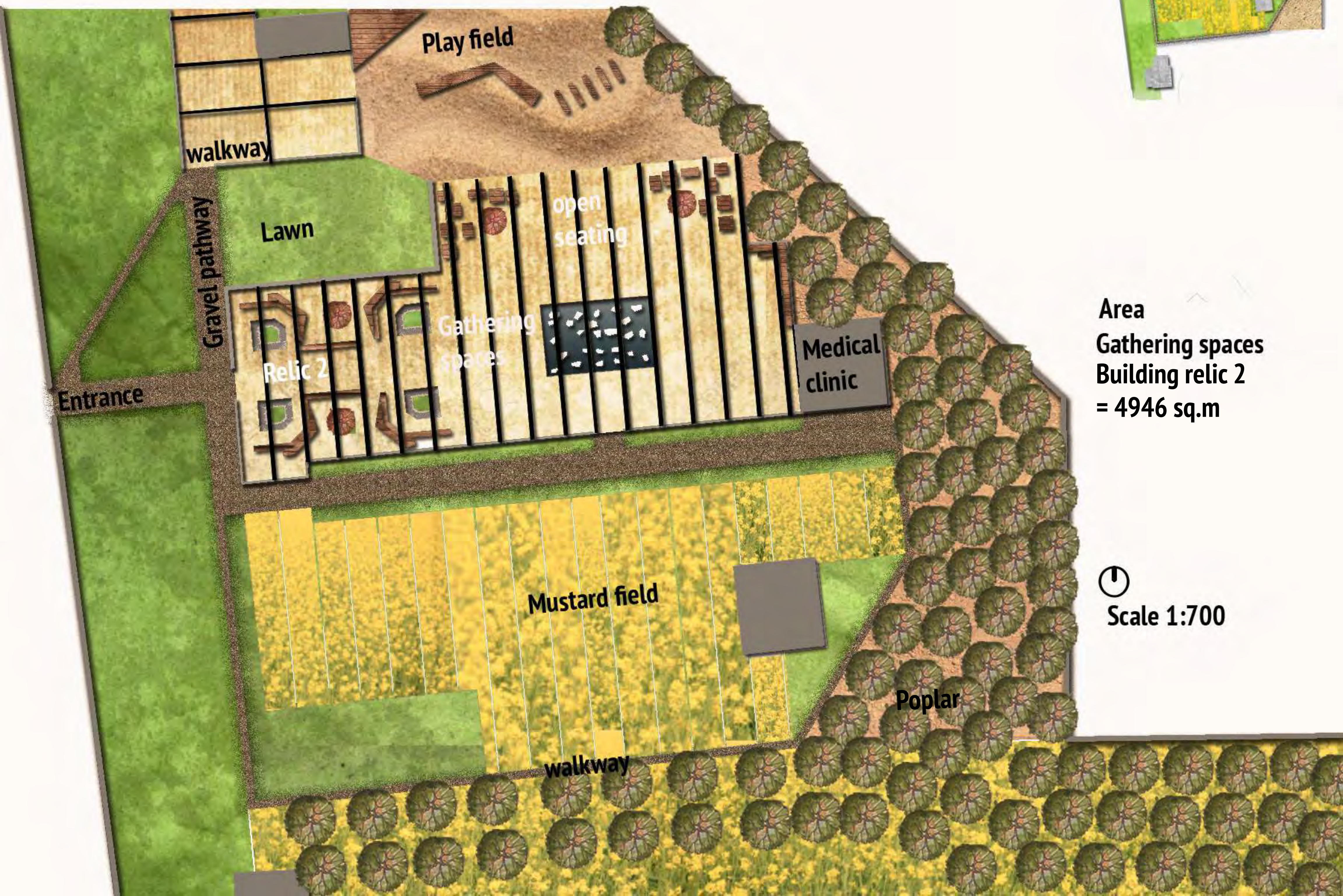
View of building relic 1 (before interventions)

Walkway building relic 1 (after interventions)

Cricket field

 Playground

Detail part 2



Area
Gathering spaces
Building relic 2
= 4946 sq.m

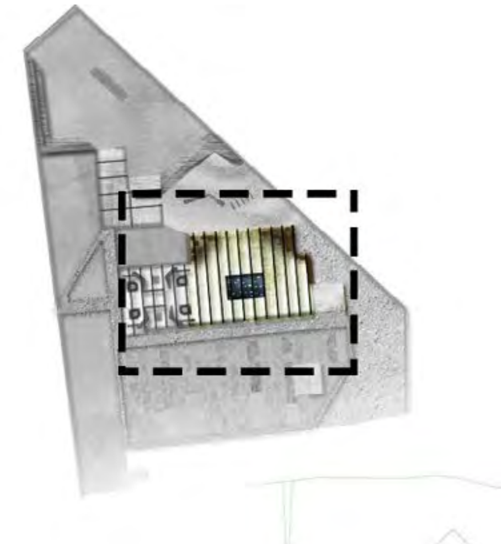
Scale 1:700

This section shows the shaded gathering area and the walkways for its access on either side. The gathering area has space for strolling and sitting. The users have physical access to the inbuilt pond and are visually connected to the play area, remediation fields and poplar plantations from this area. A medical clinic is also provided here. Paths for strolling around the area allow users to develop an understanding of what is going on on the site and connect to the past tragedy.

Scale 1:250

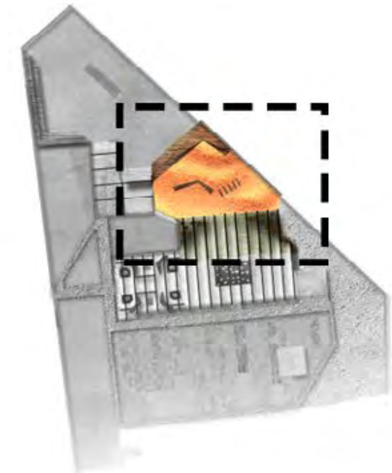
View of building relic 2 (before interventions)

Gathering spaces (after interventions)



Gathering spaces

Gathering spaces



Medical clinic entrance


Walking in the field

Conclusion

During my days as an undergraduate in Bhopal, I visited the surrounding areas of Union Carbide factory site several times. I used to think by observing the silence in that neighborhood that the nearby residents still saw the factory as a symbol of their oppression and a source of eternal torment to them. Even decades after the factory closure, the systematic and ruthless exclusion of people from the site area created a sense of mystery and people perceived it as a potential threat to their lives. To clear these clouds of secrecy and distrust I thought of proposing the construction of a tragedy memorial at the site. This memorial would provide people a place where they could gather, connect or relate to the site and share their pain and other feelings, feelings they were not able to express before.

(Luca Frediani, 2008)

By author

When I visited the factory site as part of site analysis for my practicum I realized that actually no one seems bothered anymore about what happened. Due to highly crowded neighborhood situation, kids use the site as a playground and nearby residents use the space for sitting, strolling and talking.

Further, when I started the preliminary studies for making a community engagement area at the factory site, I came to know about the contamination in the soil and the risks to the health and lives of the thousands of dwellers and visitors posed by these contaminants. So, I decided to create a framework for site cleanup and design of a community engagement area on the patches of the site that are less contaminated. This major shift in design objective was due to my personal connection to the site and the local residents.

I was deeply moved by the havoc that the tragedy created in their lives and thus it has been my clear intent to develop Union Carbide factory site as a place where these people can physically and emotionally heal.

References:

Pg-3
Nair, M., 2005. *Bhopal Gas Tragedy – A Social, Economic, Legal and Environmental Analysis* [pdf] Germany: University Library of Munich. Available at: < https://mpra.ub.uni-muenchen.de/37856/1/> [Accessed 15 October 2017].

Pg-4
Peterson, M.J., 2009. Case study: Bhopal plant disaster. *International Dimensions of Ethics Education Case Study Series*, [online] Library of University of Massachusetts Amherst . Available at: <http://scholarworks.umass.edu/edethicsinscience/4/> [Accessed 16 October 2017].

Pg-5
Center for science and environment, n.d. *India's Environment –1984-85* [pdf] Available at: <http://cseindia.org/userfiles/THE%20BHOPAL%20DISASTER.pdf> [Accessed 15 October 2017].

Pg-6
Labunska, I., Stephenson, A., Brigden, K., Stringer, R., Santillo, D. and Johnston, P.A., 1999. *Toxic contaminants at the former union carbide factory site bhopal, India: 15 years after the bhopal accident.* [pdf] England: Greenpeace Research Laboratories, Department of Biological Sciences, University of Exeter. Available at: < http://greenpeace.org.br/bhopal/docs/Bhopal_legacy.pdf> [Accessed 15 October 2017].

Pg-7
Nair, M., 2005. *Bhopal Gas Tragedy – A Social, Economic, Legal and Environmental Analysis* [pdf] Germany: University Library of Munich. Available at: < https://mpra.ub.uni-muenchen.de/37856/1/> [Accessed 15 October 2017].

Pg-8
Bright, I., 2012. Bhopal disaster: Air pollution effects of Bhopal gas leakage. [online] Self published. Available at: <http://www.tropical-rainforest-animals.com/bhopal-disaster.html> [Accessed 22 November 2017].

Pg-9
Nair, M., 2005. *Bhopal Gas Tragedy – A Social, Economic, Legal and Environmental Analysis* [pdf] Germany: University Library of Munich. Available at: < https://mpra.ub.uni-muenchen.de/37856/1/> [Accessed 15 October 2017].

Pg-11
[The MIC trail] n.d. [image online] Available at: <http://www.indiaenvironmentportal.org.in/media/iep/infographics/Bhopal%20Gas%20Disaster/index.htm> [Accessed 15 October 2017]

Pg-15
Nair, M., 2005. *Bhopal Gas Tragedy – A Social, Economic, Legal and Environmental Analysis* [pdf] Germany: University Library of Munich. Available at: < https://mpra.ub.uni-muenchen.de/37856/1/> [Accessed 15 October 2017].

Pg-16
Aggarwal, M. and Bera, S., 2016. 32 years after the Bhopal gas tragedy, govt apathy intensifies victims' pain. *livemint*, [online] Available at: <http://www.livemint.com/Politics/sBzgTl9og-cYcRJPDLVuj1L/32-years-after-the-Bhopal-gas-tragedy-govt-apathy-intensifi.html> [Accessed 22 November 2017].

Pg-17
International Environmental Law Research Centre, 2014. *Thirty years after Bhopal* [pdf] Available at: <http://www.ielrc.org/content/n1403.pdf> [Accessed 15 October 2017].

Pg-18
Singh, M. and Ghosh, S., 1987. Bhopal gas tragedy: Model simulation of the dispersion scenario. *Journal of Hazardous Materials*, Elsevier B.V., 17(1), p.21.

Pg-19
Singh, M. and Ghosh, S., 1987. Bhopal gas tragedy: Model simulation of the dispersion scenario. *Journal of Hazardous Materials*, Elsevier B.V., 17(1), p.22.

Pg-20
Shrivastava, P., 1987. 5 *Long-term recovery from the Bhopal crisis*. [online] The United Nations University Press . Available at: < http://archive.unu.edu/unupress/unupbooks/uu21le/uu21le0c.htm#5 long term recovery from the bhopal crisis > [Accessed 15 October 2017].

Pg-21
Eckerman, I., 2005. The Bhopal Saga—Causes and Consequences of the World's Largest Industrial Disaster. *Prehospital and Disaster Medicine*, 20(S1) University Press, p.92.

Pg-33
Pletcher, K., 2010. *The geography of India: sacred and historic places*. New York, NY: Britannica Educational Pub. in assoc. with The Rosen Publishing Group.
Kumar, U., Kumar, P. and Kumar, S., n.d. Geography of Bhopal, Madhya Pradesh. [online] Self published. Available at: <http://www.brandbharat.com/english/mp/districts/Bhopal/Bhopal.html> [Accessed November 23, 2017].
Anil, 1970. Bhopal birds. [online] Self published. Available at: <http://bhopalbirds.blogspot.ca/> [Accessed November 23, 2017].

Pg-34
Peterson, M.J., 2009. Case study: Bhopal plant disaster. *International Dimensions of Ethics Education Case Study Series*, [online] Library of University of Massachusetts Amherst . Available at: <http://scholarworks.umass.edu/edethicsinscience/4/> [Accessed 16 October 2017].

Pg-40
National Environmental Engineering Research Institute., 2010. *Analysis of chemical contaminants in groundwater of communities surrounding UCIL plant site in Bhopal* [pdf] Self published .<http://www.indiaenvironmentportal.org.in/files/full_report_1.pdf> [Accessed 15 October 2017].

Pg-41
National Geophysical Research Institute, 2010. Hydrogeological and simulation studies of aquifer around UCIL, Bhopal [pdf] Self published . Available at: < http://chemicals.nic.in/sites/default/files/Neeri-Annexure-II.pdf> [Accessed 15 October 2017].

Pg-42
National Environmental Engineering Research Institute, 2010. Assessment and Remediation of Hazardous Waste Contaminated Areas in and around M/s Union Carbide India Ltd., Bhopal [pdf] Self published. Available at: <http://www.bhopal.org/wp-content/uploads/2010/11/2009-BMA-Sambhavna-Bhopal-Water-Report.pdf> [Accessed 15 October 2017].p.30

Pg-43
National Environmental Engineering Research Institute, 2010. Assessment and Remediation of Hazardous Waste Contaminated Areas in and around M/s Union Carbide India Ltd., Bhopal [pdf] Self published . Available at: <http://www.bhopal.org/wp-content/uploads/2010/11/2009-BMA-Sambhavna-Bhopal-Water-Report.pdf> [Accessed 15 October 2017].p.34

Pg-68
Ramalingam, V., 2013. *Electrokinetic remediation* [pdf] Self published. Available at: <http://www.geoengineer.org/images/students/vramalingam_/ppt/ELECTROKINETIC_REMEDIATION_PPT_RAMALINGAM.pdf> [Accessed 16 October 2017].

Pg-69, 81
Kennen, k. and Kirkwood, N., 2015. *PHYTO: principles and resources for site remediation and landscape design.* ROUTLEDGE.

Pg-70
Alford, E.R., 2008. *Rhizoremediation.* [online] Available at: <http://rydberg.biology.colostate.edu/Phytoremediation/2008%20websites/Alford%20Phytostimulation%20Webpage/rhizoremediation.htm> [Accessed October 16, 2017].

Pg-79
Kornilovich, B., Mishchuk, N., Abbruzzese, K., Pshinko, G. and Klishchenko, R., (2005). Enhanced electrokinetic remediation of metals-contaminated clay. Colloids Surf.Physicochem.Eng. Aspects, 265(1), Elsevier B.V., p.114.

Ramalingam, V., 2013. Electrokinetic remediation. *The International Information Center for Geotechnical Engineers.* [online] Elxis s.a. Available at: < http://www.geoengineer.org/education/web-based-class-projects/geoenvironmental-remediation-technologies/electrokinetic-remediation?showall=1&limitstart= > [Accessed 16 October 2017].

Image's use

Credits

Cover page
Google Earth Pro 7.1.8.3036. *The Bhopal Gas Tragedy Site : Amelioration and the Way Ahead.* 23·165014, 77·244171, elevation 8660m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-ii
Clarke, G., 2012. *Bhopal still hasn't recovered from the worst industrial disaster in history.* Available at: <https://flic.kr/p/oVrDHo> [Accessed 15 October 2017].

Pg-iv
Oró, M. and Arrufat, J., 2017. *The hope to live from a victim of the Bhopal disaster.* Available at: <https://flic.kr/p/21cEktY> [Accessed 15 October 2017].

Pg-3
Bhopal Medical Appeal, 2013. *Soldiers guard the entrance of union carbide factory in Bhopal after a deadly poison gas leak.* Available at: < https://flic.kr/p/SmNZ92> [Accessed 15 October 2017].

Pg-4
[Chemical leak kills thousands in Bhopal] n.d. Available at: <http://www.writeopinions.com/union-carbide> [Accessed 15 October 2017].

Pg-6
[A tragedy and travesty of justice] n.d. Available at: <https://anuragtripathiblog.wordpress.com/2015/12/03/a-tribute-to-bhopal-gas-tragedythe-darkest-night/> [Accessed 15 October 2017].

Pg-7
Nitzsche, J., 2010. *Tank 610 in 2010.* Available at: <https://commons.wikimedia.org/wiki/File:Bhopal_Plant_7.JPG> [Accessed 15 October 2017].

Pg-8
Clarke, G., 2012. *Children outside the former union carbide facility in Bhopal, India.* Available at: <https://flic.kr/p/oVrB1E> [Accessed 15 October 2017].

Pg-9
Obi, 2006. *People of Bhopal outraged by the disaster.* Available at: <https://commons.wikimedia.org/wiki/File:BHOPAL_(231583728).jpg> [Accessed 15 October 2017].

Pg-11
[Bhopal gas tragedy after 32 years] n.d. Available at: <https://domainofscience.wordpress.com/2016/12/02/bhopal-gas-tragedy-after-32-years/> [Accessed 15 October 2017] edited.

Pg-13
Oró, M. and Arrufat, J., 2017. *A victim from the Bhopal gas disaster.* Available at: <https://flic.kr/p/22hRBBr> [Accessed 15 October 2017].

Pg-15
Bhopal Medical Appeal, 2013. *Irregular supply triggers water crisis in parts of Bhopal.* Available at: <https://flic.kr/p/SaCit2> [Accessed 15 October 2017]. (Edited)

Pg-16
Bouillet, S., 2009. *30 years after Bhopal disaster, Indians demand punishment.* Available at: <https://flic.kr/p/XMGib4> [Accessed 15 October 2017].

Pg-17
[Abandoned solar evaporation pond] n.d. Available at: <https://necrotravel.wordpress.com/2012/04/23/site-of-the-bhopal-gas-disaster/> [Accessed 15 October 2017].

Pg-19
Siddiqui, D. and Kapoor, B., 1984. *A lady sits next to her dead cattle.* Available at: <http://ermagazin.com/2016/05/sokantno-fotografije-iz-1984-bhopal-gas-tragedije.html/> [Accessed 15 October 2017].

Pg-20
Graham, D., 2009. *The aftermath of the Bhopal disaster.* Available at: <https://flic.kr/p/yX3nxA> [Accessed 15 October 2017].

Pg-21
Forget, Y., 2010. *People protesting against dow chemicals.* Available at: <https://commons.wikimedia.org/wiki/File%3ADow_Chemical_banner%2C_Bhopal.jpg> [Accessed 15 October 2017].

Pg-22
Bhopal Medical Appeal, 2013. *The ghosts of Bhopal, 30 years after disaster.* Available at: <https://flic.kr/p/R7JEfP> [Accessed 15 October 2017].

Pg-23
Google Earth Pro 7.1.8.3036. *Development in neighbourhood areas from 2002-2016.* 23·2855766, 77·387321, elevation 6118m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-24
Google Earth Pro 7.1.8.3036. *Land use around the former Union Carbide factory site.* 23·2821612, 77·4018815, elevation 1730m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-25
Google Earth Pro 7.1.8.3036. Affected neighbourhood areas. 23·2829123, 77·3973403, elevation 2482m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-27
[Universal design] n.d. [pdf] Available at: <http://www.designforall.in/dfa.pdf> [Accessed 15 October 2017].

Pg-33
Dwivedi, S., 2012. *Taj-ul-Masjid, Bhopal.* Available at: <https://en.wikipedia.org/wiki/File:Taj_ul_masjid.jpg> [Accessed 23 November 2017].

Pg-34
Google Earth Pro 7.1.8.3036. Former Union Carbide Factory site context. 23·2693799, 77·3740918, elevation 8773m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Google Earth Pro 7.1.8.3036. Former Union Carbide Factory site context. 23·2818081, 77·4049569, elevation 1740m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-35
Google Earth Pro 7.1.8.3036. Former Union Carbide Factory site context. 23·2819048, 77·4053117, elevation 1738m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-36,37
Google Earth Pro 7.1.8.3036. Present condition. 23·2816404, 77·4045335 elevation 2081m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-38
[Spreading smiles all over] n.d. Available at: <http://www.bitesfactory.com/nl/tag/india/> [Accessed 10 November 2017].

Pg-39
Water resource department Madhya Pradesh, n.d. *Rainfall data of Berasia RG station* [pdf] Available at: <http://www.mpwrd.gov.in/documents/18/10d1e381-e074-445a-8e6a-9b3ae2708082> [Accessed 15 October 2017].

Pg-40
Google Earth Pro 7.1.8.3036. GROUNDWATER FLOW (NEIGHBOURHOOD). 23·2839574, 77·3962936 elevation 5126m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-41
National Geophysical Research Institute, 2010. Hydrogeological and simulation studies of aquifer around UCIL, Bhopal [pdf] Available at: < http://chemicals.nic.in/sites/default/files/Neeri-Annexure-II.pdf> [Accessed 15 October 2017].

Pg-42
Google Earth Pro 7.1.8.3036. SOIL ANALYSIS (sectional points). 23·282757, 77·4048146 elevation 2492m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-43
National Geophysical Research Institute, 2010. Hydrogeological and simulation studies of aquifer around UCIL, Bhopal [pdf] Available at: < http://chemicals.nic.in/sites/default/files/Neeri-Annexure-II.pdf> [Accessed 15 October 2017].

Pg-45
Azadirachta indica (a)
Editinf, 2014. *Azadirachta indica.* Available at: <https://commons.wikimedia.org/wiki/File:Azadirachta_indica_planted_in_Afri.jpg> [Accessed 15 October 2017].

Eucalyptus (b)
Moss, J., 2008. *Eucalyptus olida woodland.* Available at: <https://commons.wikimedia.org/wiki/File:Eucalyptus_olida_woodland1.JPG> [Accessed 15 October 2017].

Bombax_ceiba (c)
Banswal, H., 2010. *Bombax ceiba.* Available at: <https://commons.wikimedia.org/wiki/File:Bombax_ceiba_tree%27.jpg> [Accessed 15 October 2017].

Phoenix-dactylifera (d)
Halzenski, R., 2010. *Phoenix Dactylifera.* Available at: <https://commons.wikimedia.org/wiki/File:Phoenix_dactylifera_at_Osaka_Gakuin_University_(Osaka,_Japan).JPG> [Accessed 15 October 2017].

Leucaena leucocephala (e)
[Leucaena leucocephala] n.d. Available at: <https://amyangel5.wordpress.com/2014/06/27/biomasa/> [Accessed 15 October 2017].

Acacia nilotica (f)
[Acacia nilotica] n.d. Available at: <https://flic.kr/p/MK6V9> [Accessed 15 October 2017].

Ziziphus mauritiana (g)
Djatmiko, W., 2011. *Habits of wild Ziziphus mauritiana from Bekol savanna, Baluran Nat. Park, Indonesia.* Available at: <https://upload.wikimedia.org/wikipedia/commons/thumb/8/8d/Zizip_maurit_110901-17127_H_bal.jpg/1024px-Zizip_maurit_110901-17127_H_bal.jpg> [Accessed 15 October 2017].

Hibiscus (h)
Sakaki, L., 2016. *Tropical Hibiscus 'Azalea'.* Available at: <https://commons.wikimedia.org/wiki/File:Azaleia00011.jpg> [Accessed 15 October 2017].

Dalbergia sissoo (i)
Mahmood, K., 2011. *Dalbergia Sissoo Indian Rosewood.* Available at: <https://commons.wikimedia.org/wiki/File:Dalbergia_sissoo.jpg> [Accessed 15 October 2017].

Cascabela thevetia (j)
Starr, F. and Starr, K., 2006. *Cascabela thevetia.* Available at: <https://commons.wikimedia.org/wiki/File:Starr_060916-8884_Thevetia_peruviana.jpg> [Accessed 15 October 2017].

Saraca asoca (k)
[Ashoka tree] n.d. Available at: <https://americanindianimports.wordpress.com/2014/10/16/ashoka-saraca-indica-remover-of-sorrows/> [Accessed 15 October 2017].

Delonix regia (l)
Anichkova, A., 2009. *Delonix Regia, Gul Mohr Tree.* Available at: <https://commons.wikimedia.org/wiki/File:Delonix_regia_4257.jpg> [Accessed 15 October 2017].

Tamarindus indica (m)
[Tamarind] n.d. Available at: <https://flic.kr/p/LcMMGj> [Accessed 23 November 2017].

Santalum (n)
AntanO, 2014. *Wood-apple tree in Trincomalee, Sri Lanka.* Available at: <https://commons.wikimedia.org/wiki/File:Wood-apple_tree.JPG> [Accessed 15 October 2017].

Psidium guajava (o)
[Psidium guajava also known as guava] n.d. Available at: <https://flic.kr/p/E2Taio> [Accessed 15 October 2017].

Magnifera (p)
Aranas, U., 2014. *Mangifera indica tree.* Available at: <https://commons.wikimedia.org/wiki/File:Paitan_Sabah_Common-mango-Mangifera-indica-01.jpg> [Accessed 15 October 2017].

Ficus religiosa (q)
[Ficus infectoria also known as white fig or peepal tree] n.d. Available at: <https://flic.kr/p/cvDBX3> [Accessed 15 October 2017].

F. benghalensis (r)
Garg, J.M., 2008. *Banyan Ficus benghalensis.* Available at: <https://commons.wikimedia.org/wiki/File:Banyan_tree_(Ficus_benghalensis)_in_Secunderabad,_AP_W_IMG_6635.jpg> [Accessed 15 October 2017].

Prosopis cineraria (s)
Burdak, L.R., 2008. *Khejri, the tree that inspired Chipko movement, is dying a slow death.* Available at: <https://commons.wikimedia.org/wiki/File:Khejri.jpg> [Accessed 15 October 2017].

Butea monosperma (t)
Shyamal, 2009. *Butea monosperma.* Available at: <https://commons.wikimedia.org/wiki/File:Butea_monosperma_1.jpg> [Accessed 15 October 2017].

Pg-48
[Bhopal gas: A lethal trade secret] n.d. [image online] Available at: <https://gvk2.wordpress.com/2009/11/30/bhopal-gas-a-lethal-trade-secret/> [Accessed 15 October 2017].

Pg-50
Google Earth Pro 7.1.8.3036. SOIL ANALYSIS (sectional points). 23.282757, 77.4048146 elevation 2492m. 3D Building layer [online]. Available at: <https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-52
Google Earth Pro 7.1.8.3036. Soil sampling inside the site. 23·2811294 , 77·4067561 elevation 1451m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-53, 55,57
National Environmental Engineering Research Institute., 2010. *Analysis of chemical contaminants in groundwater of communities surrounding UCIL plant site in Bhopal* [pdf] <http://www.indiaenvironmentportal.org.in/files/full_report_1.pdf> [Accessed 15 October 2017].

Balentine, B.L., 1995. *Permissible limit of metals* [pdf] Available at: <http://occeweb.com/og/metals-limits.pdf> [Accessed on 22 November 2017].

Pg-54,56
Google Earth Pro 7.1.8.3036. Soil sampling outside the site and GroundWater sampling outside the site. 23·296845, 77·3957637 elevation 7362m. 3D Building layer [online] . Available at: < https://www.google.ca/maps/place/Arif+Nagar,+Bhanpur,+Bhopal,+Madhya+Pradesh,+India> [Accessed 20 October 2017]. (Edited)

Pg-67
[Dynamic compaction] n.d. [image online] Available at: <https://erkrishneelram.wordpress.com/2015/03/06/soil-improvement-liquefaction/> [Accessed 10 November 2017].

Pg-68
Cameselle et al., 2013. *Principle of Electrokinetic Remediation.* Available at: <https://www.intechopen.com/books/organic-pollutants-monitoring-risk-and-treatment/advances-in-electrokinetic-remediation-for-the-removal-of-organic-contaminants-in-soils> [Accessed 10 November 2017]. (edited)

Pg-69
Kennen, K. and Kirkwood, N., 2015. *PHYTO: principles and resources for site remediation and landscape design.* ROUTLEDGE.(edited)

Pg-70
Rohrbacher, F. and St-Arnaud, M., 2016. *Rhizoremediation: a beneficial plant-microbe interaction.* Available at: <http://www.mdpi.com/2073-4395/6/1/19/htm> [Accessed 10 November 2017]. (edited)

Pg-74
Graham, D., 2009. *Children play cricket within the grounds of the abandoned factory.* Available at: <https://flic.kr/p/yGKJzs> [Accessed 10 November 2017].

Pg-80
Kennen, K. and Kirkwood, N., 2015. *PHYTO: principles and resources for site remediation and landscape design.* ROUTLEDGE. (edited)

Pg-83
Populus deltoid (a)
Herman, D.E., et al. 1996. *Populus deltoides.* Available at: <https://commons.wikimedia.org/wiki/File:Populus_deltoides_pode3_010_pvp.jpg> [Accessed 10 November 2017].

Ipomea cornea (b)
Primejyothi, 2014. *Ipomoea pes-capre.* Available at: <https://commons.wikimedia.org/wiki/File:Ipomoea_pes-caprae_DSCN0356_02.JPG> [Accessed 10 November 2017].

Pg-85
Holcus lanatus (c)
Dumat, M., 2011. *Holcus lanatus.* Available at: < https://flic.kr/p/9e31ma> [Accessed 10 November 2017].

Zea mays (d)
Zell, H., 2009. *Zea mays.* Available at: <https://commons.wikimedia.org/wiki/File:Zea_mays_003.JPG> [Accessed 10 November 2017].

Pg-87
Alfalfa (e)
Bogdan, 2005. *Alfalfa.* Available at: <https://commons.wikimedia.org/wiki/File:Medicago_sativa_02_bgiu.jpg> [Accessed 10 November 2017].

Coriander (f)
[Coriander foliage] n.d. Available at: <https://pxhere.com/en/photo/1023405> [Accessed 10 November 2017].

Wheat (g)
[Wheat] n.d. Available at: <https://pixabay.com/en/wheat-grass-barley-autumn-harvest-863392/> [Accessed 10 November 2017].

Indian mustard (h)
Indiaphotoblog, 2008. *Indian mustard flower.* Available at: <https://commons.wikimedia.org/wiki/File:Yellow_mustard_flower.jpg> [Accessed 10 November 2017].

Chilli (i)
[Pepper field] n.d. Available at: <http://maxpixel.freegreatpicture.com/Vegetables-Pepper-Field-Pepper-Vegetable-Hot-Pepper-1704266> [Accessed 10 November 2017].

Pg-89
Pearl Millet (j)
[Pearl millet] n.d. Available at: <https://pixabay.com/en/pearl-millet-bajra-cultivation-204105/> [Accessed 10 November 2017].

Pg-113
Frediani, L., 2008. Crop memorial. Available at: <https://commons.wikimedia.org/wiki/File%3ABhopal-Union_Carbide_1.jpg> [Accessed 21 November 2017].