Safe Water at the Point-of-Use: Continuous UVC-LED Disinfection to Overcome Prevalence and Recontamination of Bacterial Indicators

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CWAS CENTER FOR WATER AND SANITATION
CRDF CEPT UNIVERSITY
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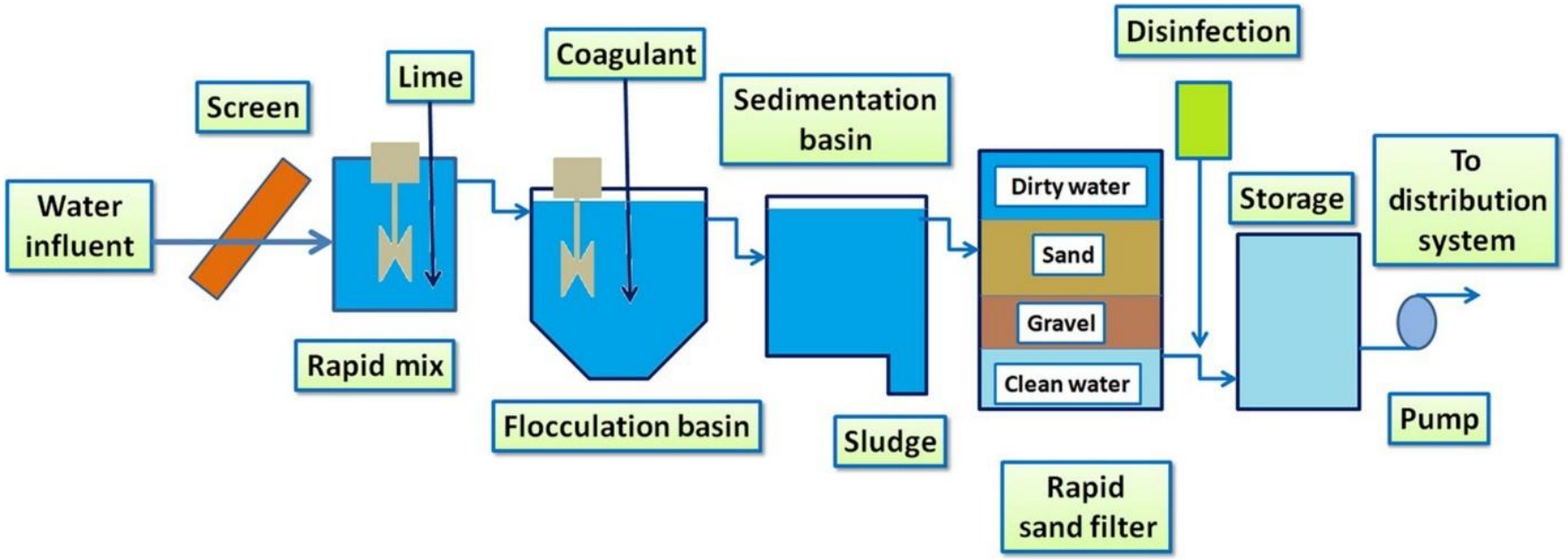
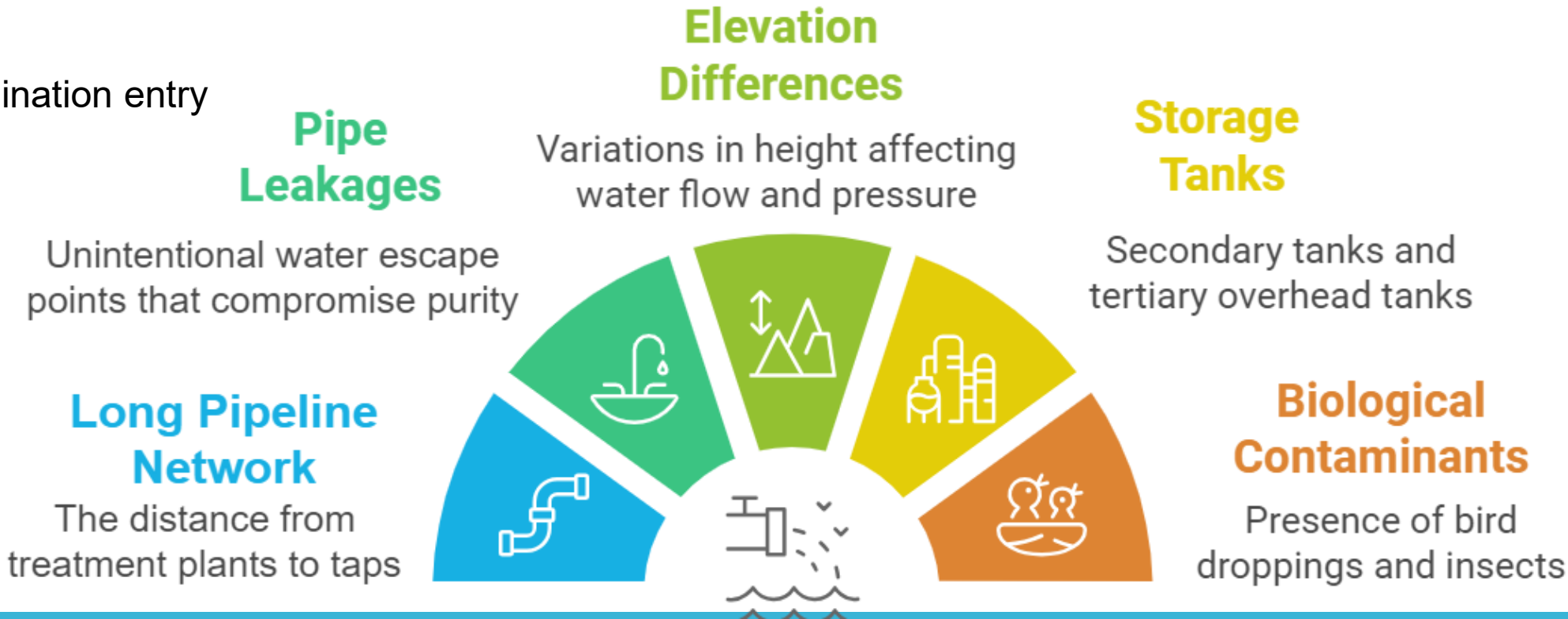


Figure: Typical Drinking Water Treatment Plant

Figure: Recontamination entry points



Total Heterotrophic Bacteria

USEPA: 500 CFU/mL

Membrane Filtration Technique
Nutrient agar

Total Coliform Bacteria

WHO, BIS, CPCB: 0 CFU/100 mL

Membrane Filtration Technique
Rapid Coliform agar

Bacterial Water Quality Testing

E. coli

WHO, BIS, CPCB: 0 CFU/100 mL

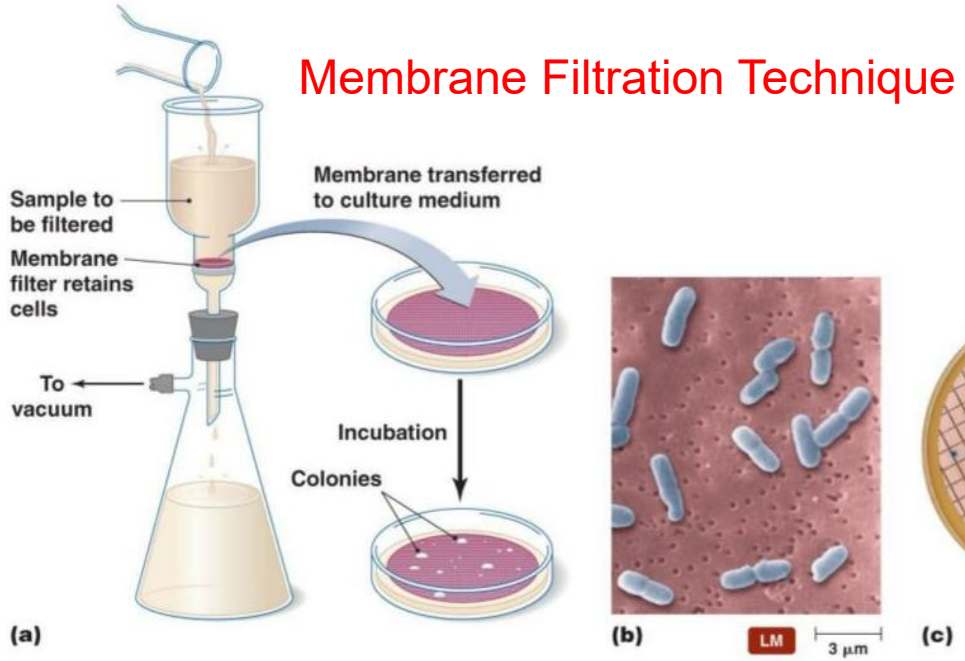
Spread Plate Technique
Nutrient agar

Fecal Coliform Bacteria

WHO, BIS, CPCB: 0 CFU/100 mL

Membrane Filtration Technique
mFC media agar

Membrane Filtration Technique



Spread Plate Technique

1. Sample (0.1 mL) poured onto solid medium
2. Spread sample evenly over the surface
3. Plate incubated until bacterial colonies grow on the surface of the medium

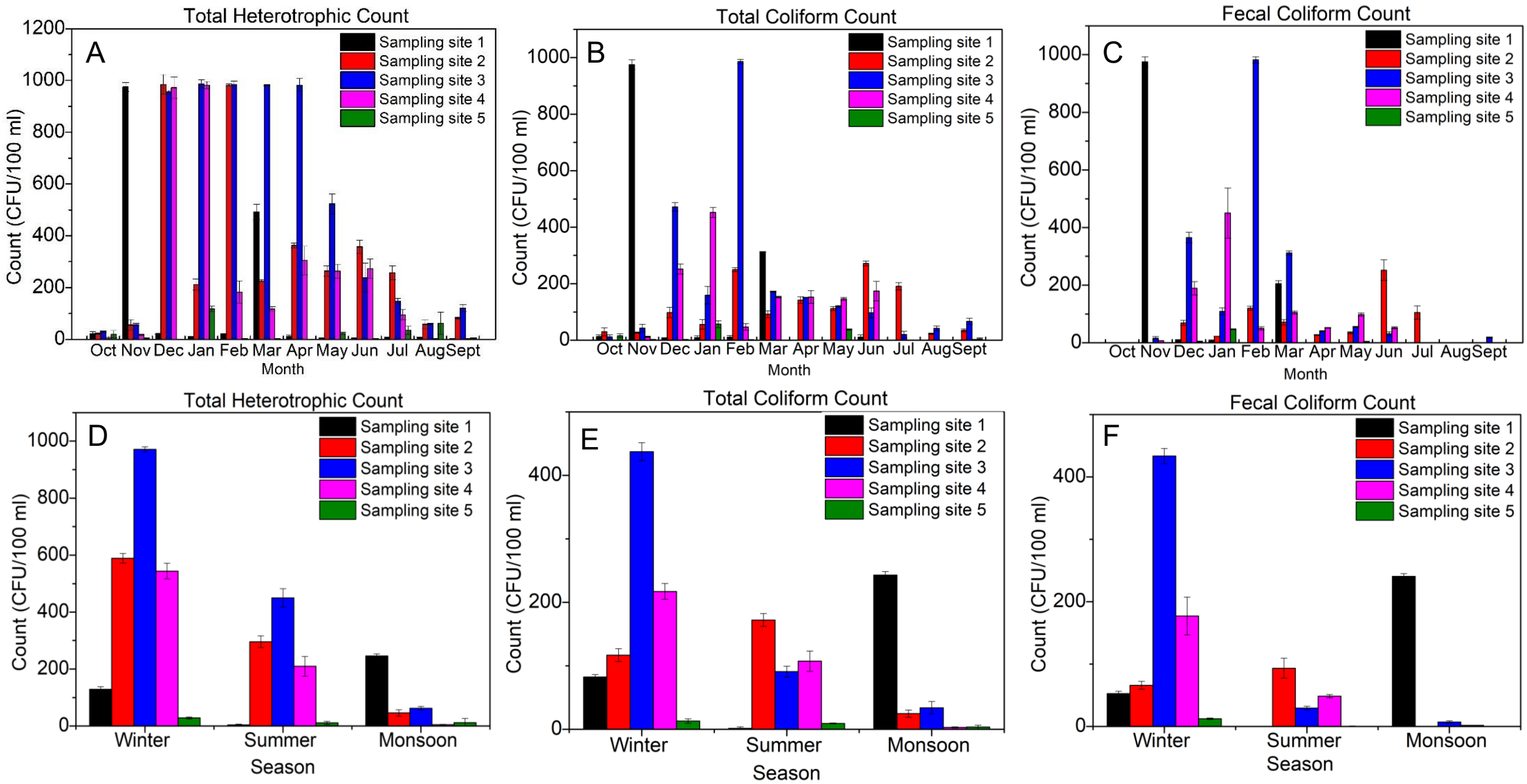


Figure: Enumeration of bacterial count from five sampling sites for a year long duration. The data collected biweekly and averaged for every month (A, B, C). Variation of bacterial count in different seasons (D, E, F).

Table: Physicochemical characterisation of tap water

Parameters	Permissible limit (BIS/USEPA)	GOA
Temperature (°C)	NA	28.5 - 30.3
Dissolved Oxygen (mg/L as O_2)	NA	7.2 -7.58
pH	6.5 - 8.5	7 - 7.6
BOD (mg/L as O_2)	5 mg/L	BDL
Nitrate (mg/L as NO_3^--N)	45	0.14 - 0.98
Nitrite (µg/L as NO_2^--N)	3	BDL
Turbidity (NTU)	1 - 5	1.45-3.02
Total alkalinity (mg/L as $CaCO_3$)	200	15.5 -24.5
Chloride (mg/L as Cl^-)	250	4.62 - 5.46
Free Chlorine (mg/L as Cl_2)	0.2	0 - 0.01
COD (mg/L as O_2)	10 mg/L	4 - 5.5
Ammonia (mg/L as NH_3-N)	1.5	0.04 - 0.175
Hardness (mg/L as $CaCO_3$)	200	17 - 36.5
Calcium (mg/L as Ca^{2+})	75	3.2 - 9.4
Magnesium (mg/L as Mg^{2+})	30	3.5 - 4.9
Sulfate (mg/L as SO_4^{2-})	200	2.47 - 3
Total Dissolved Solids (mg/L)	500	25.5 - 59.25

Point of Use (POU) water treatment

- Chlorination Tablets
- Boiling
- UV based purifier
- Membrane filtration
- Gravity Filter

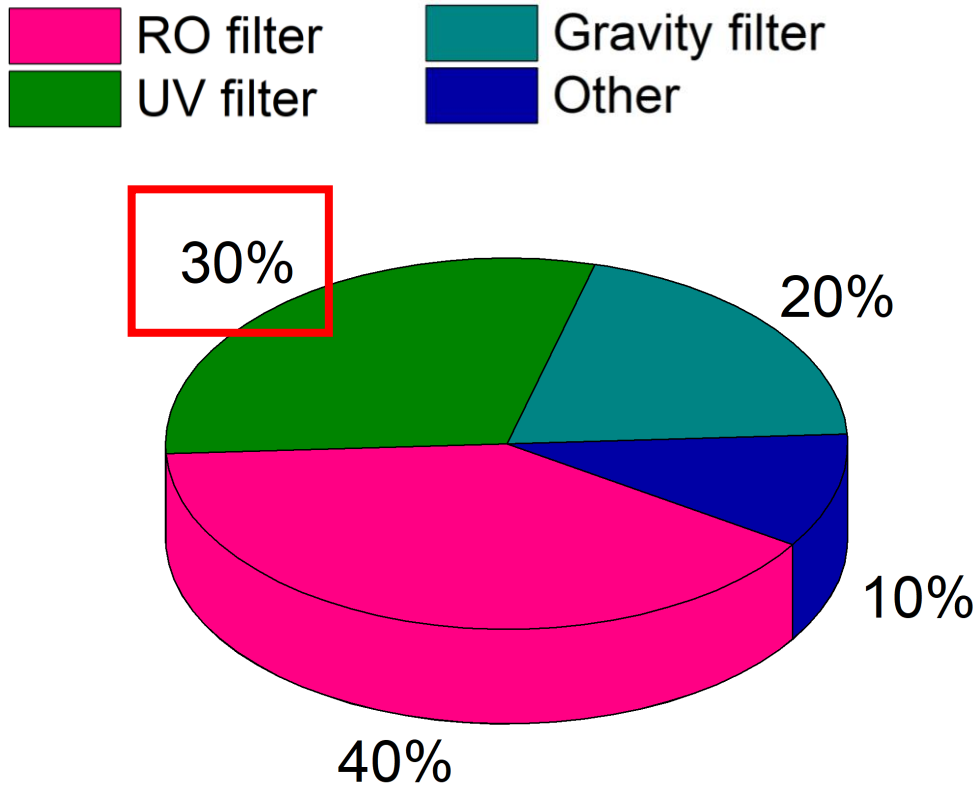
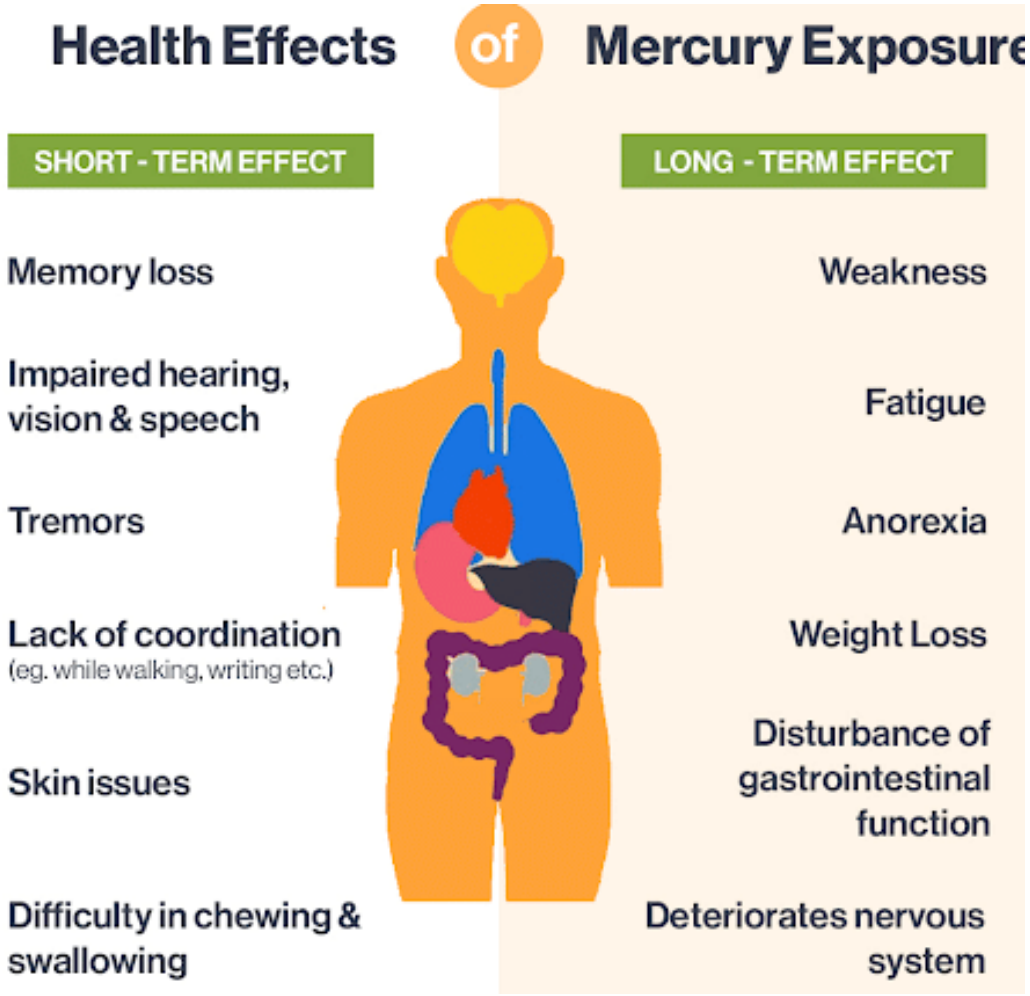
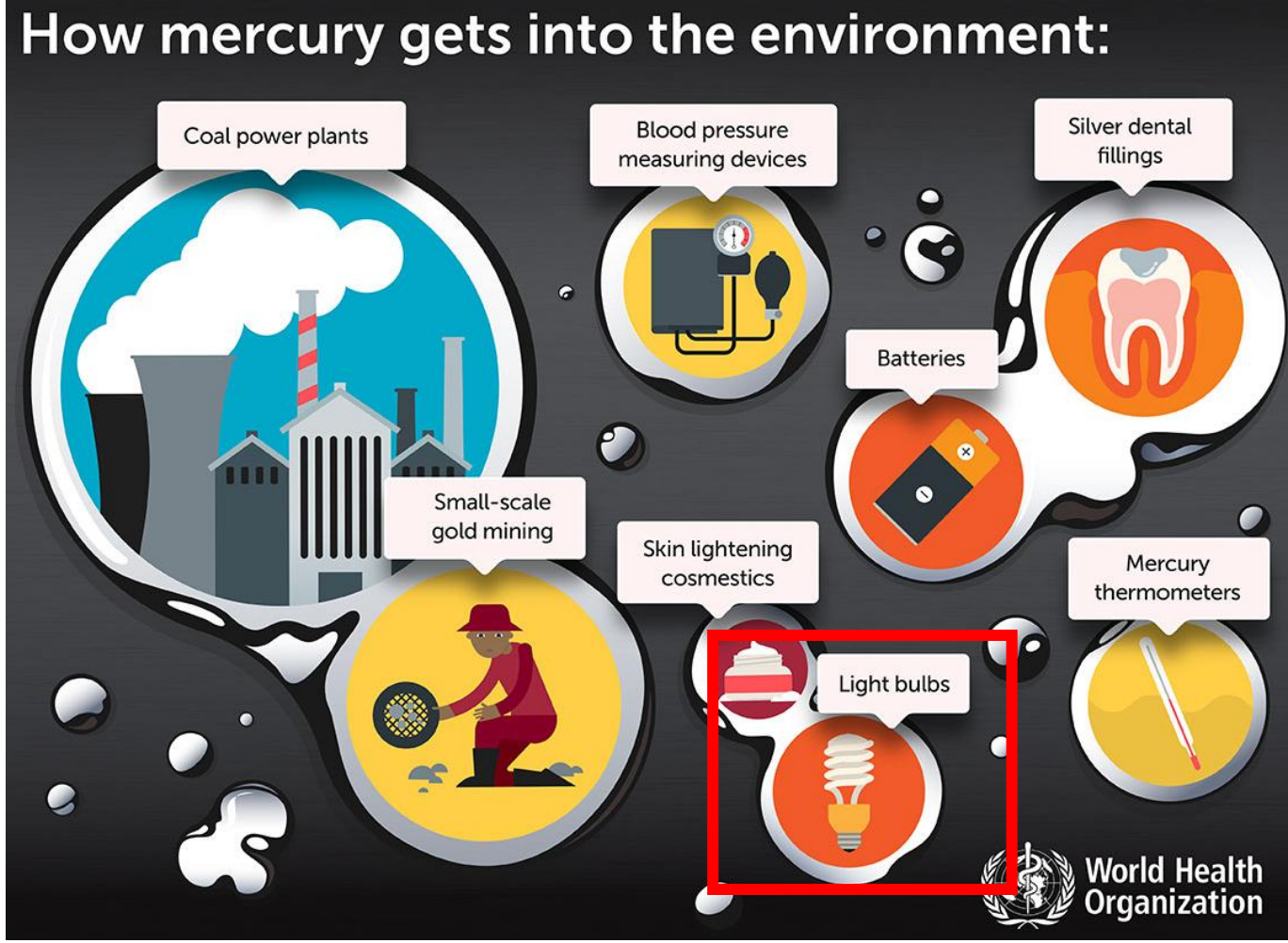


Figure: UV mercury lamp (254 nm)

150-200 mg Hg/lamp





Minamata Convention

- Phase ban of mercury based product
- International agreement , 128 countries

UVC LED device as alternative to mercury lamp

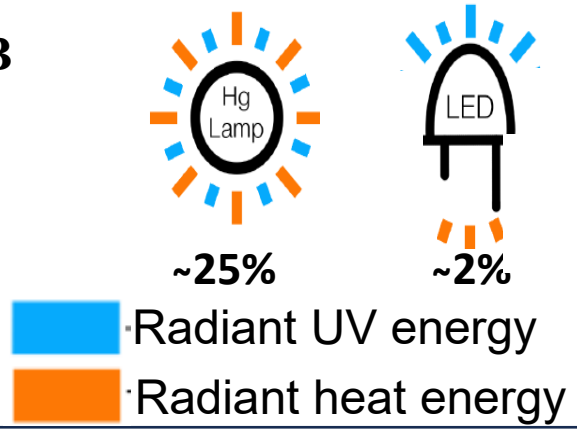
A

Mercury lamp

UVC LED

Mercury lamp issues	UVC LED benefits
Toxic mercury (200 mg)	Environment friendly
Low lamp life (5k h)	High lamp life (10-20k h)
High maintenance	Low maintenance
Warm up time needed	Instant on and off
Phase ban (Minamata Convention)	RoHS (Restriction of Hazardous Substance)

B



UVC LED Challenges	Our Solution
Heat generation	No abrupt heating issue (3 patent published; 1 accepted)
Low wall plug (WP) efficiency	Efficient reactor design to maximize light utilization

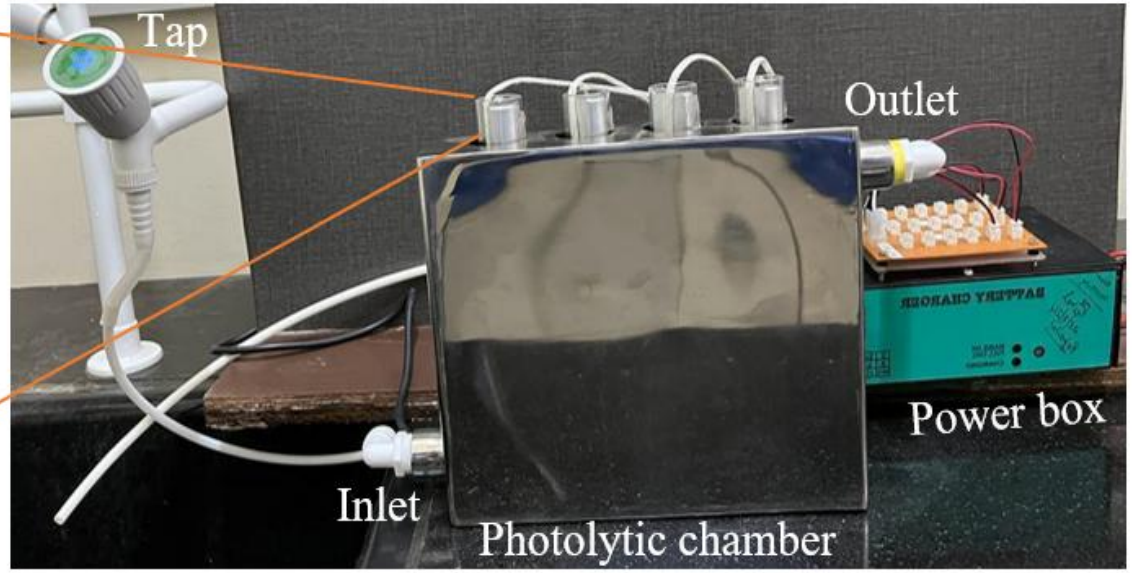
Figure: (A) Mercury lamp, and UVC LED device for water treatment. (B) Wall plug efficiency of mercury lamp vs UVC LED.

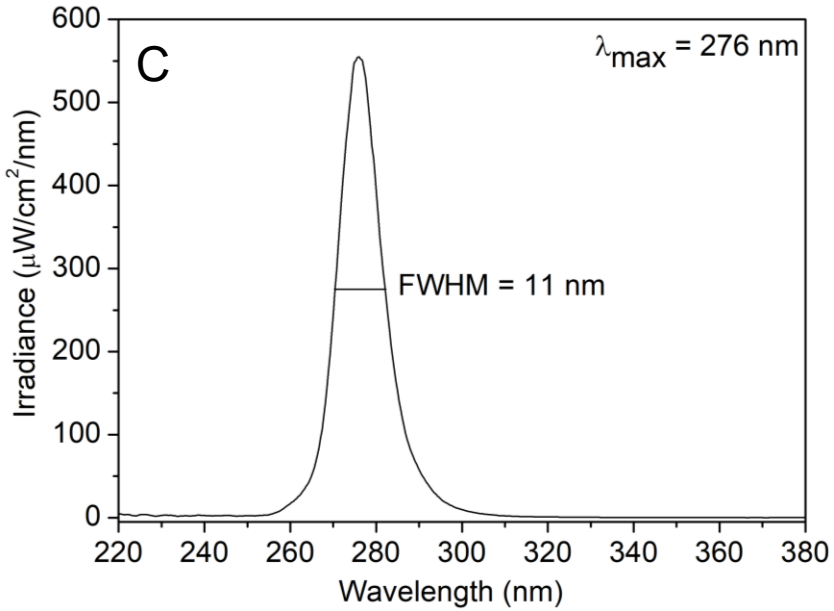
Photovoltaic panel

A

UVC LED device

B





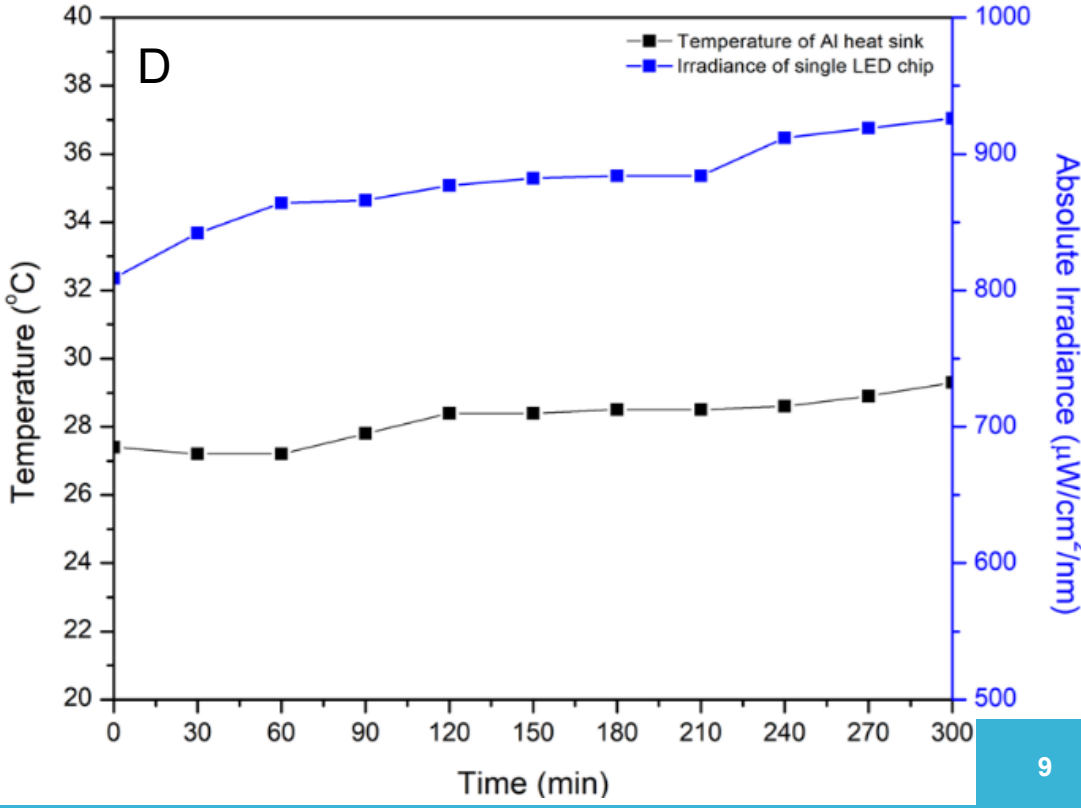


Figure: (A) UVC-LED device; (B) Stainless steel (SS 316) photolytic chamber with UVC-LED devices connected to tap; (C) Spectral emission of UVC LED chip measured by spectroradiometer; (D) Effect of continuous operating time on temperature and irradiance

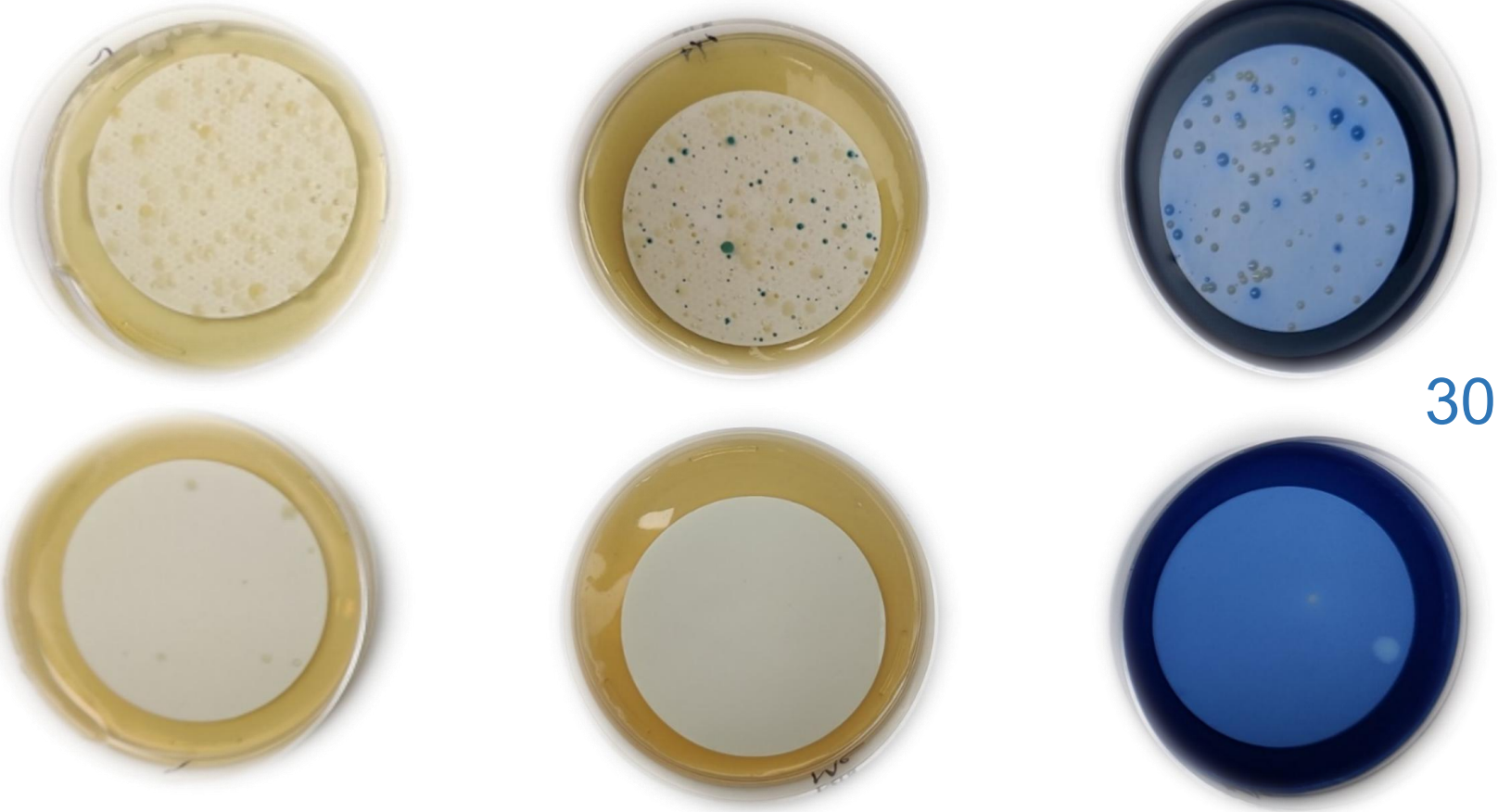
Month	Initial load (CFU/100 mL)			Flow rate for total inactivation (LPH)
	THC	TC	FC	
Jan	982 962	452 427	450 327	30
Feb	182 120	47 30	50 42	30
Mar	307 365	153 149	105 98	30
Apr	305 227	153 121	52 50	30
May	263 225	146 138	98 90	37
Jun	273 221	174 125	52 47	37

Month	Initial load (CFU/100 mL)			Flow rate for total inactivation (LPH)
	THC	TC	FC	
Jul	95 67	1 0	0 0	49
Aug	2 1	0 0	0 0	49
Sep	2 1	2 0	0 0	49
Oct	0 0	1 1	0 0	49
Nov	18 14	12 9	7 7	49
Dec	972 912	252 227	189 156	30

Heterotrophic Bacteria

Total Coliform Bacteria

Fecal Coliform Bacteria



Untreated

30 LPH; UV Dose = 10 mJ/cm^2

Treated

Nutrient Agar

Rapid Coliform Agar

m FC Agar

Figure:
UVC LED
Wall mount

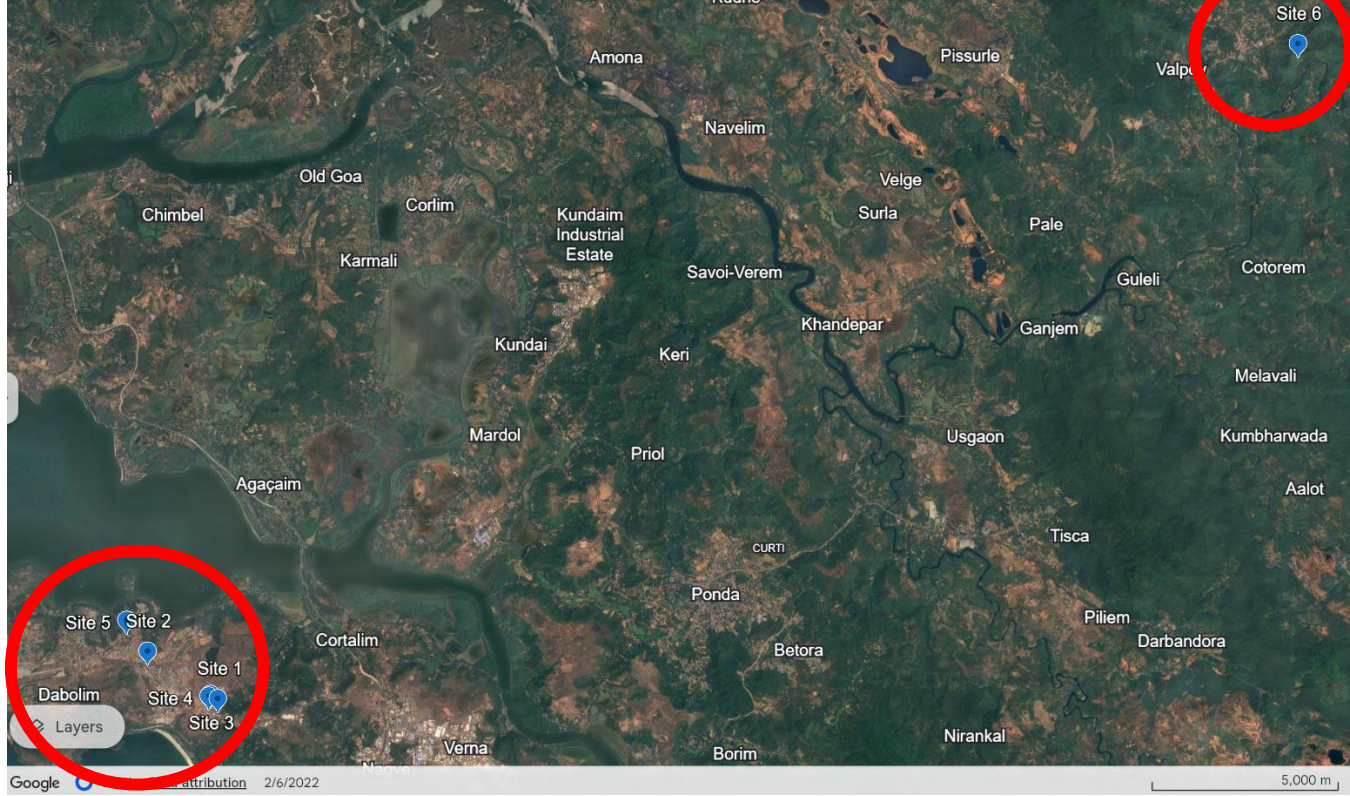
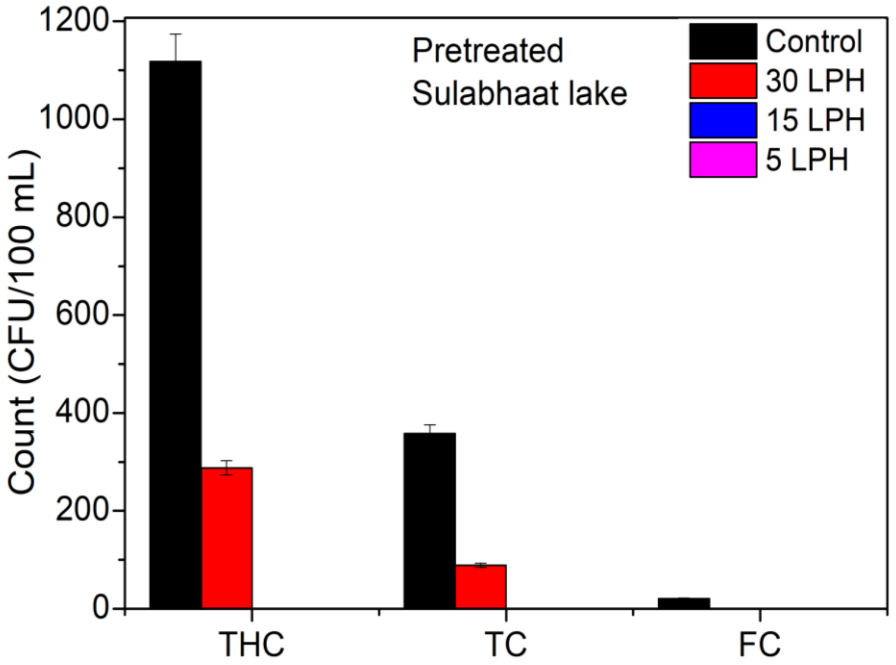
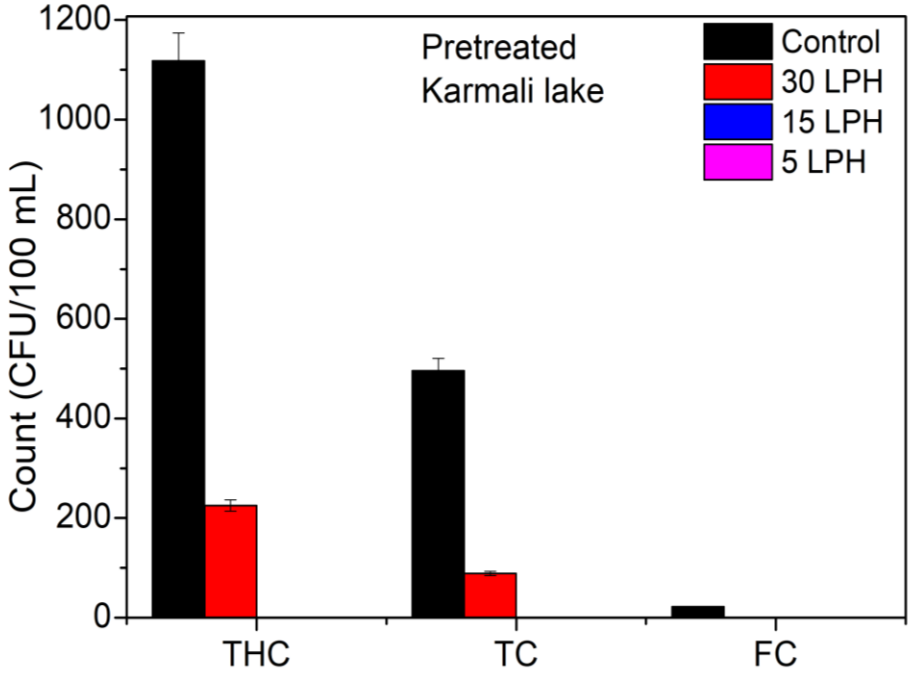


Figure: Map showing 6 sites where FAU was installed for tap water treatment in Goa.

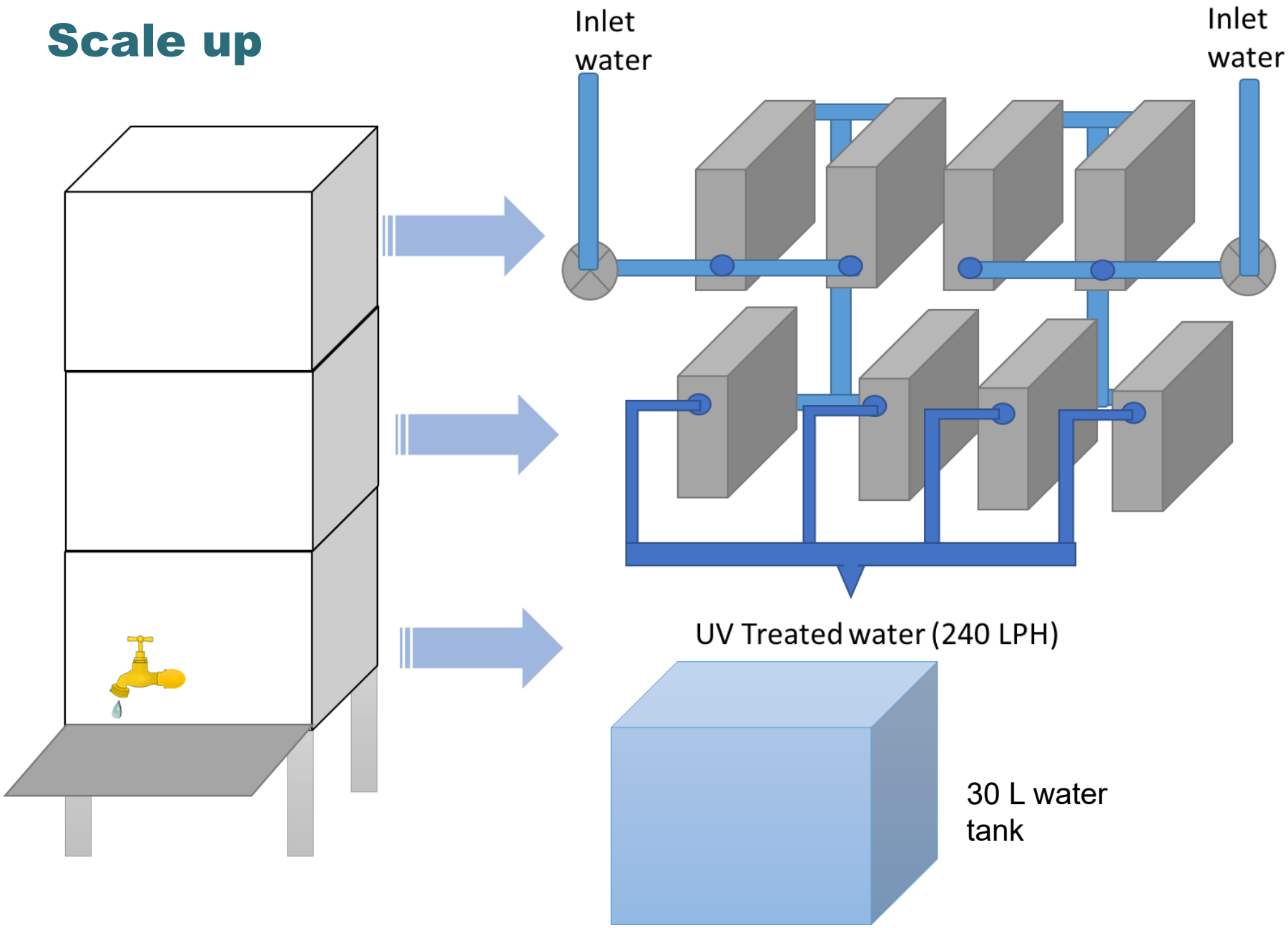
Surface Water

Figure: Lake water and alum treated lake water





Scale up


Inlet water
Inlet water
UV Treated water (240 LPH)
30 L water tank

Cost and Energy Economics

UV LED wall mount (30 LPH)	Cost (INR)	Quantity	Total (INR)
UVC LED array with quartz (per piece)	1563	4	6252
Stainless steel reactor SS 316	3500	1	3500
Electrical connections, piping, connectors	2000	1	2000
Prefilters and cage	1500	1	1500
Total Price			**~13252**

$$\text{Electrical Energy } (EE_3) = \frac{P}{F \times \text{Log} \frac{N_t}{N_o}}$$

The electrical energy is determined to be 1.397 kWh/m^3

Operational Cost = EE_3 (kWh /m^3) × Electricity cost per kWh

The electricity cost for treating 1 m^3 of bacterially contaminated real drinking water with initial load of 10^3 CFU/100 mL was estimated to **₹ 9.03** (€ 0.09 or $ 0.10)

Acknowledgments

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- CWAS CDRF CEPT University

Thank You

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