REVIEW ARTICLE

Alternative Methods for Chemical Disinfection of Potable Water

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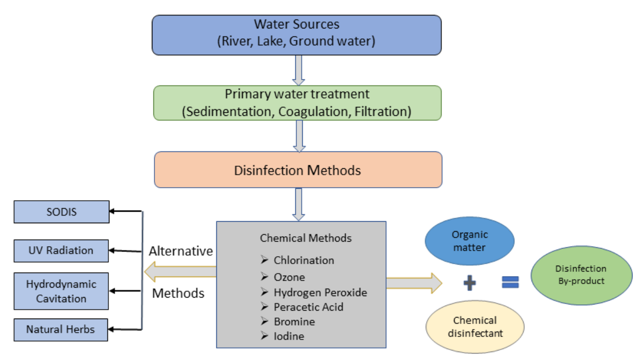
DOI: 10.5185/amp.2020.040416

Microbial contamination in drinking water proves to be a sustainable threat to human health. Several methods are being utilized for disinfecting contaminated drinking water varies from simple boiling method to advanced technologies such as membrane technologies (Micro filtration, Ultra filtration, Reverse osmosis). Various chemical methods practiced are chlorination, ozone, hydrogen peroxide, iodine, bromine, and peracetic acid treatment. Chemical disinfectants lead to formation of toxic by-product which degrade the quality of water. The present review paper discusses alternative methods for chemical disinfection of potable water.

Introduction

Water purification has experienced a great deal of improvement over the last century. Drinking water disinfection has decreased the number of outbreaks of waterborne diseases such as cholera, hepatitis, dysentery, typhoid, etc. Water protection is usually synonymous with the lack of disease-causing microbes or viruses and is accomplished through disinfection [**1**]. Most pathogenic microorganisms are extracted utilizing water treatment methods, such as coagulation, flocculation, sedimentation and filtration, and disinfection is used as a final treatment phase. As shown in scheme 1 the source of drinking water is either river, lake, well water or underground water. There are different disinfectants that either destroy or deactivate pathogenic microorganisms. Examples of disinfectants are chlorine, sodium hypochlorite, calcium hypochlorite, hydrogen peroxide, bromine, iodine, silver-copper, ozone and UV. In general household-based methods used for disinfection of water includes boiling, solar water disinfection (SODIS), alum, lime, potassium permanganate, sand and ceramic filters. The most common method to disinfect community water is chlorination. Chlorine and chlorine-based disinfectants such as calcium and sodium hypochlorite are used to treat tanks and distribution pipeline. Also, industrial effluent, municipal wastewater, swimming pool water is disinfected by using ozone, chlorine, hydrogen peroxide and per acetic acid (PAA), bromine etc. All disinfectant have advantages and drawbacks and can be used for water disinfection depending on the circumstances. Most chemical disinfectants, if overdosed or not properly used, can react with organic and inorganic substances present in water to produce disinfection by-products (DBPs) with adverse health effects resulting in changes in the quality of water, such as taste, smell.



Scheme 1. Schematic image of various disinfection processes.

Enumeration methods of microorganisms

The methods of enumeration in microbes can classified as,

Direct counts (Total and Viable)
Microscopic count method
Plate count method
Indirect counts (Total and Viable)
Most probable number method (MPN)
Turbidity method

Direct approaches require measuring the bacteria, while indirect approaches require calculation. Viable approaches only count cells that are metabolically alive, whereas overall counts contain active and inactive cells [**2**].

Direct count method

Microscopic count method

The direct microscopic approach counts the complete cells of the microorganisms found in the sample. This approach involves the use of a standardized slide called the Petroff-

Hausser count panel, in which a fraction of a cell culture or liquid medium is measured. The quantity of cells in a specified amount of culture fluid is actually used in the 10-20 magnifying range of the lens. The standard number of cells per area is estimated and the quantity of bacterial cells per ml of particular example can be calculated. A major benefit of direct counting is that it is a cheap, quick and easy approach which demands minimal equipment. In any case, as it is always impossible to distinguish living from dead cells, the simple microscopic counting method is not helpful in deciding the quantity of viable cells [**3**].

Plate count method

This approach quantifies the amount of viable cells in a culture by putting a specified volume of cell culture on a petri dish with a growth medium (Nutrient agar) and then the petri dish can be incubated for a specific duration of time at a given temperature (generally for 24-48 hrs at 27-44ºC). If the cells scatter evenly on the petri dish, each cell will give birth to a new colony. The overall number of colonies forming units (CFUs) on the plate is calculated by numeration of each colony. Through multiplying this count by the cumulative dilution of the solution, the actual amount of CFUs in the initial sample will be calculated. This method has the benefit of measuring only live bacteria. Any number of microorganisms can easily be counted if the correct dilution is placed and minimal equipment is needed. Disadvantages of this approach are the hidden colonies that are much smaller than those that appear to be on the surface. Therefore, one must be cautious to measure them, so that none of them is missed, Loss of viability of heat-sensitive organisms encountering with hot agar.

Indirect count method

Most probable number

Most Probable Number (MPN) is a technique used to calculate the density of alive microorganisms in a liquid sample. Liquid nutrient broth is used to grow micro-organisms. It is commonly used to compute microbial populations in soils, waters and agricultural products. Sample to be tested is diluted sequentially and injected in lactose broth, coliform bacteria if present in sample use the lactose present in the medium to produce acid and gas. The existence of acid is shown by change in colour of the medium and the existence of gas is observed in the form of bubbles collected in the inverted Durham tube inserted in the liquid medium. The number of total coliforms is observed by counting the number of tubes giving positive reaction (colour change and gas production) and comparing the figure of positive results with standard statistical tables. Advantages of this method is, ease of interpretation, either by observation or gas emission and disadvantages are, it takes long time to get results, results are not very accurate, requires more glassware and media [**4**].

Turbidity method

A simple and economical technique for estimating the number of bacteria present in a liquid media. By calculating the turbidity or cloudiness of the liquid medium and converting the calculation into cell numbers. This process of counting microorganisms is easy and is typically used when a large number of cultures have to be analysed. The spectrophotometer or colorimeter is used to calculate the turbidity of the liquid medium, which includes a light source and a light detector separated from the sample case. Turbid solutions, such as cell cultures, conflict with the light passage through the sample; This methods can be used as long as each individual cell blocks or stops light; as soon as the mass of cells becomes so large that some cells systematically shield other cells from the light, the measurement is no longer accurate.

Chemical methods of disinfection

Chemical methods of disinfection of drinking water mainly includes Chlorine (Cl_2), Hypochlorite (OCl^-), Chloramine (NH_2Cl), Chlorine dioxide (ClO_2), Hydrogen Peroxide (H_2O_2), Bromine (Br), Iodine (I), Per acetic Acid ($C_2H_4O_8$).

Chlorination

Chlorination is a mechanism by which chlorine is applied to drinking water to remove and destroy microorganisms, such as bacteria and viruses. Chlorine destroys the cell membrane of microorganisms. Chlorine is available for disinfection as chlorine gas, sodium hypochlorite, calcium hypochlorite, chlorine dioxide and chloramine. Almost any type of chlorine applied to the water during the treatment phase may result in the production of hypochlorous acid (HOCl) and hypochlorite ions (OCl^-) which are the major disinfectant compounds in chlorinated water.

Chlorine Gas

Sahem Shash *et al.* (2015), Studied Bactericidal activity of chlorine gas on some pathogenic bacterial strains isolated from Nile water. They have used chlorine gas for deactivation of four bacterial strains separated from inlets of some drinking water treatment plants in Sharkyia governorate. The outcome shows that the percentages of removal of Escherichia coli O157:H7, Staphylococcus epidermis, Pseudomonas aeruginosa and Bacillus subtilis were 99.98, 100, 99.92 and 98.83% respectively, after 10 min contact time. The breakpoints of these bacteria were observed at chlorine doses 1, 2.2, 1.4 and 0.6 mg/L, respectively [**5**].

Sodium hypochlorite (NaOCl)

V. Mezzanotte et al (2007), carried out disinfection test on pilot scale plant, the effluent, which used for disinfection tests, showed microbiological counts (total coliforms – 1 to 3 $\times 10^5$CFU/100 ml, faecal coliforms – 2 to 7.3 $\times$ 10^4 CFU/100 ml, Escherichia-coli – 8 $\times$ 10^3 to 1.6 $\times 10^4$ CFU/100 ml), Sodium hypochlorite was applied on this effluent at different concentrations from 0.5, 1, 2, 3, 4, 5 and 7.5mg/L for time period of 6, 12, 18, 36, 42, 54 minutes. Maximum log removal obtained by sodium hypochlorite was at 7.5mg/L after 18 minutes [**6**].

Natalie Wilhelm *et al.* (2018), conducted laboratory and field studies to find sodium hypochlorite dosage for household and emergency water treatment. In laboratory study they found that at 3.75 mg/L dose of sodium hypochlorite was able to reduce > 4 log reduction of Escherichia coli. In field study that they concluded with low turbidity water sample 1.88 mg/L dose of sodium hypochlorite; they were able to achieve 91-94% reduction in Escherichia coli growth [**7**].

Calcium hypochlorite ($Ca(OCl)_2$)

Pankaj Kumar Roy *et al.* (2016), figure out the chlorine demand analysis utilizing $Ca(OCl)_2$ bleaching powder for ground water. Bleaching powder (25 % w / w of available chlorine) solution was prepared by adding 1 g of bleaching powder ($Ca(OCl)_2$) in 1 L of drinking water. Dilution was developed in the 4, 6, 8, 10 and 12 mg / L levels of calcium hypochlorite. After preparation of the bleaching mixture ($Ca(OCl)_2$), chlorination was performed to disinfect the pond water. The interaction time was 30 min. The chlorine requirement for the samples was determined to be 4 and 8 mg / L, respectively. The overall coliform and faecal coliform count of the two samples was tested after 10, 20 and 30 minutes of chlorination. The result shows that 30 minutes were required for the full deactivation of total coliform and faecal coliforms using calcium hypochlorite as a disinfectant [**8**].

Owoseni *et al.* (2017), examined chlorine resistance and inactivation of Escherichia coli in wastewater treatment plants in the Eastern Cape, Southern Africa. Deactivation process was achieved by exposing Escherichia coli to a chlorine dosage of 1.5 mg /L at intervals of 10 min over 30 min of treatment. Thirty-seven microliters of 1% (w / v) calcium hypochlorite was applied to 100 ml of bacterial mixture at an initial bacterial count of 1.6–1.7 × 10^8CFU/ml. The mixture was mixed on a magnetic stirring plate at 160 rpm for 30 minutes. At intervals of 10 min, a fraction of 10 ml was extracted from the mixture and tested for residual chlorine concentration. The average reduction of 7.3 log units was obtained at a chlorine concentration of 1.5 mg / L [**9**].

Asmaa N. Mohammed (2019), studied the biocidal activity of calcium hypochlorite [$Ca(OCl)_2$], silver nanoparticles (AgNPs) and $Ca(OCl)_2$/AgNPs composite against bacteria isolated from drinking water supplies (tap and hand pump water).$Ca(OCl)_2$ loaded on AgNPs at a concentration of 1.5 mg/L showed a destructive effect (100%) on Escherichia coli, Staphylococcus aureus and Klebsiella pneumoniae following 180 min of exposure [**10**].

Chlorine dioxide

C. J. Volk *et al.* (2002), evaluate the response of a full-scale drinking water distribution system to a change in disinfectant from chlorine to chlorine dioxide, in terms of its effect on microbiological stability and disinfection by-product formation. Chlorine dioxide maintained microscopic count and plate count of total bacteria below 2 × 10^5 cells/ml and 1000 CFU/ml, respectively. The alteration in disinfectant from chlorine to chlorine dioxide shows 85% reduction in trihalomethanes that is from 30 to 5 μg/L and 60% reduction in halo acetic acids that was from 20 to 8 μg/L. Chlorine dioxide, as a disinfectant produces high quality water and was a strong alternative to chlorine for different types of distribution systems [**11**].

Huang Junli *et al.* (1997), studied disinfection effect of chlorine dioxide on bacteria in water with various conditions such as disinfectant dose, contact time, pH value etc. Experiment was conducted on Escherichia coli. Various dosage of chlorine dioxide were applied on Escherichia coli, for 20 min. The result obtained showed that at dose of 1.4 mg/L of chlorine dioxide gave 95% killing effect [**12**].

Yifei Wang *et al.* (2014), studied disinfection of Guangzhou bore well water with chlorine dioxide and hydrodynamic cavitation. The bore well water had an initial bacterial population 2500–3000 (CFU)/ml. The disinfection efficiency and the effect of hydrodynamic cavitation on water using chlorine dioxide was, 78.2 % only, using 1 mg/L chlorine dioxide at 60 min comparing to 81.8 % and with use of hydrodynamic cavitation and 0.5 mg/L chlorine dioxide at 30 min. The results indicate that hydrodynamic cavitation can shorten 50 % disinfection time and decrease 50 % doses of chlorine dioxide for almost same disinfection rate [**13**].

Ozonation

Ozone is a reliable disinfectant as compared to other chemical disinfectants. Ozone is an effective germicide and, at the same time, oxidizes organic matter which improves the consistency of the wastewater. This is an incredibly strong disinfectant that has a stronger disinfection function that is more effective in killing certain microorganisms relative to other commonly used chemical disinfectants. Ozone disinfection is very successful for the elimination of both coliform and chlorine-tolerable bacteria. The germicidal activity of ozone indicates complete or partial degradation of the cell wall of microorganisms. Overall, thus, it allows to obtain higher effluent efficiency and improved physiochemical and microbiological consistency levels until discharge.

Nguyen Hoang Nghi *et al.* (2018), studied Ozonation process and water disinfection. Water samples were taken from the small stagnant lake. Initial microbial count of lake water for total coliform was 2.2×10 ^{4}MPN /100 ml and for Escherichia coli was 1.5 × 10^4 MPN/ 100 ml. After ozone treatment for 4 min total coliform count reduced to 1.5 × 10^4 MPN /100 ml and Escherichia coli was not seen, and after 8 min of ozone treatment final total coliform was 1.5 and Escherichia coli was not seen [**14**].

K. Verma *et al.* (2016) reviewed the disinfection of secondary processed water treatment system effluent utilizing ozone. The original total coliform count was

15 × 10^5. The experimental findings revealed that the ozone dosage of 30 mg / L was needed to obtain a total coliform count of 1000 CFU/100 ml, with a reduction of 99.9 percent. Ozone leads to the production of various DBPs, such as aldehydes, ketones, mono-and dicarboxylic acids, etc., with natural products found in the waste. However, these by-products are less harmful relative to chlorinated DBPs. Ozone has been commonly used to monitor THMs and other DBPs because it tends to generate less chlorinated DBPs and to have excess disinfection efficacy [**15**].

Hydrogen peroxide

Hydrogen peroxide is effective disinfectant against a broad range of microorganisms, such as bacteria, fungi, viruses, yeasts, and spores. It acts on microorganisms by producing destructive hydroxyl free radicals that can attack membrane lipids, DNA, and other necessary cell components. Hydrogen peroxide acts very fast and forms water along with oxygen, which is responsible for increased level of oxygen in water. Reaction mechanism of hydrogen peroxide when used as disinfectant is as follows,

$$H_2O_2 \longrightarrow H_2O + O_2$$

Alasri *et al.* (1992) examined the deactivation of bacteria present in water and wastewater (Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus) with hydrogen peroxide and combination of hydrogen peroxide with peracetic acid. High concentration of hydrogen peroxide was required to achieve 5-log reductions of Escherichia- coli (≥ 700 mg/L with contact time of 2 hours). However, when hydrogen peroxide was used with peracetic acid, 100 mg/L of hydrogen peroxide was required in the presence of 0.75 mg/L of per acetic acid. When per acetic acid was used alone, 3 mg/L was required for the same effect. They also found that the action of hydrogen peroxide was slow, with bactericidal effects found even after 4 hours for certain organisms. Also, the action of peracetic acid was fast and, in many cases, no further change was observed after 30 minutes [**16**].

Peracetic acid (PAA)

Peracetic acid is a strong disinfectant with a broad range of antimicrobial activity. Due to its bactericidal, fungicidal, and sporicidal potency shown in various industrial wastewater treatment. The benefits of peracetic acid as a disinfectant for wastewater effluents are observed in recent years. A significant property of peracetic acid for wastewater disinfection is its ease of implementation, low capital investment, broad range of activities even in the existence of heterogeneous organic matters, absence of toxic or mutagenic residuals or by-products, small dependency on pH, short contact time, and effectiveness for primary and secondary effluents. R. Gher *et al.* (2002) observed that for physiochemically prepared (aluminium or ferric chloride) municipal primary effluents, PAA doses of 2 to 6 mg / L were needed to produce 1,000 colony forming units (CFUs)/100 ml of faecal coliform at a contact period of 60 min. For secondary effluents, a lower PAA dose of 0.6 to 4 mg / L was needed to achieve 1000 CFU/100 ml of faecal coliform [**17**]. Baldry *et al.* (1989) observed that for tertiary effluents, PAA concentrations were as small as 2 mg / L. approximately 2-log reduction in faecal coliform amounts was reported. Again, far higher doses of PAA (400 mg / L and 20 min of contact time) were needed to achieve 2 CFU/100 ml of total coliform in tertiary effluents for re-use in agriculture [**18**]. Liberti *et al.* (2000) noted that a dosage of 10 mg / L of PAA with a contact period of 30 min was needed for a target of 1000 CFU/100 ml of faecal coliform [**19**]. Poffe *et al.* (1978) observed that a PAA dosage of 5 to 10 mg / L and a contact period of 15 min was prescribed for secondary effluents, resulting in a reduction of more than 95% of total and faecal bacteria forms [**20**]. Lefevre *et al.* (1992) noticed that the PAA dosage of 5 to 7 mg / L with 60 min of contact time lowered the overall coliform and faecal streptococci concentrations in secondary effluents to less than 1000 CFU/100 ml and less than 100 CFU/100 ml respectively [**21**].

Bromine

Bromine components are disinfectants and can be used as choice for chlorine. In swimming pools, bromine is used against the growth of algae, bacteria and formation of odours in swimming water. Good enough *et al.* (1964), demonstrated the use of bromine as a disinfectant for swimming pool water. A residual of 0.8 mg/L highly decreases count of bacteria, but it did not eliminate total bacterial counts, bactericidal activity was also shown to increase with decrease with pH **[22].** Lindley studies (1966) bromine productivity against Escherichia coli and f2 coliphage, which were further developed by Krusé *et al.* (1970), demonstrated that bromine at a level of 4 mg/L was capable to bring down about a 5 $\log_{10}$ reduction of Escherichia coli and a 3.7 $\log_{10}$ reduction of f2 coliphage within 10 minutes at pH 7.0.

Iodine

Iodine-based disinfection of water has a long history. Iodine in concentrations between 2.5–7 mg/L ppm has been utilized for potable water treatment since early 1900s, once elemental iodine (I_2) is added to water, reaction mechanism is as follows,

$$I_2 + H_2O \longrightarrow HIO + I^- + H^+$$

A broad study of disinfection efficacy was performed by Chang & Morris (1953), studied the bactericidal effects of several CT combinations of iodine on different bacterial pathogens. Tests conducted with Escherichia coli showed that iodine concentrations of ≥ 0.05 ppm systematically reduced the concentration from 10^4 bacteria cells/mL to less than 1 cell/mL within 10 min (25ºC, pH 8.1–8.5) [**23**].

Impact of chemical disinfection process on drinking water

One of the significant worries about chemical disinfection processes is the formation of by-products that can be risky for the human wellbeing. DBPs are shaped because of disinfectant overdose or ill-advised use. Organic and inorganic compounds present in water react with the disinfectant and form by-products, Organic compounds incorporates trihalomethane (THM) and halo acetic acids (HAAs). Inorganic compound forms bromate, chlorate. The first DBP research occurred in the 1970s, when Rook *et al.* (1974) identified chloroform and other THMs in drinking water [**24**]. DBPs can have harmful effects on human health. Extended research has shown that DBPs are responsible for cancer and reproductive / developmental consequences. Sadiq *et al.* (2004) studied the effects of THM on human health, negatively affecting human organs such as the liver, kidney and nervous system and causing cancer [**25**]. Recently, THMs have been thoroughly studied for human health, such as infertility, teratogenicity, kidney and liver failure, nervous and hematopoietic outcomes. Several epidemiological studies focus on the harmful effects of chlorine by-products and link their increased concentrations to the increased risk of various forms of cancer growth [**26**]. Although it is assumed that only surface waters are responsible for the formation of DBPs due to their organic load, groundwater is also responsible for the formation of DBPs due to the presence of anthropogenic contaminants in ground water. More than 600 DBPs have been reported. Some of the DBPs are monitored and others are examined as emerging DBPs because they have lower levels of existence and toxic effects [**27**]. Richardson *et al.* (2007) studied the computational existence and health effects of DBPs. And as a result, drinking water is a compounded fusion, and therefore there are joint results. People are exposed to water not only through drinking but also through other activities such as bathing, washing, cleaning, etc. Furthermore, the study of the outcome of individual DBPs does not disclose the actual condition, as DBPs exist in water at different concentrations, with different conjoined effects. Those involve chloroform, dichlorodifluoromethane, dibromochloromethane and bromoform [**28**]. Regulations and guidance are structured to monitor DBPs and reduce customer exposure. The World Health Organisation (WHO) has established a permissible contaminant standard of 100 mg / L for total THMs. WHO guidance set the concentration of chloroform at 0.2 mg / L, chlorodibromomethane and bromoform at 0.1 mg / L each and bromodichloromethane at 0.06 mg / L each. Baldry *et al.* (2001) have mentioned that PAA causes poisonous or mutagenic by-products following reactions with organic material found in processed wastewater effluents or surface waters used for drinking water.

Alternative methods for chemical disinfection

It is generally recognized that disinfection is important for the supply of safe water to the consumers. However due to the DBPs formation using chemical disinfectant, may cause adverse effects on human health. Hence it is appropriate to consider alternative methods of disinfection for chemical disinfection.

Solar Disinfection of Water (SODIS)

It is a simple and low-cost technique used to disinfect contaminated drinking water. SODIS attach light and thermal energy to inactivate pathogens by interactive mechanism [**29**]. Around 4–6% of the solar spectrum reaching the surface of the earth is in the UV domain, with maximum reported value of around 50 W/m^2.Transparent bottles (preferably PET) are filled with contaminated water and placed in direct sunlight for 6 hours. After exposure, the water is safe to drink as the viable pathogen quantity can be significantly decreased. Investigators have shown that SODIS is effective against a vast range of microorganisms which are responsible for different diseases [**30-32**]. The inactivation of resistant protozoa has also been reported [**33-35**]. Field trials have demonstrated an important health benefits from consumption of SODIS treated water [**36**]. The productivity of SODIS against cholera was also revealed in a Kenyan health impact assessment, where 86% reduction of cholera cases was observed in households regularly using SODIS.

Ultraviolet light (UV)

Disinfection by ultraviolet light is considered as a cost effective and easily implementable system for drinking water disinfection. UV radiation, primarily at 254 nm, is absorbed by cellular RNA and DNA of microbes and hence it is most used. Interest in UV disinfection process has been increased sharply in drinking water industry. Bukhari *et al.* (1999); Clancy *et al.* (2000) demonstrated that even at very low dosage of UV light could inactivate microorganisms effectively. Valeria Mezzanotte *et al.* (2007) found out UV radiation appears to show a lower effect towards Escherichia coli than towards total and faecal coliforms even at low doses (10 to 20 mJ/cm^2) [**37, 38**].

Hydrodynamic cavitation

Organic toxins and microorganisms may be easily extracted from water with use of hydrodynamic cavitation. The rate of organic compound degradation and disinfection of water is correlated with reaction time and operating temperature. The disinfection efficiency may be increased by growing the reaction time or by raising the operating temperature. K.K. Jyoti *et al.* (2000), studied water disinfection by acoustic and hydrodynamic cavitation. Experiment done on bore well water and it was observed that when bore well water was subjected to cavitation, the bacterial population decreased as the time of treatment increased from 5 to 20 minutes, and at the end of 20 min of treatment 85% disinfection was attained [**39**]. L. Mezule *et al.* (2008), investigated effect of hydrodynamic cavitation on disinfection of Escherichia coli in laboratory scale device. The cavitation was generated using a rotor, driven by a simple milling cutter, in the thin layer of water which was circulated from and to a reservoir. Disinfection efficacy was analysed by measuring respiratory activity using 5-cyano-2, 3-ditolyl tetrazolium chloride (CTC) method and capacity of multiplication of Escherichia coli was measured by using direct viable count (DVC) method. Experimental result shows that hydrodynamic cavitation was very effective in reducing growth of Escherichia coli by 75% [**40**].

Natural herbs

Drinking water disinfection utilizing natural herbs, such as Neem (Azadirachtaindica), Tulsi (Ocimum sanctum), was studied by T. Bhattacharjee *et al.* (2013) based on assessing the efficacy of Ocimum sanctum and Azadirachtaindica to disinfect water from the pool, river as well. Antibacterial tests were also performed using aqueous leaf extract and fresh leaf juice against Salmonella typhi and coliform microorganisms. Ocimum sanctum (Tulsi) and Azadirachtaindica (Neem) have shown to have strong antimicrobial activity as the concentration rises with contact time (18 hrs). The antimicrobial activity of aqueous extract showed a stronger reduction of MPN. For well water Neem aqueous extract showed reduction from 313 to 7; for lake water it showed reduction from 175000 to 16000; and for river water it showed 125000 to 7000 reduction. When Tulsi aqueous extract used on well water showed reduction from 313 to 10; for lake water Tulsi extract showed 175000 to 40000 reduction and for river water Tulsi extract showed 125000 to 26000 reduction in microbial activity. The fresh leaf juice of Neem and Tulsi showed lesser reduction than aqueous extract. For well water Neem leaf juice showed 313 to 345; for lake water Neem leaf juice showed reduction from 175000 to 152000 and for river water Neem leaf juice showed 125000 to 180000 microbial activity. Tulsi leaf juice showed for well water 313 to 1800; for lake water Tulsi leaf extract does not showed any effect, means it remains from 175000 to 175000 and for river water it was from 125000 to 210000. The alcoholic extract of Neem and Tulsi showed the best result, for well water Neem showed reduction from 313 to 0, for lake water 175000 to 400 and for river water 125000 to 2000 reduction in microbial activity. Also, Tulsi alcoholic extract used on well water showed reduction from 313 to 2, on lake water showed reduction from 175000 to 2000 and on river water showed 125000 to 2000 [**41**].

S. Somani *et al.* (2011), did analysis of efficiency assessment of natural herbs for antibacterial function in water purification. Extracts of natural herbs Tulsi (Ocimum Sanctum), Neem (Azadirachtaindica), Wheatgrass (Triticum Aestivum), Amla (Phyllanthus Emblica) and Katakphala (StrychnosPotatorum) were evaluated at varying exposure times and concentrations against Escherichia coli. The impact of contact period on the elimination of Escherichia coli for all extracts of herbs up to 30 minutes was calculated. The contact time of 30 minutes was considered to be ideal for all herbs used in this analysis. The percentage removal of Escherichia coli was found 82.05%, 71.79%, 64.1%, 41.03% & 28.20% by using Tulsi, Neem, Wheatgrass, Amla and Katakphala herbs extract respectively, at 30-minute optimum contact time [**42**].

Conclusion & future prospective

The methods discussed in this review paper are alternative methods for chemical disinfection of potable water. As such chlorination is considered universal choice for water disinfection because chlorinated compound requires low residence time and concentration for disinfection. chlorination will kill almost all the microbes present in water(except Giardia or Cryptosporidium protozoa) by injecting excess dosage, but it has some disadvantages also it will form toxic by-products, excess dosage will give unpleasant taste and odour to water and thus dechlorination process is required. Also, technical expertise is needed for proper dosage. Ozonation will not give any unpleasant taste and odour to water and it will provide effective protection against Giardia or Cryptosporidium at low level of dose, but process needs high operational and maintenance cost and does not produce residue. Hydrogen peroxide requires high concentration for disinfection. So, there is requirement of an alternative disinfection methods like solar water disinfection, UV radiation, hydrodynamic cavitation and natural herbs. These alternative methods require high operational and maintenance cost and takes long period for treatment, UV radiation will only paralyse microorganism if residence time is low. Natural herbs will add unpleasant taste and odour if excess dosage is applied, but they will not form any toxic by-products and some methods are simple and effective. Thus, application of these methods of disinfection is depends upon on purpose and consumption of water.

In future perspectives, the role of disinfection process should be considered important due to the control of emerging microbial contaminants of potable water. Additionally, current research will lead to a deeper knowledge of chemical disinfection methods and DBPs; thus, the use of alternative technologies, such as UV- based methods, solar water disinfection, natural herbs and combination of different disinfectants will increase. The choice of disinfection method often depends on cost, treatment time, water quality, and antimicrobial activity of disinfectant. Therefore, alternative methods should provide low treatment time, low cost and high degree of microbial reduction which leads to achieve complete disinfection of potable water.

Acknowledgements

This work was supported by Water Quality Centre of Excellence, promoted by Wilo Foundation-Vishwakarma University.

Conflicts of interest

"There are no conflicts to declare".

Supporting information

Supporting information's are available online at journal website.

Keywords

Disinfection, chlorination, UV radiation, green disinfection methods.

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Graphical abstract

It is generally recognized that disinfection is important for the supply of safe water to the consumers. However due to the DBPs formation using chemical disinfectant, may cause adverse effects on human health. Hence it is appropriate to consider alternative methods of disinfection for chemical disinfection like Sunlight, UV light, Hydrodynamic cavitation, and Natural herbs.