Health Risk Associated with Chemicals used in Water Treatment

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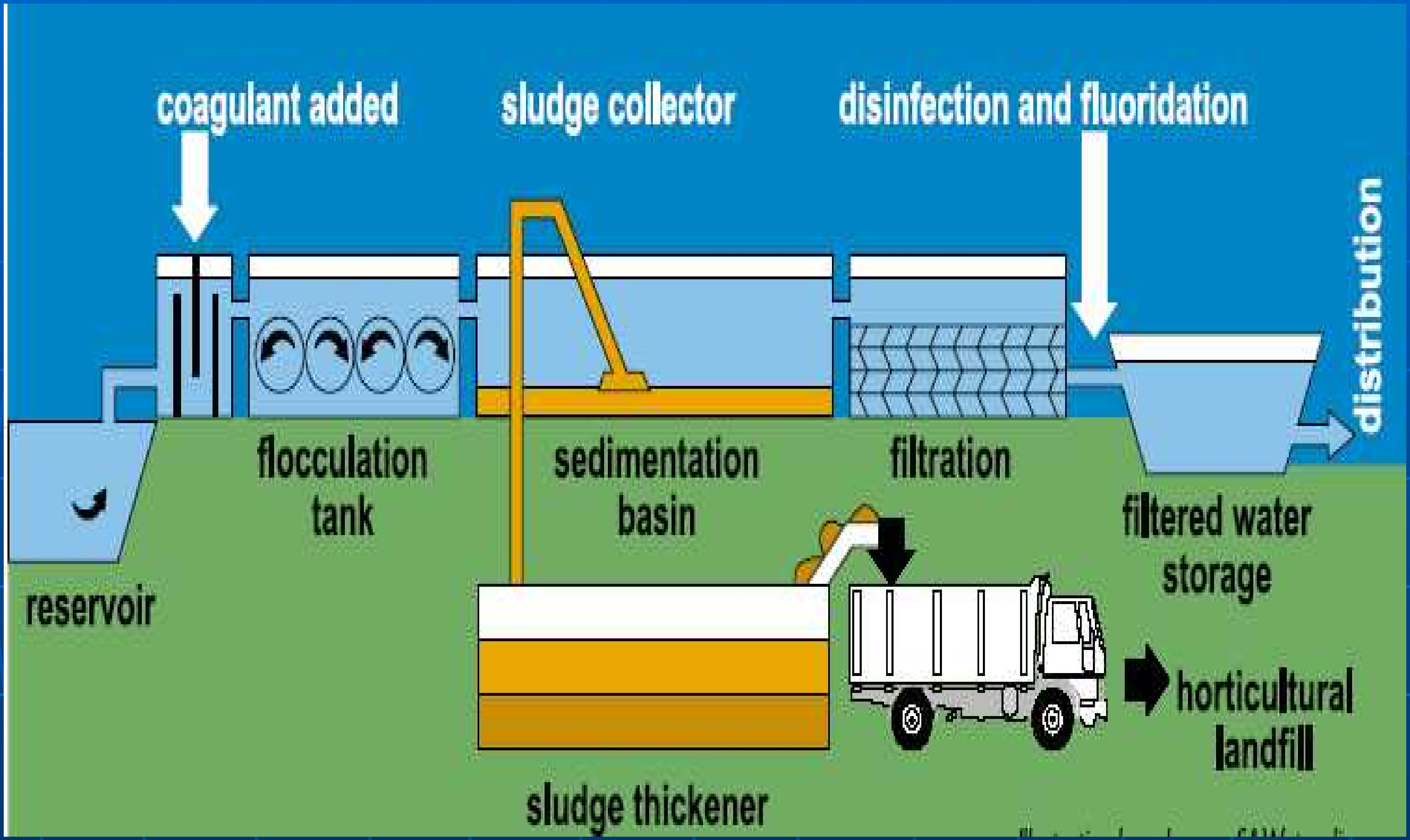


Water Treatment Process

Coagulants: Aluminum derivatives viz.PAC, Iron derivatives. Lime.

CHEMICALS USED IN WATER TREATMENT PROCESS

Odour control: Powdered clay coagulant.

Disinfectants: Chlorine, chlorine dioxide, ozone, ammoniation, UV irradiation and ozonation

Coagulant aids: synthetic-organic aids & natural-organic aids

Coagulants used in water treatment

Name	*Advantages*	*Disadvantages*
Aluminum Sulfate (Alum) $Al2(SO_4)_3.18H_2O$	Easy to handle and apply; most commonly used; produces less sludge than lime; most effective between pH 6.5 and 7.5	Adds dissolved solids (salts) to water; effective over a limited pH range.
Sodium Aluminate $Na_2Al_2O_4$	Effective in hard waters; small dosages usually needed	Often used with alum; high cost; ineffective in soft waters
Polyaluminum Chloride (PAC) $Al_{13}(OH)_{20}(SO_4)_2.Cl_{15}$	In some applications, floc formed is more dense and faster settling than alum	Not commonly used; little full scale data compared to other aluminum derivatives
Ferric Sulfate $Fe_2(SO_4)_3$	Effective between pH 4–6 and 8.8–9.2	Adds dissolved solids (salts) to water; usually need to add alkalinity
Ferric Chloride $FeCl_3.6H_2O$	Effective between pH 4 and 11	Adds dissolved solids (salts) to water; consumes twice as much alkalinity as alum
Ferrous Sulfate (Copperas) $FeSO_4.7H_2O$	Not as pH sensitive as lime	Adds dissolved solids (salts) to water; usually need to add alkalinity
Lime $Ca(OH)_2$	Commonly used; very effective; may not add salts to effluent	Very pH dependent; produces large quantities of sludge; overdose can result in poor effluent quality

Non-conventional vs. Conventional Coagulants

Conventional Coagulants (Alum, Ferric Chloride, lime)

- Greater volume of sludge
- Sludge contains more amount of water
- More amount of alkaline chemicals is needed
- Amount of TDS generated is more
- More carryover of iron or aluminium

Non-Conventional (Polyelectrolytes)

- 50 to 90% reduction in sludge.
- Sludge contains less amount of water
- Less amount of alkaline chemicals needed
- Do not add to total dissolved solids
- Carryover soluble- iron or aluminium.

Effects of Aluminium based coagulants

Carcinogenic

Damage to the central nervous system

Dementia

Severe trembling

Alzheimer's disease

Loss of memory

Listlessnes
s

Aluminium ions react with phosphates
causing scarcity of phosphates to aquatic organisms

Health effects of Polyacrylamide

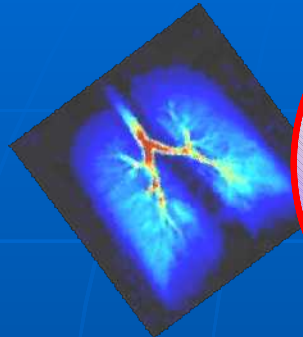
Humans –
Skin irritant
Effects respiratory tract
(IARC 1985).
Neurotoxicant

Increase in mortality of animals, birds & growth retardant in plants.

Developmental disorders in aquatic life

Humans: Chromosomal aberrations, dominant lethality, sister chromatid exchanges and unscheduled DNA synthesis in various in vitro and in vivo systems

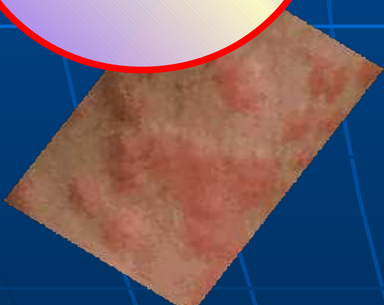
Humans:
Ingestion of contaminated drinking water has causes drowsiness, disturbances of balance, confusion, memory loss, and hallucinations (HSDB 1994).



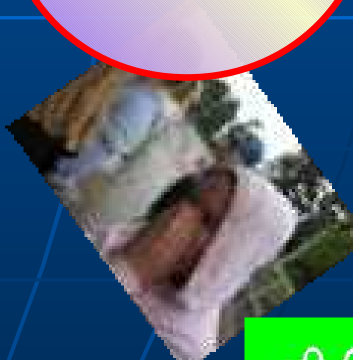
Affects human respiratory system

Effects of Chlorine

Causes irritation in skin, eyes



Coughing and chest pain



In Environment it combines
with organic &
inorganic compounds to
form various
toxic pollutants

Formation of Halogenated compounds in Water

Naturally occurring organic matter → Chlorine (Br) →

- Trihalomethane (THMs)
- Low Mol. Wt. Halogenated compounds
- High Mol. Wt. Halogenated compounds

Chlorination:-

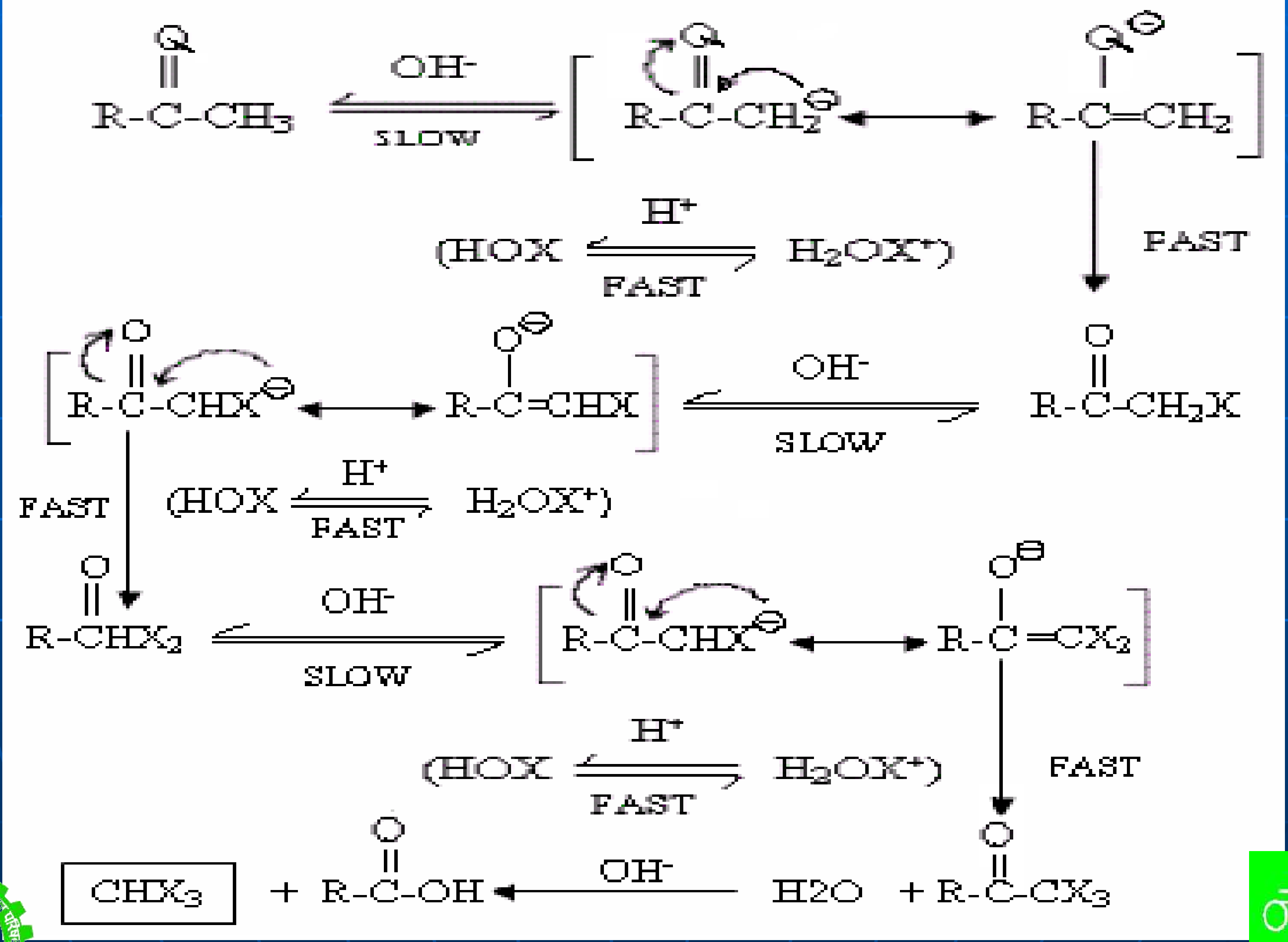
$$Cl_2 + H_2O \longleftrightarrow HOCl + HCl$$

$$HOCl \rightleftharpoons OCl^- + H^+$$

Haloform Reaction:-

$$R\text{-}\overset{O}{\overset{\|}{C}}\text{-}CH_3 + 3OX^- \longrightarrow R\text{-}\overset{O}{\overset{\|}{C}}\text{-}O^- + CHX_3 + 2OH^-$$

Mechanism of Haloform Reaction



General reaction of THMs formation

Chlorine + Precursor → Chloroform (+ other THMs)

Natural Organic Material (NOM) consisting of humic & fulvic acids is the principal precursor of THMs formation in most water & represents the major portion of TOC

$CHCl_3$ + Other Disinfection By-products

↑

NOM

+

Free Cl_2 + $Br + H_2O$ → $HOBr + Cl^- + HCl$

+

NOM

↓

CH_3Br + Other Disinfection By-products

Prominent Trihalomethanes (THMs) in Water

1

```
     Cl
     |
H – C – Cl
     |
     Cl
```

$CHCl_3$

Trichloromethane
(Chloroform)

2

```
     Br
     |
H – C – Cl
     |
     Cl
```

$CHBrCl_2$

Bromodichloro-
methane

3

```
     Br
     |
H – C – Cl
     |
     Br
```

$CHBr_2Cl$

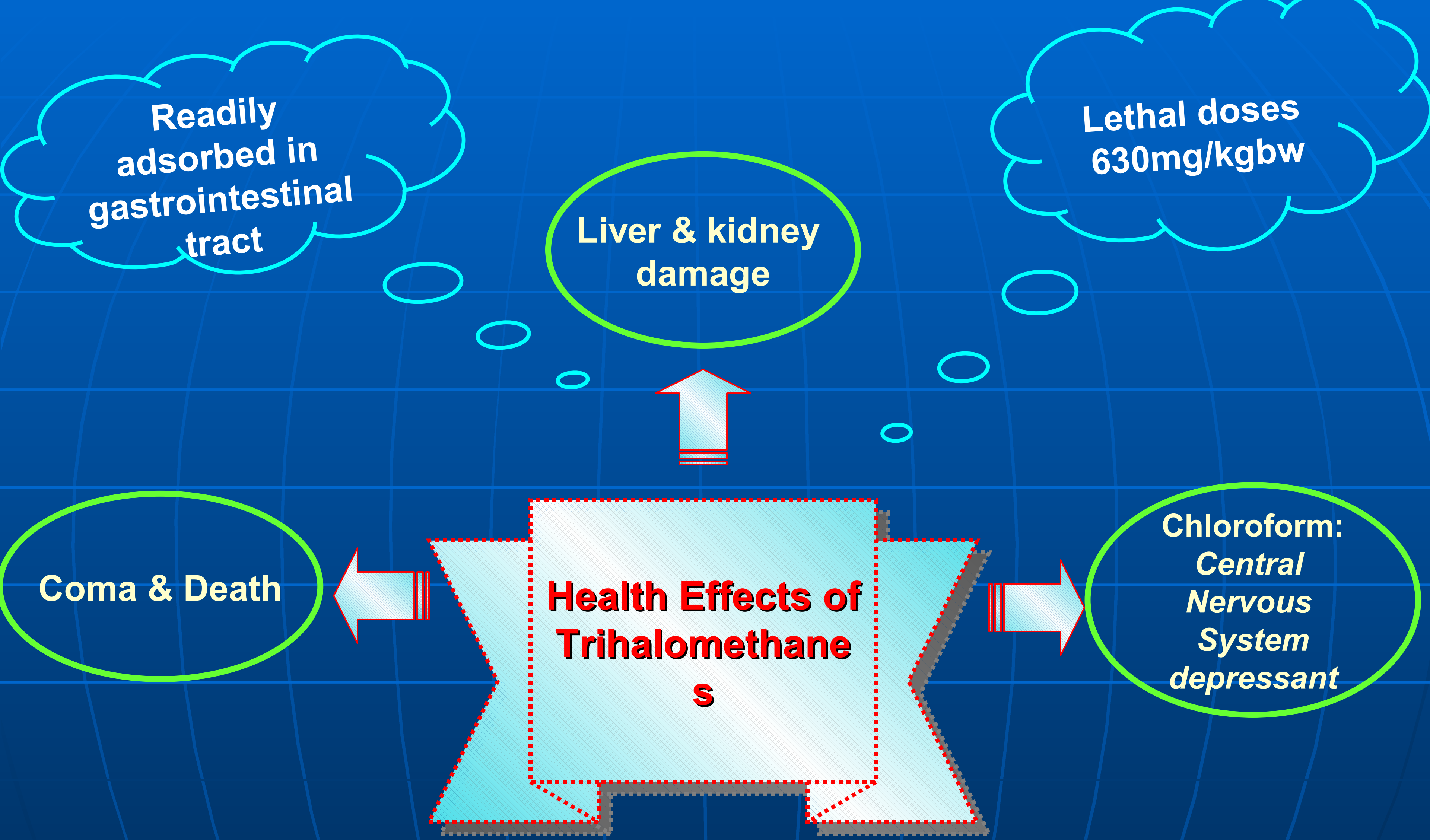
Dibromochloro-
methane

4

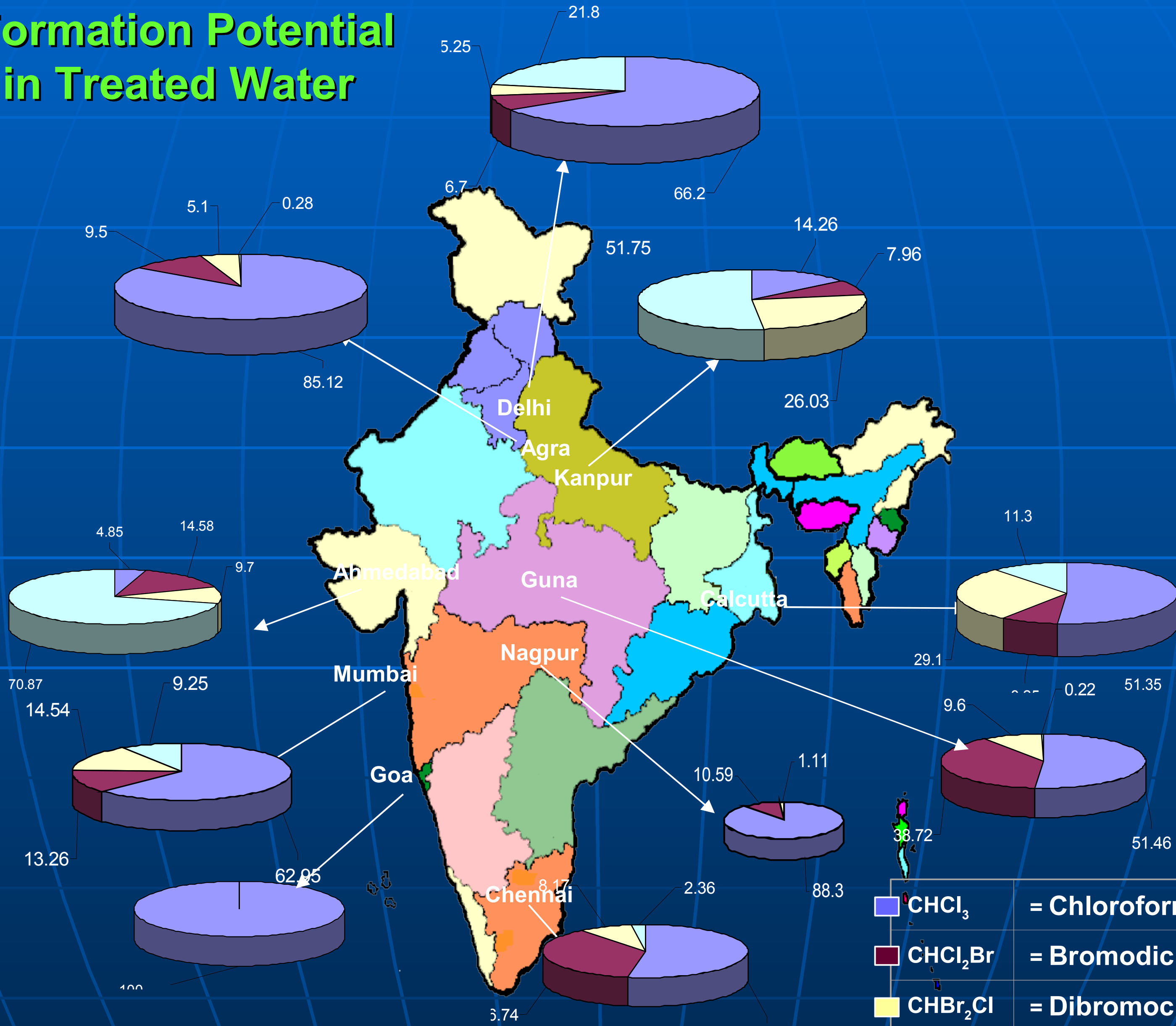
```
     Br
     |
H – C – Br
     |
     Br
```

$CHBr_3$

Tribromomethane
(Bromoform)


Readily adsorbed in gastrointestinal tract
Liver & kidney damage
Lethal doses 630mg/kgbw
Coma & Death
Health Effects of Trihalomethanes
Chloroform: *Central Nervous System depressant*

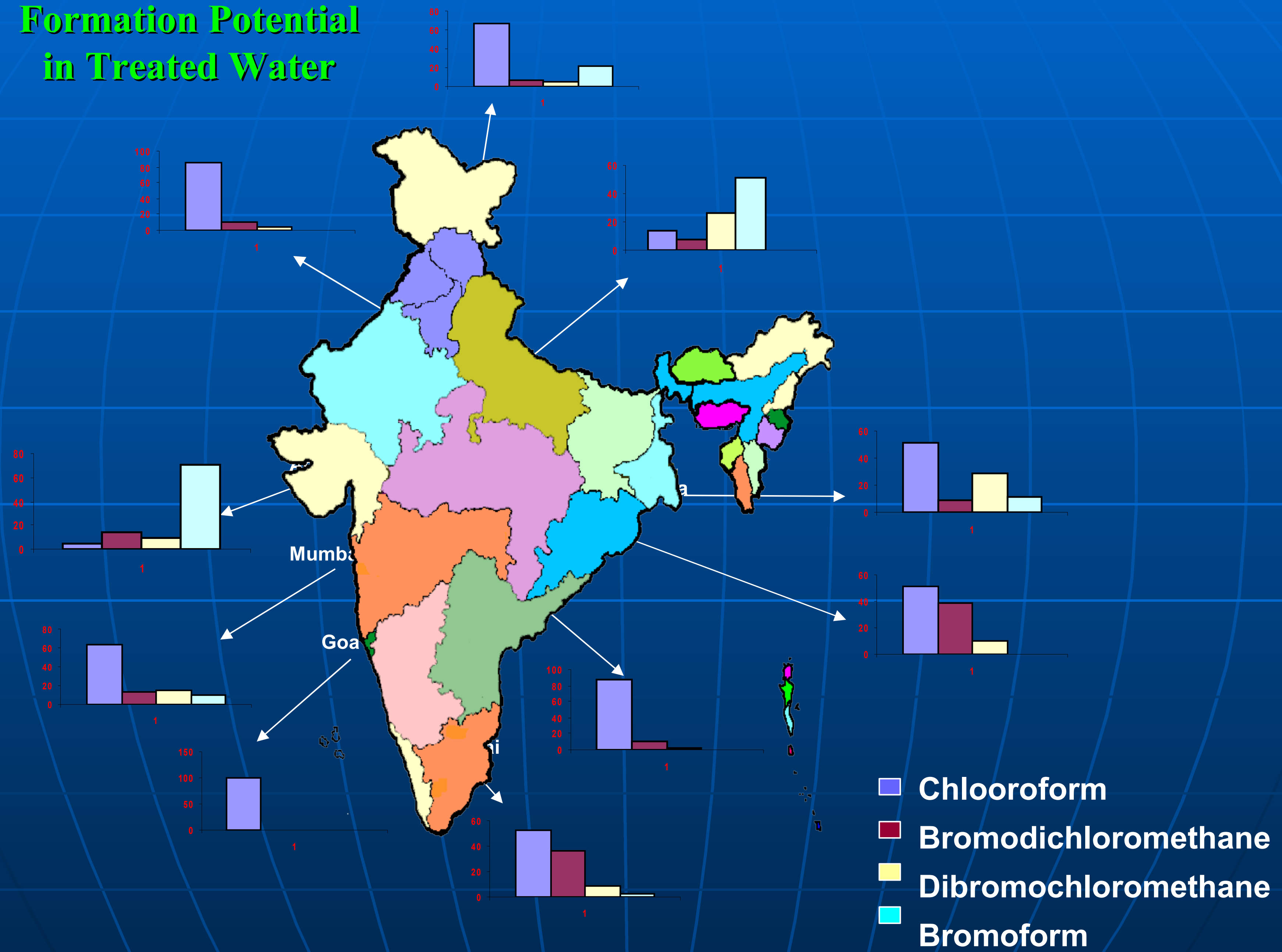
Trihalomethane Formation Potential in Treated Water



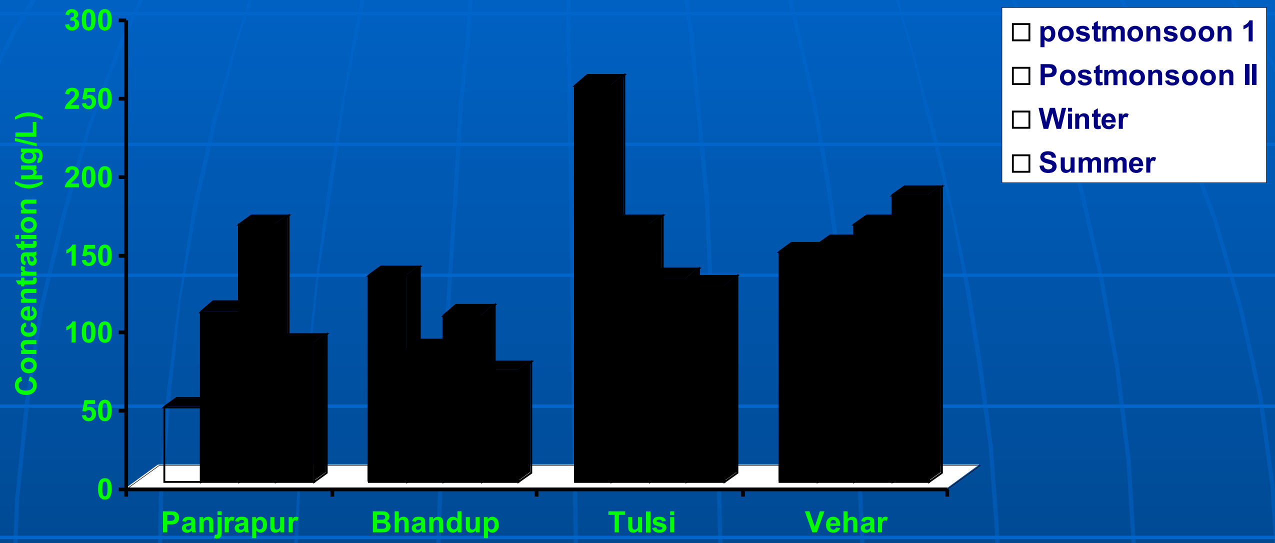
$CHCl_3$	= Chloroform
$CHCl_2Br$	= Bromodichloromethane
$CHBr_2Cl$	= Dibromochloromethane
$CHBr_3$	= Bromoform

Ref: Thakkar et.al, Ind. Wat.Wks. Assoc.,

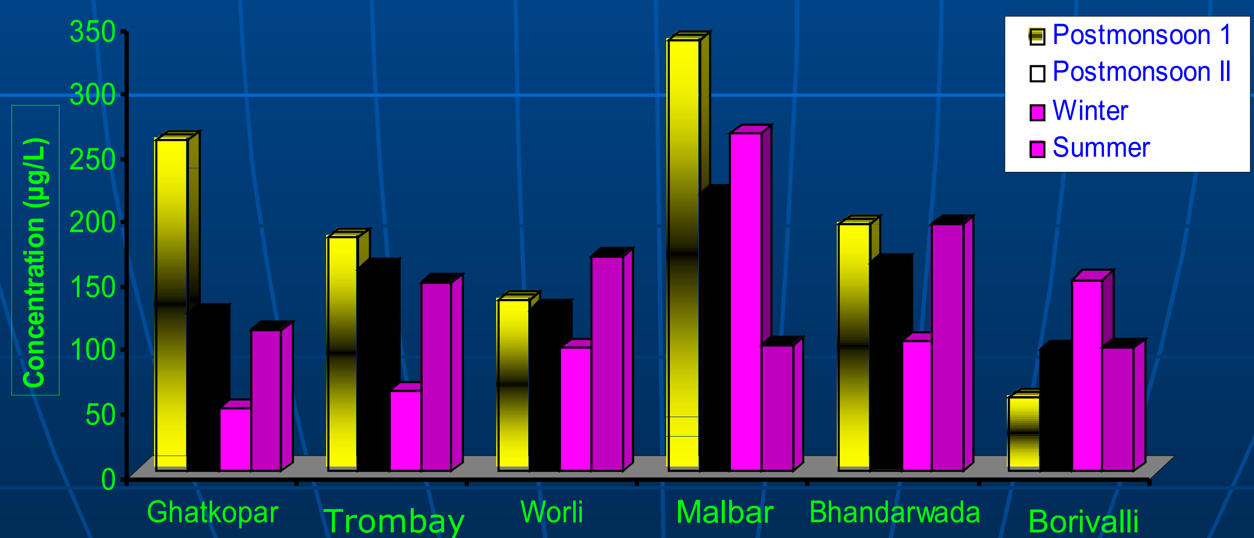
Trihalomethane Formation Potential in Treated Water



Seasonal Variation in Trihalomethane Formation Potential in Treated Water at Mumbai

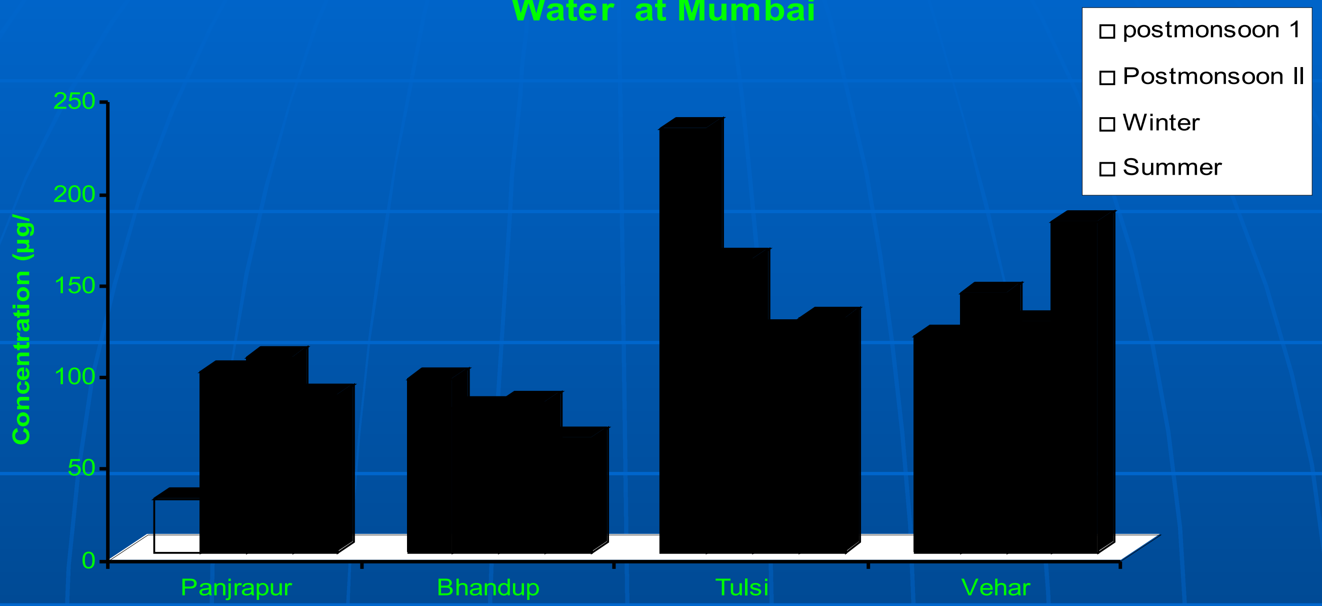


Seasonal Variation inTrihalomethane Formation Potential in Reservoirs at Mumbai

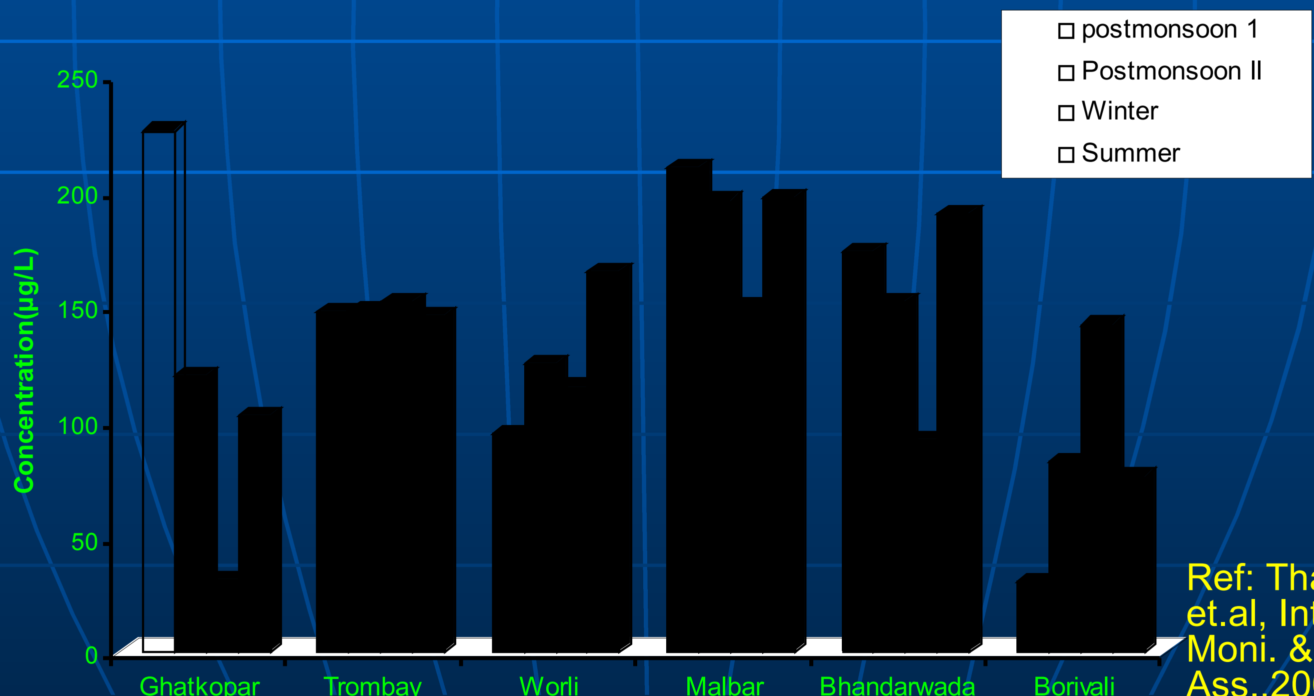


Ref: Thacker et.al, Int.Jour. of Moni. &Ass., 2002

Seasonal Variation in Chloroform Concentrations in Treated Water at Mumbai

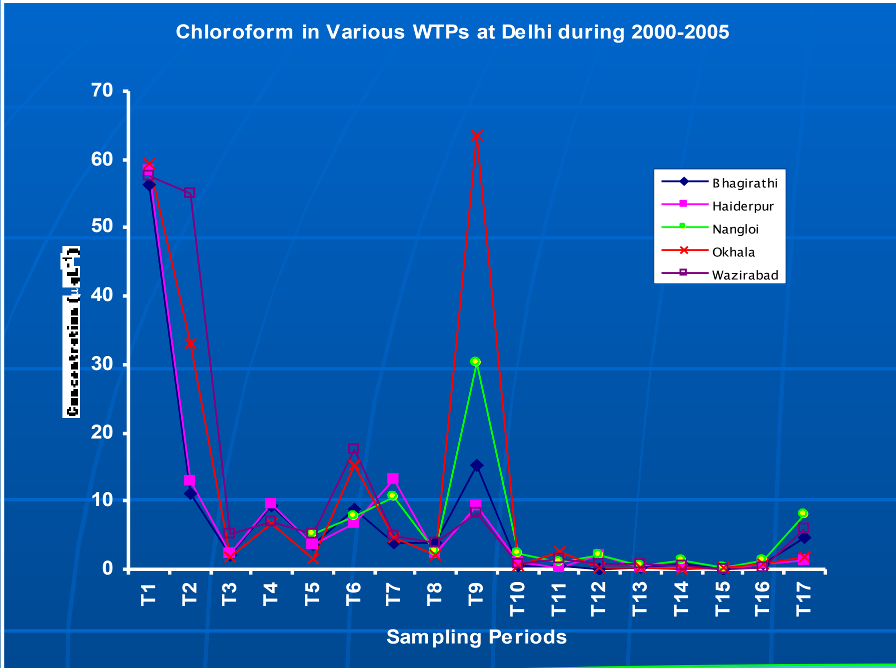


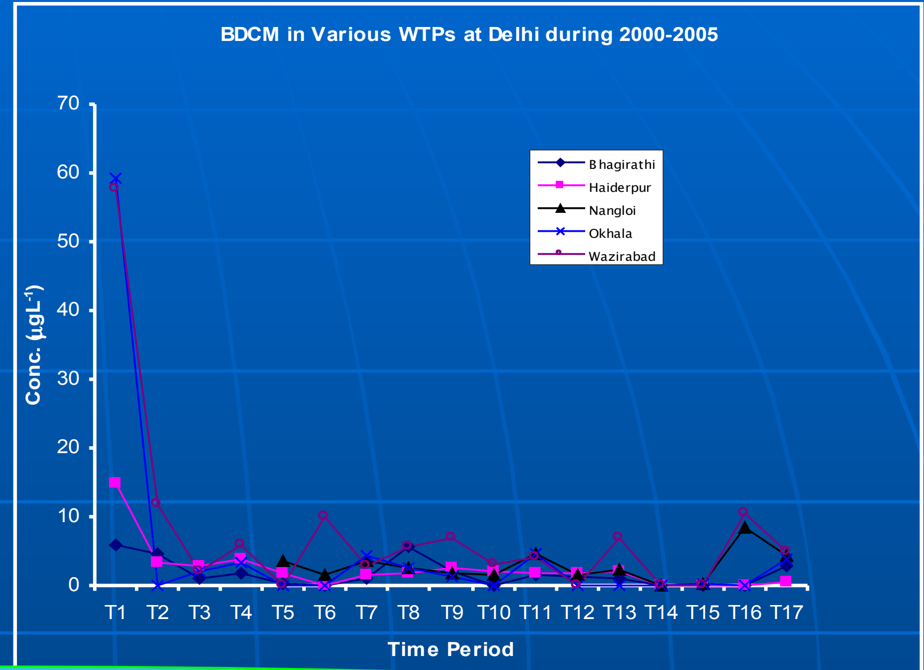
Seasonal Variation in Chloroform Concentrations in Reservoirs at Mumbai

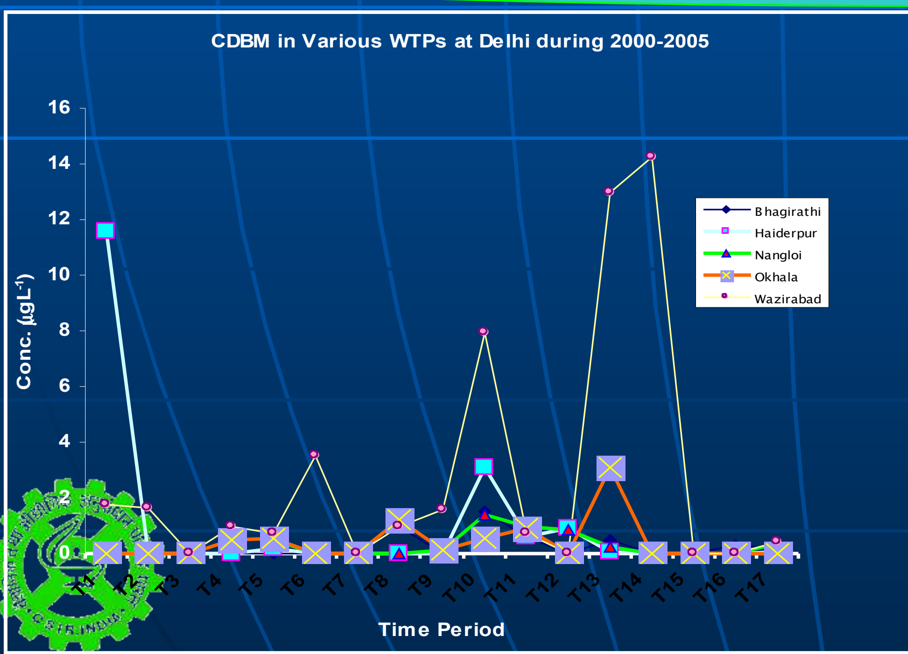


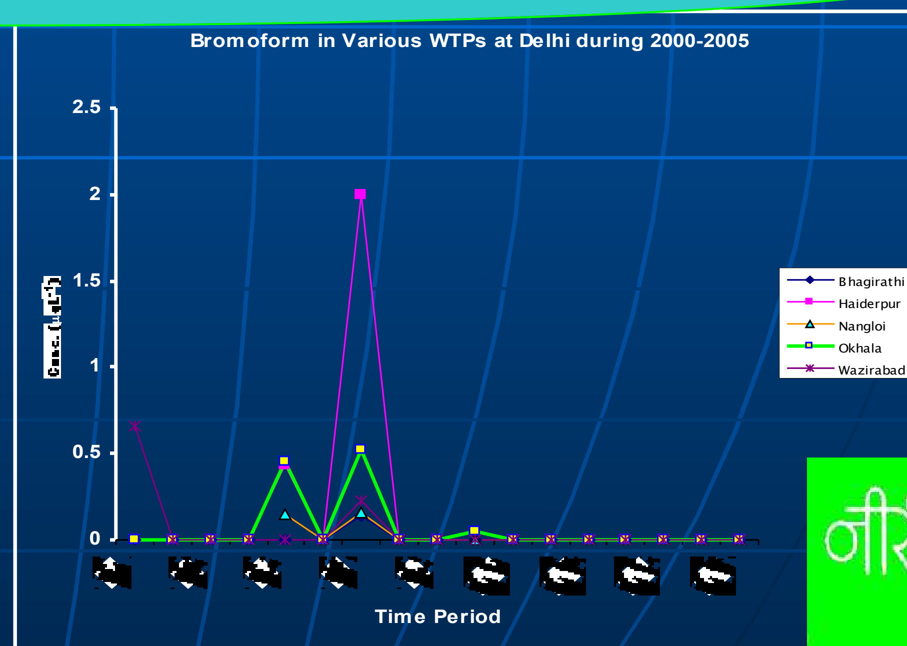
Ref: Thacker et.al, Int.Jour. of Moni. & Ass.,2002 2002

THM formation potential at various water treatment plants at Delhi during 2000-2005









Effect of Polyaluminium Chloride (PAC) on THMs Formation in water treatment plant

Instantaneous Trihalomethane (Inst.THMS) in Final Water of a Treatment Plant at Mumbai (μgL^{-1})

Sample Details	Chloroform	BDCM	CDBM	Bromoform	TTHMs*
Sample (Alum)	ND	ND	ND	ND	ND
Sample (Alum + PAC)	ND	ND	ND	0.093	0.093
WHO GVs (μgL^{-1})	200	60	100	100	-

Trihalomethane Formation Potential (TFP) in Final Water of a Treatment Plant at Mumbai (μgL^{-1})

Sample Details	Chloroform	BDCM	CDBM	Bromoform	TFP as $CHCl_3$
Sample (Alum)	2.937	ND	ND	0.009	2.941
Sample (Alum +PAC)	2.986	ND	ND	0.026	2.99
WHO GVs (μgL^{-1})	200	60	100	100	

ND: Not detectable
BDCM Bromodichloromethane
CDBM Chlorodibromomethane
* Total Trihalomethanes

Management Strategy for Reducing Trihalomethane Formation

- The use of non-THM generating disinfectants or alteration of the present method of chlorination
  - Ozonation, chlorine dioxide and chloramines as alternative disinfectants
- Removal or reduction of the precursors prior to chlorination
  - Aeration and ozonation conventional treatment
- Removal of the THMs after formation
  - Conventional treatment
    - Coagulation and flocculation
    - adsorption
    - aeration and adsorption
  - Non conventional treatment
    - Photocatalytic method

Use of Alternative Disinfectants

Ozonation

Advantage

- Excellent biocide
- Biocidal activity not affected by pH of the water
- THMs will not be formed

Disadvantage

- It does not produce a disinfectant residual
- The health hazards of the by-products of the reaction of ozone with organic matter is not known
- Organics in water become more biodegradable and thus can results in higher microbiological activity in the distribution system

Use of Alternative Disinfectants

Chlorine Dioxide

Advantage

- **Good biocidal activity**
- **It can be generated and feed readily**
- **It produces residual that can persist through the distribution system**

Disadvantage

- **It results in to the formation of chlorite and chlorate**
- **USEPA has recommended the maximum permissible level for the sum of residuals of chlorine dioxide, chlorite and chlorate in the drinking water as 0.5 mg/L**

Use of Alternative Disinfectants

Chloramine (Combined chlorine residual)

Advantage

- Easy to generate, feed and produce a persistent residual
- Chloramines are weaker action biocides and the activity is reduced when pH of water is high because of monochloramine formation which is favoured over dichloramine

Disadvantage

- Chloramines are suspected carcinogens

Removal of THMs by Conventional and Non-Conventional Treatment Process

(Initial Conc.: 50-350 ug/L)

Sl. No.	THMs	Removal %							
		Conventional *						Non-conventional	
		Coagulation	Adsorption			Aeration		Photolysis	
	Chemical	Alum	GAC		PAC	Tray-type	Cascade Aerator 12 L/min	Solar + H_2O_2	UV + H_2O_2
	Dose (µgL^{-1})	50	Indigenous	Imported	250 mg/L	Flow 1-5 L/min			(200 nm + 0.1%) H_2O_2
1	Chloroform	38	49	78	79	95	87	60	100
2	BDCM	38	68	92	84	97	93	72	100
3	CDBM	52	70	93	90	93	89	38	100
4	Bromoform	60	74.5	100	92	77	86	42	100
Initial Concentration range (µg/L)		50 – 200		68.4 – 209.3	78.4 – 204.3	70.6 – 263.5	173.6	200	45 min

1 Bromodichlorochloromethane

2 Chlorodibromomethane

Ref: Thacker et.al, Int. Jour. of Env. Moni. & Ass., 2005;

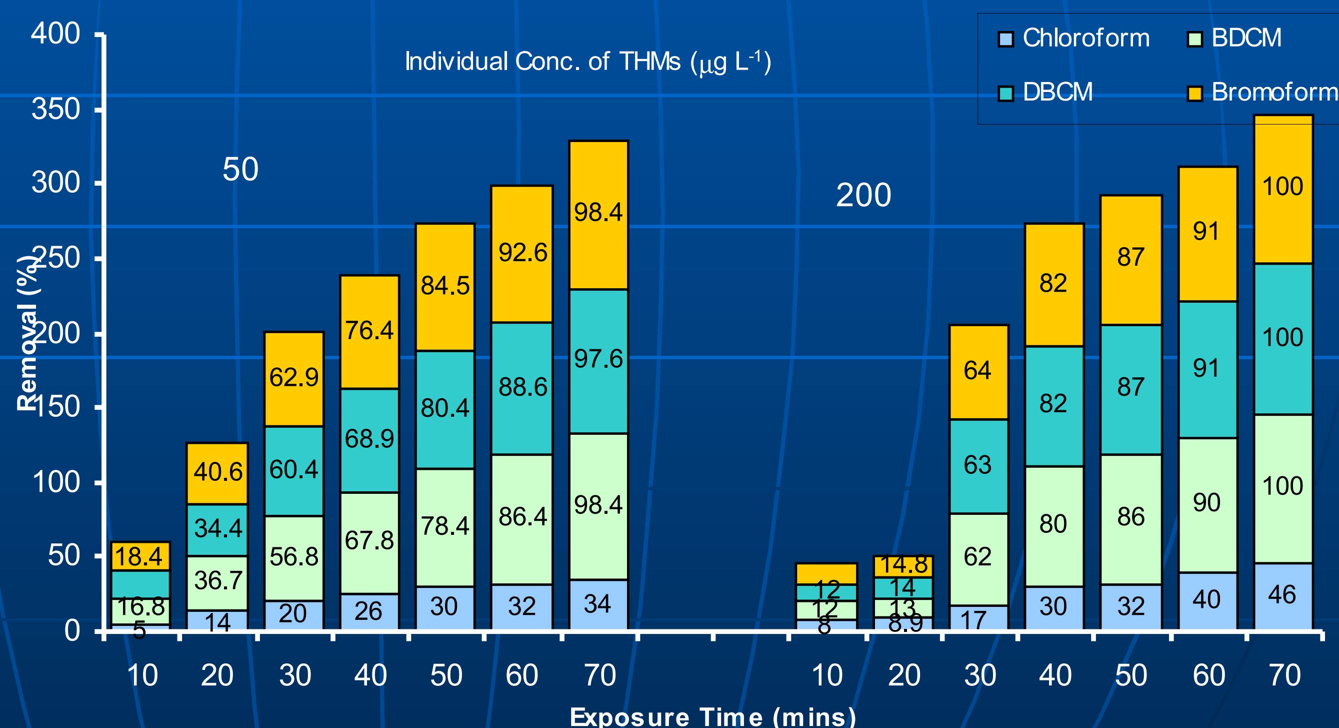
Thacker et.al., Int. Jour. of Pest., People & Nature, 2000

Effect of UV radiation on removal of trihalomethanes

- **Initial Concentration: 200 μgL^{-1}**
- **Contact time: 70 mins**
- **Removal:100 % - 46%**

- **Initial Concentration: 50 μgL^{-1}**
- **Contact time: 70 mins**
- **Removal: 98 % - 34%**

★ **Removal of 92-100% with UV radiation (83 W) in conjugation with H_2O_2 (0.1%) and 90 mins of contact time**



Effect of UV irradiations on removal of trihalomethanes

Ref: Thacker et.al, Int. Jour. of Env. Moni. & Ass., 2005

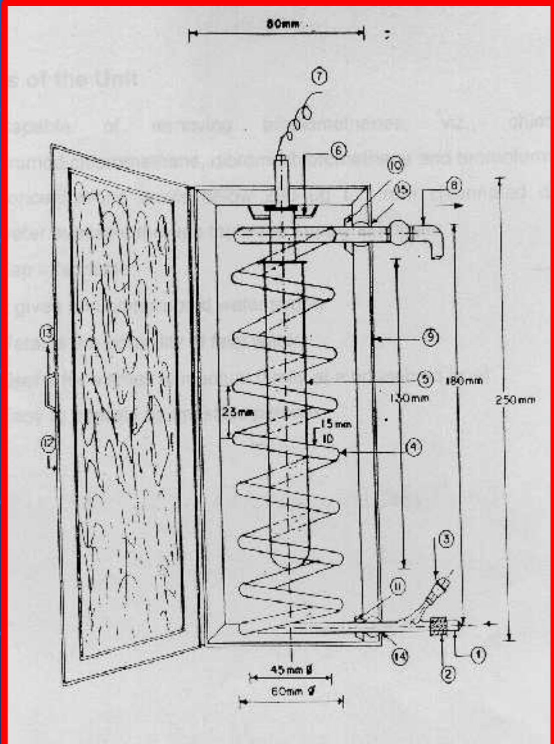
Trihalomethane Removal by Cascade Aerator

- Initial conc.: 112.4-370.6 µg/L
- Flowrate: 12.5L/min
- Average percentage removal : 56 – 67% .

Test Water sample interval (min)		Chloroform (µg/L)		Dichlorobromo-methane (µg/L)		Chlorodibromo-methane (µg/L)		Bromoform (µg/L)	
		370.62		112.46		210.40		215.47	
		Residual concentration	% removal	Residual concentration	% removal	Residual concentration	% removal	Residual concentration	% removal
1		150.03	59.52	43.20	61.60	99.66	52.63	76.31	64.58
2		141.21	61.90	42.37	62.38	95.22	54.74	74.94	65.22
3		132.38	64.28	38.71	65.38	84.16	60.00	65.57	69.57
Average			**61.90**		**63.16**		**55.79**		**66.46**

Ref: Thacker et.al., Int. Jour. of Pest., People & Nature, 2000

Water Filter for Removal of Trihalomethanes



Details of the Unit

- Capable of removing trihalomethanes, viz., chloroform,bromodichloromethane, bromochloromethane and bromoform at the concentrations levels below 200 µg L^{-1} from chlorinated drinking water available through tap water supply in houses
- Tap attachable
- It gives an uninterrupted water supply
- Retains the potability of final water
- Useful for a small to medium family at a household level
- Easy to operate by unskilled persons

(1) Inlet for raw water
(2) Rubber tube
(3) Stopper with valve
(4) Spiral coil
(5) UV lamp
(6) Clamp to hold UV lamp
To power supply
(8) Outlet for treated water
(9) Wooden chamber
(10) Clamp to hold spiral coil upper part
(11) Clamp to hold spiral coil lower part
(12) Shutter for wooden chamber
(13) Handle attached to wooden chamber for the shutter
(14) Provision opening in the wooden chamber for the inlet
(15) Provision opening in the wooden chamber for the outlet

Ref: Thacker et.al, Ind.Journ. of Environ. Hlth., 1998

Conclusion

I. Poly aluminum chloride (PAC) as a coagulant

- In water treatment using conventional coagulation method, alum can be replaced by PAC
  - 90% reduction in sludge formation
  - Minimization of TDS
  - Al carry over in effluent reduce
  - Do not contribute to THMs formation

II. Chlorine as a disinfectant

- A optimum chlorine dose for disinfection must be advocated to achieve a balance between both microbiological quality and formation of trihalomethanes in drinking water. However, the microbiological quality must always take precedence.

Action needs to be taken

- Formulation of national health- based standards for Trihalomethane levels in drinking water
- The WHO and EPA standards could easily be used as a starting point
- Approach to Trihalomethane formation in chlorinated water safety standard should be based on Indian environmental regulation
- Standards should be set at the level of detection
- The norms should be based on scientific studies and should be achievable
- Formulated standards should be made legally enforceable


THANK YOU