Silver Ionization vs In Chlorination: Cost Comparison

Prepared by:

Jal Jeevan Mission Team, IIM Bangalore

1. Introduction:

The JJM aims to provide every rural household with FHTC delivering water daily in adequate quantity (minimum 55 lpcd) of prescribed quality (BIS:10500). The operational guidelines for the Jal Jeevan mission include 13 basic water quality parameters as mentioned in Table 1. Currently, chlorination is performed to remove pathogenic contaminants in drinking water, and the process of adding chlorine is detailed in the handbook of the Central Public Health and Environmental Engineering Organization (CPHEEO). The free chlorine residue in drinking water is a direct indicator to ensure that adequate chlorination has been performed and that the water is free of pathogens.

Characteristic	Unit	Requirement (Acceptable limit)	Permissible limit in the absence of alternate source
pH		6.5- 8.5	No Relaxation
TDS	Milligram/ litre	500	2000
Turbidity	NTU	1	5
Chloride (As Cl)	Milligram/ litre	250	1000
Total Alkalinity as Calcium Carbonate	Milligram/ litre	200	600
Total Hardness (as CaCO3)	Milligram/ litre	200	600
Sulphate (as SO4)	Milligram/ litre	200	400
Iron (as Fe) *	Milligram/ litre	1.0	No Relaxation
Total Arsenic (as As)*	Milligram/ litre	0.01	No Relaxation
Fluoride (as F) *	Milligram/ litre	1.0	1.5
Nitrate (as NO3)	Milligram/ litre	45	No Relaxation
Total coliform bacteria	Shall not be detectable in any 100 ml of sample		
E.coli/ Thermotolerant coliform bacteria	Shall not be detectable in any 100 ml of sample		
Free residual Chlorine	Milligram/ litre	0.2	1
Colour	Hazen units	5	15
Odour		Agreeable	Agreeable

**region specific contaminants*
Table 1: Basic water quality parameters

Bacteriological (pathogens, bacteria, etc.) contamination of drinking water leads to diseases like cholera, dysentery, diarrhoea, typhoid, etc., which have an immediate impact on human body in terms of morbidity and sometimes lead to even mortality. WHO has listed the commonly occurring water-borne pathogens as Bacteria, Viruses, Protozoa and Helminths (Appendix). Under the IS

10500 standards, the bacteriological requirement for drinking water is indicated by the absence of coliform organisms. It also describes about the biological requirements of drinking water inter alia microscopic organisms. The presence of coliform bacteria, specifically E. coli (a type of coliform bacteria), in drinking water suggests that the water may contain pathogens that can cause diarrhoea, vomiting, cramps, nausea, headaches, fever, fatigue, and even death sometimes. Infants, children, elderly people, and people with weakened immune systems are more likely to be affected by pathogens in drinking water. Some of the pathogens that are known to be transmitted through contaminated drinking-water lead to severe and sometimes life-threatening diseases. Examples include typhoid, cholera, infectious hepatitis (caused by hepatitis A virus [HAV] or HEV) and disease caused by Shigella spp. and E. coli O157. Others are typically associated with less severe outcomes, such as self-liming diarrhoeal disease (e.g., Norovirus, Cryptosporidium).

Generally, surface water contains higher concentrations of pathogenic contaminants as compared to groundwater. Appendix 1 shows the types of pathogens that may be present in drinking water, including bacteria, viruses and protozoa (2011). Fig 1 provides a flow-chart which would be useful for decision making for disinfection when coliforms are detected more than the thresholds.

Several physical and chemical methods are available for disinfecting drinking water at the point-of-use (referred as end-user). Physical methods of water purification include boiling, filtering (e.g. through cloth), and UV disinfection with lamps. Chemical treatment methods include coagulation-flocculation and precipitation, adsorption (removal of minerals or other particles from a liquid by attaching to another solid), ion exchange (a process in which the ions are exchanged between two solutions) and disinfection with chlorine(2013)

The primary objective of this report is to carry out cost comparison of in-chlorination systems with silver ionization disinfection systems for drinking water and the possible impact of this choice on water charges at a household level.

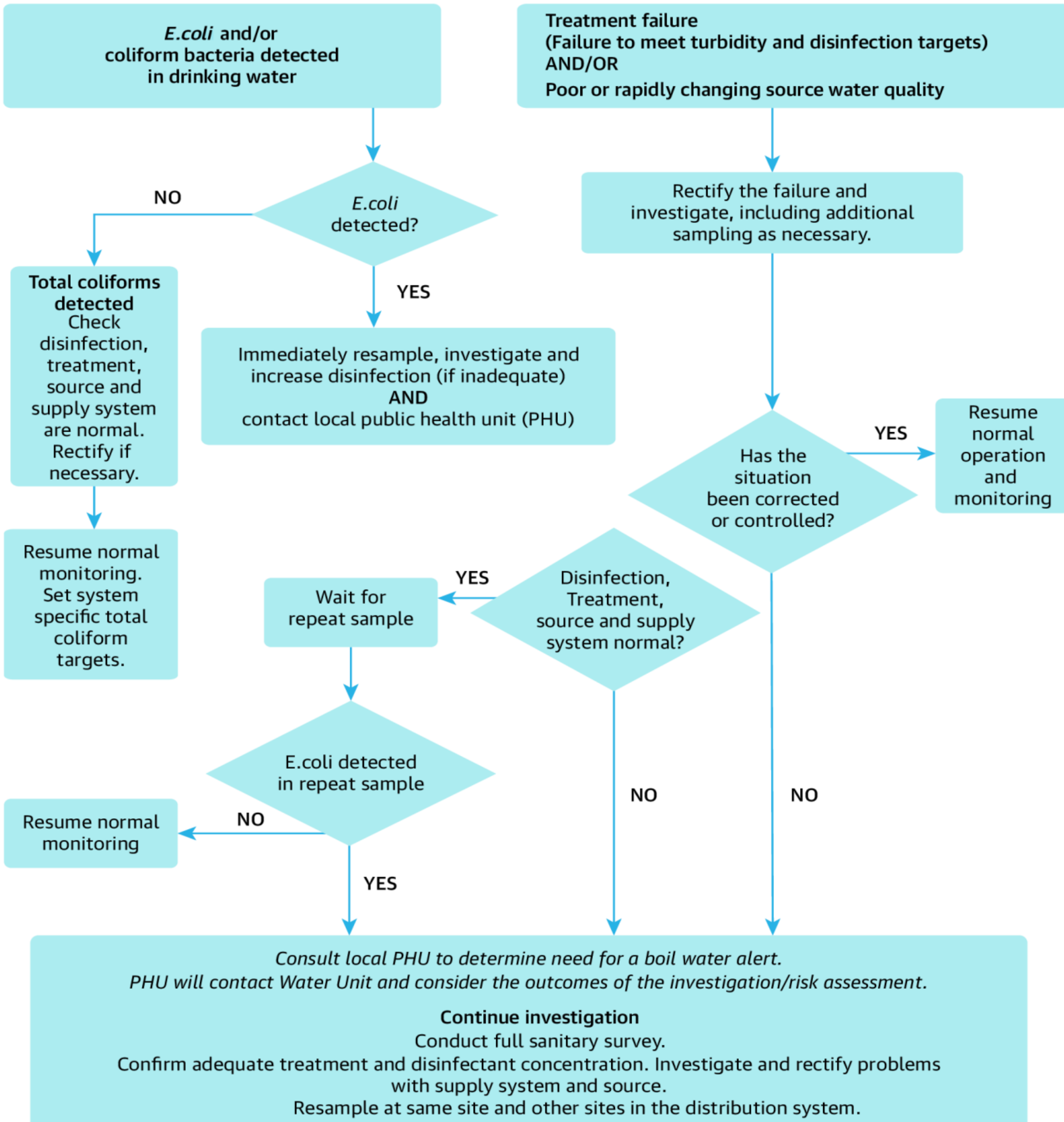


Fig 1. Decision-Making Flow Chart: When Coliforms Detected in Exceedance of Standards (World Bank, 2020)

2. Methods of Water Disinfection

The aim of water disinfection is to remove pathogenic microbes and improve taste and odour of drinking water (Shailendra Yadav, 2020). While there are multiple methods available for disinfection of pathogenic contaminants, we will be limiting our assessment to in-chlorination (both electro-chlorination and hypochlorite dozer pump) and Silver ionization disinfection.

2.1. **Disinfection by Chlorination-**

The most common method for disinfecting drinking water is chlorination. Chlorine is used to deactivate most microorganisms (excluding protozoa, which are resistant), and the process is relatively inexpensive. This process includes adding chlorine or chlorine by-products (sodium hypochlorite or calcium hypochlorite) to water, where the chemicals react and form a negatively charged molecule known as hypochlorous acid (HClO), which kills disease-causing microorganisms such as bacteria, viruses and parasites. Hypochlorous acid, a stronger disinfectant than hypochlorite ion, requires a lower pH for maximum efficacy. Chlorination kills both bacteria and viruses by attacking the protein coat of their cells, but it also produces several potentially toxic by-products (Pichel et al., 2019). As protozoa are resistant to chlorine, it is advised to treat the water with filtration or disinfection by ultraviolet (UV) light.

The influencing factors to be considered in chlorination process are the following:

- Chlorine concentration
- Contact time
- pH
- Temperature and
- Interfering substances

For effective chlorination of drinking-water, the following ideal conditions are recommended (WHO, Principles and Practices of Drinking Water Chlorination, 2017) :

Parameter	**Specifications**
Turbidity	**<1 NTU (preferably lower where achievable)** Where not achievable, <5 NTU should be the aim; above 5 NTU, chlorination should still be practised, but higher chlorine doses or contact times will be required to inactivate harmful microorganisms
pH	**<pH 8.0** Above pH 8.0, chlorination should still be practised but higher chlorine doses or contact times will be required to inactivate harmful microorganisms
Minimum contact time	**At least 30 minutes contact time**, where the residual chlorine concentration is ≥0.5 mg/L and the pH of the water is <pH 8

- Once chlorination at the water treatment plant is complete, the residual chlorine concentration during distribution to the point of consumer delivery should aim to be between 0.2 and 0.5 mg/L.
- To maintain a residual chlorine concentration of 0.2 mg/L at the point of consumer delivery, it will sometimes be necessary to keep levels above 0.5 mg/L in parts of the water distribution system despite aesthetic concerns about taste and odor produced by higher concentrations (above 1–3 mg/L).
- At all times, the concentration of chlorine in drinking-water supplied to consumers should be below the WHO guideline value of 5 mg/L

The types of chlorination discussed here are :

i) In chlorination using dosing pump:

ii) Electro chlorination

2.1.1. Chlorine Dozer pumping method:

Generally, chlorine dozer works on water as a source of energy which activates the pumping of concentrated dose. Hypochlorite or the chlorine powder is added to the container which feeds chemical to the injection pump or dosing pump. Two pipes are connected to the pump one is an inlet and other is an outlet. Treated drinking water is passed through inlet pipe and reaches the injection pump where chlorine is added in regulated manner in respect to the flow of water. The free chlorination of treated water should be 0.2mg to 0.5mg per litre as per the WHO guidelines (Chlorine dosing pumps/Drinking water treatment, n.d.). The schematic illustration of a Chlorine dosing pump is given in Fig 2

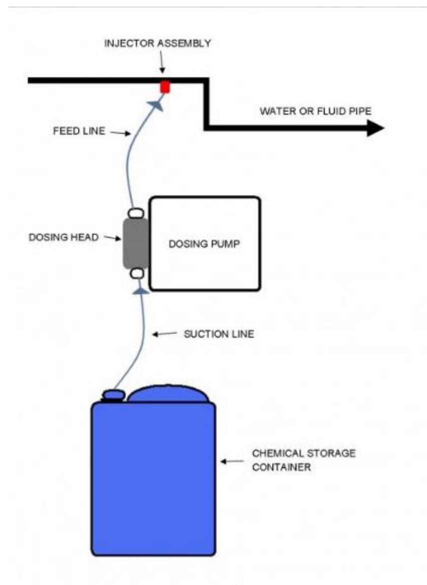


Fig 2: Schematic Diagram of Chlorine Dosing Pump

2.1.2. **Electro chlorination(CPHEEO, 2005)-**

Electro chlorination involves common salt (Equivalent to IS797 Grade II) being dissolved in water to prepare brine solution. This solution is passed across electrodes and low voltage direct current is applied on it to produce a diluted 0.6–0.8% sodium hypochlorite solution.

The direct current passes through the brine flowing in the electrolyser, where the sodium chloride is completely dissociated into the ions Na^+ and Cl^-. The complete process is complex, but the result is well represented by the following formula:

$$NaCl + H_2O + energy----. NaOCl + H_2$$

Thus generated solution contains 0.7% to 1% chlorine as <1% hypochlorite is classified as a non-hazardous chemical. The only by product, hydrogen is safely vented into the atmosphere. Electro chlorinator is a safer, more economical, and easier way to disinfect water than using chlorine gas, commercial bleach or other chemical treatments.

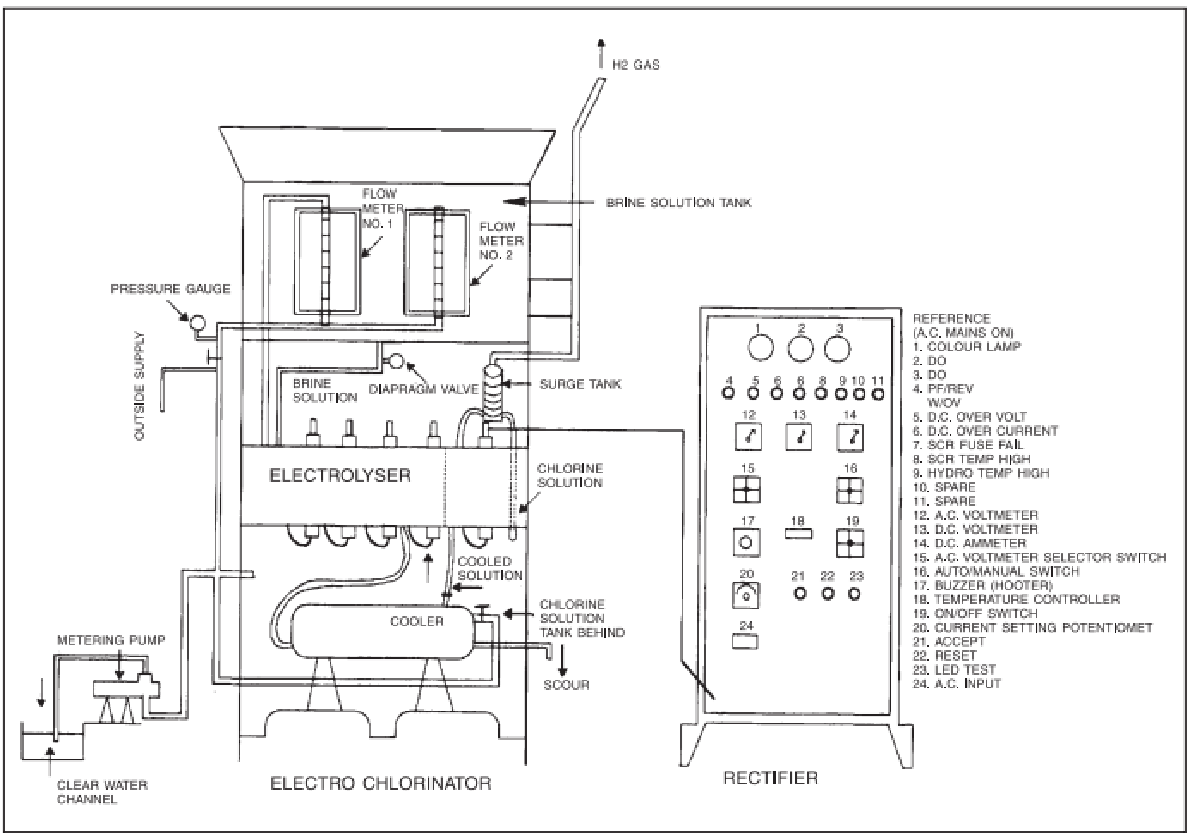


Fig- 3 typical Electro-chlorinator (CPHEEO, 2005)

2.1.3. **Disinfection by Silver ionisation** (Ministry of Drinking Water and Sanitation, April, 2015)

In silver ionization system the disinfections of water with silver ions start simultaneously with pumping of water. While in chlorination, powdered solution has to be prepared beforehand, in silver ionisation regulation is automatic. Chlorination regulation depends on strength of bleaching powder and is totally manual. Conventional chlorination kills bacteria whereas silver ionization effectively destroys viruses, bacteria, spores and fungi.

The role of water chemistry is likely to be important in determining the efficacy of silver as a disinfectant in real-world conditions. Salinity and Electrical conductivity which indicates presence of anions like chloride, bromide, carbonate and phosphate, have shown to reduce the antibacterial capacity of silver ions (WHO,2018)

The other advantages of silver ionization are as under:

- Bacterial disinfection efficiency will be 100% even at high level of E-coli (4000 to 5000/ml)
- Silver ions remain in water even after 51 hours after ionization without any significant loss.
- No change in physio-chemical characteristics in treated water
- Silver ionization is safe, consumer friendly and reliable method over conventional disinfections using chlorine/ bleaching powder.
- Maintenance involves cleaning of electrodes daily and replacement of electrodes after the design life.
- Silver ionization ensures disinfection of drinking water without the problem of smell with chlorine/ bleaching powder.

Argentum Oligodynamic Online Drinking Water Disinfection Technology (SENCO Make) is based on Silver Ionization infusing small quantity of silver ions (Ag^+) within the permissible limit of BIS 10500 standards, into drinking water for its disinfection. Water from source passes through a stainless steel (SS 304) grade water chamber which houses the silver electrodes. The quantity of silver ions dosed is regulated by a micro-controller-based control panel. The positively charged silver ions will attract and kill all Coliform and E.coli bacteria present in water. Silver is effective because of its ability to interfere with DNA production and accelerating the death phase of bacteria.

Because of the charge in the dispensed ions, they repel each other and are always in suspension. As their size is small, they have a large surface area per unit volume. The large surface area to volume ratio enhances the surface chemistry of silver.

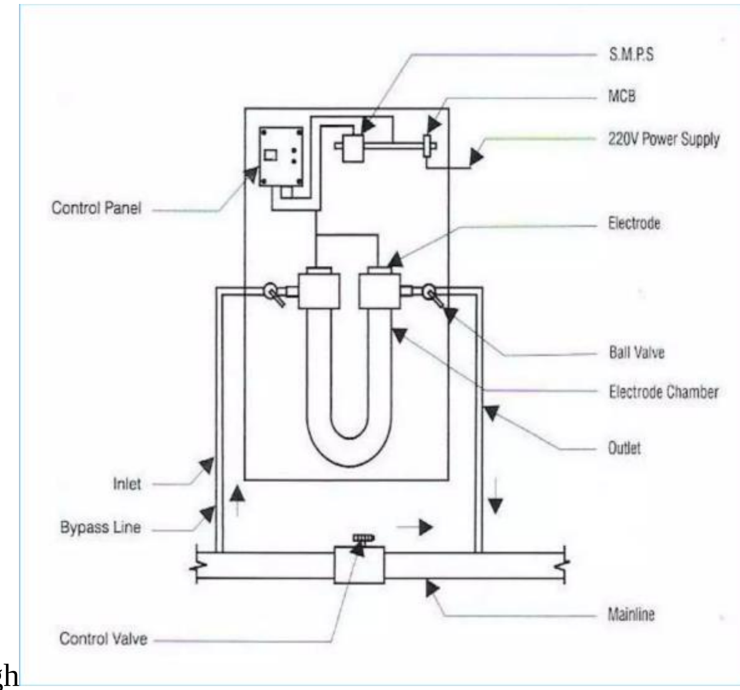
siegh 

Fig 4. Schematic Diagram (Source- ('Silver Ionization Water Disinfection Equipment in India | Copper Silver Ionization System Manufacturers'.))

Comparison Between Silver Ionisation and Chlorination-

Silver Ionisation	**Chlorination**
Uses silver for disinfection	Uses Bleaching powder, Gas Chlorine, Sodium Hypochlorite Solution
Fully automatic, dosage starts when the pump runs	Manual, Mixing is not uniform
Uniform Dosage	High Concentration for nearby habitations very low concentration for faraway habitations
Low Running Cost	Running Cost could be higher
Odourless & No change in taste	Smells and tastes like chlorine
Does not form Carcinogenic byproducts	Forms Carcinogenic byproducts
Non-Corrosive	Corrosion occurs ln pipelines, pumps, starters etc.

The electrode has to be changed only once in 3 to 4 months. Hence, one electrode can be kept as inventory for one plant	Inventory has to be stocked for several months. During storage, it will lose its strength considerably

3. Cost Comparison:

We have attempted to compare the costs of the three disinfection approaches adopted for rural water drinking supply. All information regarding the equipment for the illustration, including capital costs, power consumption and annual maintenance costs, have been obtained from officials working at SENCO. We have been able to obtain quotes for 4 standard makes of electro chlorination equipment from the vendor. The capacities considered here are the capacity of silver ionisation available in the market. The cost of equipment and operations could vary basis the actual tender offer and equipment selected for the process.

The cost of per unit water being disinfected is a function of:

1. Chlorine Dosage: The dosage of chlorine required for disinfection is dependent on the contamination levels of feed water which affects the cost of disinfection
2. Capacity utilisation: The cost of power of operating a silver ionisation or electro chlorination machine will be constant per batch irrespective of the amount of water being disinfected. Higher capacity utilisation will translate to lower per litre cost
3. Material and maintenance costs: including cost of disinfection materials like chlorine, common salt, and the cost of replacement of electrodes in electro chlorination and silver ionisation equipment

The unit cost of disinfection also varies according to the capacity utilisation of the equipment since running one batch means all the associated variable costs will be incurred. For example, the equipment for electro chlorination is the same at 3.9 lakh litres/day and 4.68 lakh litres/day. The impact of operating at 78,000 litres lower per day with the same equipment is 40 paise per 10k litres of disinfection. However, the impact of this is at a household level, with a standard consumption 8,250 litres per month, is small, that is, 33 paise per month

While computing the cost for the project life, inflation rate of raw material cost in the next 10 years is assumed to be the same as that as that between 2010-2020. The inflation in electricity expenses is at 2% and the inflation rate for silver is 3.79%. However, the prices of chlorine in the commodity market have remained relatively stable between 2010-2022, barring for the COVID-19 related spike in price.

The standard dosage of chlorine considered, for both hypochlorite dozer and electro chlorination, in calculations in 2 ppm (mg/litre). The operational cost of hypochlorite dozer is highly dependent on the dosage as well as the cost of chlorine being delivered. The below figure shows the operational cost of disinfection as the dosage and capacities are varied

		Dosage of cl in ppm mg/lit				
		1	**2**	**3**	**4**	**5**
Capacity	**97500**	11.94	15.44	18.94	22.44	25.94
	162500	8.56	12.06	15.56	19.06	22.56
	195000	7.72	11.22	14.72	18.22	21.72
	390000	5.61	9.11	12.61	16.11	19.61
	468000	5.26	8.76	12.26	15.76	19.26
	585000	4.91	8.41	11.91	15.41	18.91
Operating Cost of Chlorination (Rs per 10k litre)						

Total project cost and the operational cost of disinfection have been looked at separately. Since operational cost of disinfection will directly affect the water charges levied on the village, our approach has been to highlight the method of disinfection which requires minimum operational expenses.

Capacity per day	Opex Cost/ 10k Litre		
	Hypochlorite Doser	**Electro Chlorination**	**Silver Ionisation**
97500	11.11	2.98	5.42
162500	8.70	2.90	5.31
195000	8.09	2.42	5.29
390000	6.58	1.74	5.23
468000	6.33	1.45	5.22
585000	6.08	1.91	5.21

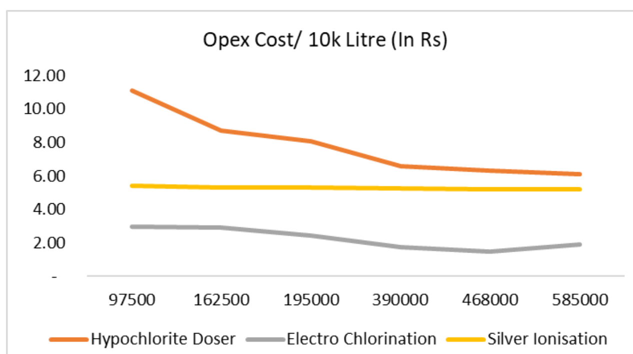


Fig 6: Opex cost/ 10k litre of all different methods of disinfection

As the capacity per day increases, the cost of disinfection goes down for all the three methods of disinfection. The operating cost of electro chlorination is the lowest of all the three methods since it consumes lesser electricity, and the electrodes need to be replaced once in 5 years only.

The cost of disinfection per household (family size of 5) is shown in Fig 7. The cost of disinfection per family per month is higher by Rs 2.51 per month for silver ionisation when compared to electro chlorination.

Disinfection Capacity per day	Disinfection Cost/HH per month (in Rs)		
	Hypochlorite Doser	Electro Chlorination	Silver Ionisation
97500	9.17	2.46	4.47
162500	7.17	2.39	4.38
195000	6.68	1.99	4.36
390000	5.43	1.44	4.31
468000	5.22	1.20	4.30
585000	5.02	1.57	4.29
Average	6.45	1.84	4.35

Fig 7: Cost of Disinfection per household

When the total cost/litre of all the 3 methods is compared over a lifetime of 10 years, silver ionisation stands to be the most expensive method. While the net present cost of all the three methods goes down with an increase in capacity, both methods of chlorine disinfection have a lower discounted cost due to high upfront cost involved in procuring the silver ionisation equipment.

Capacity per day	Net Present Cost		
	Hypochlorite Doser	Electro Chlorinatio n	Silver Ionisation
97500	(415,432)	(286,049)	(351,789)
162500	(535,785)	(482,005)	(602,726)
195000	(595,961)	(482,005)	(663,985)
390000	(957,019)	(718,114)	(1,215,536)
468000	(1,101,442)	(718,114)	(1,443,056)
585000	(1,318,077)	(1,027,578)	(1,813,087)

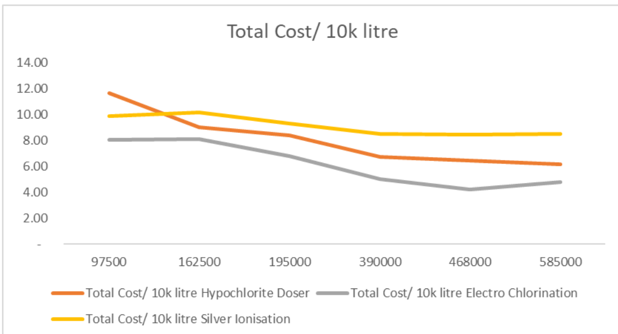


Fig 5: Total cost/litre of the methods of disinfection

We have also attached a calculator along with the note which can be used by RDWSD before shortlisting the technology.

4. Conclusion:

In terms of long-term cost comparison, it is difficult to make a definitive statement as the cost of the two systems will depend on a variety of factors such as the size of the system, the water quality, and the price of the materials. The water chemistry play an important role in selecting the disinfection method. Before judging the cost efficiency of disinfection, each GP will have to conduct a thorough water quality test to shortlist the effective method. While electro- chlorination is a marginally cost-efficient method of disinfection (Rs 2.51 per household per month), one has to see whether this cost advantage overrides the other advantages of silver ionization mentioned earlier. Silver ionisation can eradicate all pathogens and ensure delivery of safe potable water without the problem of smell of chlorine/ bleaching powder. Therefore, it may be beneficial to invest in silver ionisation technology for a more thorough and reliable water disinfection system as long as the water chemistry, especially salinity (<500 mg/l) and Electrical conductivity (< 0.025 S/m) allows for it (Landau, 2007, Wilcox L , 1955).

5. Appendix

Size (µm)	**Pathogen**	**Resistance[1] to Chlorine**	**Relative[2] Infectivity**	**Significance with respect to the protection of human health**
Bacteria				
0.1 - 10	Salmonella spp.	Low	Moderate	Most cause gastro-intestinal illness but certain species may give rise to more serious illnesses. The majority are relatively sensitive to chlorination, and do not persist in the environment for long periods of time. E coli and Campylobacter can arise from animal sources. While most bacteria require high numbers to initiate infection, some bacteria such as E coli O157, Shigella and Salmonella do not require to be present in high numbers.
	Shigella spp	Low	High	
	Yersinia enterocolitica	Low	Low	
	Campylobacter spp.	Low	Moderate	
	Escherichia coli (pathogenic)	Low	Low	
	Verocytotoxigenc E-coli including Ecoli-O157	Low	High	
	Pseudomonas aeruginosa	Moderate	Low	
	Mycobacterium spp	High	Low	
Viruses				
0.05 - 0.1	Rotavirus	Moderate	High	The majority of infections result in gastro-intestinal illness but other complications may occur. Viruses leading to human infection tend to be specifically of human origin. They can persist for long periods of time in the environment and have a moderate resistance to chlorination. High human infectivity requiring low numbers to initiate infection.
	Astrovirus	Moderate	High	
	Norovirus	Moderate	High	
	Parvovirus	Moderate	High	
	Adenovirus	Moderate	High	
Protozoa				

4 - 15	Entamoeba histolytica	High	High	Protozoa are causative agents of gastrointestinal illness. They can arise from both human and animal sources. They can persist for long periods of time in the environment and are resistant to chlorination. Low numbers are required to initiate infection
	Cryptosporidium spp.	High	High	
	Giardia spp	High	High	
Helminths (Parasitic Worms)				
Visible	Drancunculus medinesis	Moderate	High	Guinea worm disease, also known as dracunculiasis, is spread to humans through drinking water infested with copepods (tiny aquatic insects) that carry the guinea worm larvae.
	Schistosoma	Moderate	High	Schistosomiasis is a disease caused by parasitic worms. The most common type of schistosomiasis, intestinal schistosomiasis, can cause abdominal pain and diarrhea along with bleeding in the stool.

[1]At conventional doses and contact times and with a pH between 7 and 8, Low means 99% inactivation at 20°C in generally, 1 minute, Moderate 1-30 minutes and High >30 minutes
[2]From epidemiological evidence, High means infective doses between 1 - 100 organisms, Moderate 100-10,000 and Low >10,000

6. References

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