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Review Article

The Effectiveness of Ultraviolet Based Methods versus Other Novel Methods in the Disinfection of Escherichia Coli Found in Drinking Water: A Systematic Review

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Abstract:

Summary: A total of 19 studies with different disinfection methods, primarily grouped into Ultraviolet (UV) only, combination and Non-UV, are selected to find the effectivity of UV disinfection compared to other novel disinfection methods in the inactivation of Escherichia coli (E. coli) present in drinking water. All methods chosen produce significant results regarding E. coli inactivation.

Background: Drinking water is an essential part of life that everyone needs. Many drinking water sources are contaminated with E. coli. There are numerous disinfection methods, including UV irradiation. Author wants to find out which disinfection modality, UV irradiation or other methods, is more effective at inactivation E. coli found in drinking water.

Objectives: To find the effectivity of UV disinfection compared to other novel disinfection methods in the inactivation of Escherichia coli present in drinking water.

Method: Literatures from PubMed, Science Direct and Google Scholar published in 1990-2020 were searched using MeSH terms and the Boolean Logic 'AND', with the key words included being 'Disinfection', 'Ultraviolet Rays', 'Drinking Water' and 'Escherichia coli'. Then these literatures were filtered according to inclusion and exclusion criteria. Key data extracted from each finding included details of study design and duration of observation, type of water sample used, movement of water sample, water sample volume, comparison group, method of disinfection, source of disinfection, dose of disinfection, duration of disinfection, enumeration method of counting E. coli , type of E. coli, initial concentration of E. coli and outcome of concentration of E. coli after disinfection.

Results: 19 studies were included in this systematic review. All studies shows significant decrease in E.coli concentration after disinfection.

Conclusion: UV treatment could significantly reduce E. coli found in drinking water.

Keywords: Drinking water, Escherichia coli, Ultraviolet, UV, Disinfection

Introduction:

According to the latest WHO [1] report on progress on drinking water, sanitation and hygiene, 59 million people collects drinking water directly from surface water sources. A considerable proportion (18%) of Indonesian households rely on surface water sources, such as springs, rivers, ponds and lakes for their drinking water, which are prone to contamination problems [2]. This shows that drinking water may expose citizens of Indonesia to dangerous disease-causing bacteria like pathogenic Escherichia coli (E. coli) and many more, thus causing endemics of disease such as diarrhoea and others.

Drinking water, which is water that has gone through or has not gone through processing that meets the health standard and can be directly drunk [3] is considered safe for consumption if it meets the physical, microbiological, chemical, and radiological parameters. An example of the microbiological parameter that should be met is the amount of E. coli found per 100ml of sample, in which the number should not exceed 0. E. coli is chosen as a parameter as it is a faecal coliform, in which when present, it signifies drinking water is contaminated with faecal particles. Not only that, some strains of E. coli are particularly pathogenic [3].

Various methods of drinking water disinfection from harmful bacteria are utilised by people from all over the world, including Indonesia. Most countries rely on using ultraviolet (UV) for inactivating bacteria such as E. coli in drinking water, with some using UV lamps in their water systems [4], and others utilising the naturally occurring sun rays with the help of small-scaled solar disinfection (SODIS) appliances, in which drinking water is stored in clear PET bottles or pipes and then subjected to sunlight for 6 hours [5,6] when sunny or 2-3 days when cloudy , especially in areas with stronger sunlight [7]. Nowadays, novel methods that either incorporates UV disinfection into their instrument or does not use UV in their disinfection methods are emerging. Example of such novel instruments that combines UV with other disinfection methods is TiO2 photoreactor [8], and that of Non-UV methods is reactive electrochemical membrane (REM) [9,10].

But drinking water obtained do not always meet the standard given by the government [11], potentially giving way for coliforms and bacteria to present in the drinking water. This means that harmful bacteria such as E. coli that may be found in the filtered water are not exposed to heat, thus the bacteria are not killed and stays in the filtered water, waiting to be consumed. Because of this, there is a potential that a health problem will persist in the community or district because of the presence of harmful components found in the filtered water [12].

This systematic review presents and discusses published data from the literature, aiming to give an analysis of the evidence of the efficacy of UV disinfection and other methods of water disinfection, both combination of UV with other methods and non- UV methods when it comes to disinfecting different sources of drinking water with different concentrations of E. coli present in the water.

Author also wishes to find which method yields the best result, and which method is applicable for use in Indonesia, either in city settings or rural areas that lack access to proper electricity sources and advanced materials. To the best of the authors' knowledge, this is the first systematic review paper on the application of UV and other novel methods for water disinfection.

Methods:

The search for relevant literature was carried out in the following databases: PubMed, Science Direct and Google Scholar. MeSH terms and the Boolean Logic 'AND' were used, with the key words included being 'Disinfection', 'Ultraviolet Rays', 'Drinking Water' and '*Escherichia coli'*. Combination of keywords used are shown in Table 1. Only studies in English were included and the search was carried out by one independent author.

Table 1: Search terms and database strategy

ID	Search Terms
1.	Disinfection
2.	Ultraviolet Rays
3.	Drinking Water
4.	Escherichia coli
5.	1 AND 2 AND 3 AND 4
6.	1 AND 3 AND 4

Abstracts and other details of relevant studies were compiled in a bibliographic database. A spreadsheet, comprising of a series of headings against which the characteristics of each study are recorded, was made to help see any trend in the study. Study characteristics were recorded by author in these spreadsheets.

The present study includes laboratory-based experiments. Only literature published between the year 1990-2020 are chosen for the study selection and studies that fulfil the inclusion and exclusion criteria up to date were included. Literature that uses water samples from common drinking water sources such as mineral water, tap water, rain water harvesting systems, rain-feed ponds and river water are included Findings that uses water samples from effluent or wastewater and sea water were excluded. The review is further restricted to microbiological measures of contamination and excludes chemical aspects of water quality. Studies using more unusual microbiological testing measures (e.g. somatic coliphages) are not included in the review. The review is therefore limited to *E. coli*, and all types and strains of *E. coli* are included. Literature where *E. coli* is not submerged in water is excluded. There was no restriction in the water sample volume and initial concentration of *E. coli* present in the water sample used. Studies that manufacture *E. coli* contaminated water were also included.

After the article search and removal of duplicates, the titles and abstracts of the articles retrieved in the database search were screened for further analysis.

Key data extracted from each finding included details of study design and duration of observation, type of water sample used, movement of water, volume of water sample, comparison group, method of disinfection, source of disinfection, dose of disinfection, duration of disinfection, enumeration method of counting *E. coli*, type of *E. coli*, initial concentration of *E. coli* and outcome of concentration of *E. coli* after disinfection.

Results:

The combined database search resulted in 3312 studies identified using the predefined search terms (Figure 1). After removal of duplicates (n = 8), the title and abstract of 3304 studies was screened. Most of the studies excluded were not concerned with drinking water (n = 1996), and *E. coli* (n = 825). In addition, a further 208 studies were excluded because they did not use disinfection methods (n = 33), and a few of them were book chapters (n = 95), indexes (n = 21), excerpts from the encyclopedia (n = 12), guidelines (n = 4) and reviews (n = 43). Aside from that, 7 studies were not in English, 19 full texts were unavailable and 224 studies did not use *E. coli* in their experiment. Further 25 remaining studies were screened, and 6 studies were excluded because *E. coli* tested was not suspended or submerged in water. A total number of 19 laboratory based experiments that met the inclusion and exclusion criteria were selected.

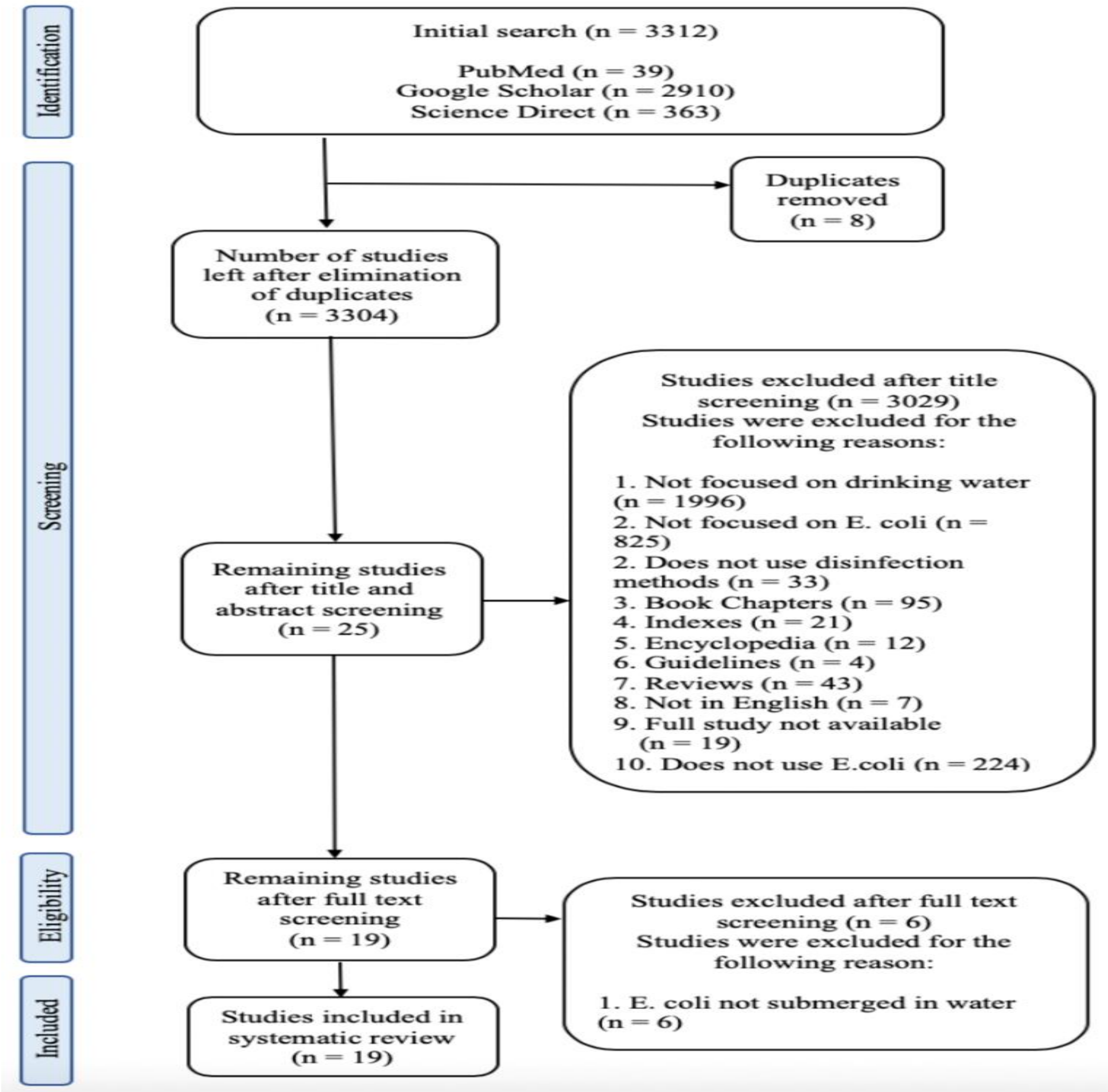

Figure 1: Study Selection Flowchart

Detailed information on the variables of study design, type of water sample used, comparison group, method of disinfection, source of disinfection, duration of disinfection, enumeration method of counting *E. coli*, type of *E. coli*, initial concentration of *E. coli*, outcome of concentration of *E. coli* after disinfection and conclusion is taken note of and detailed in Table 2. In some studies, dose of disinfection is given but duration of disinfection is not given, so equalization of duration of disinfection is included in the table. Values are derived according to formula and protocol by Bolton et al [13], which is based from the paper by Bolton and Linden [14], with some [15][16] being a rough estimate as a few variables needed in the formula is not available in the study. Conclusion from and of each study are also added into the table.

The most frequently used *E.coli* enumeration method is plate count (*n* = 18) ([17][18][19][20][15][21][22][23][24][25][26][27][16][28][29][30][9]). Other methods include membrane filtration (MF) [31] and double staining [32] which detects apoptosis. Aside from plate count, Biswas and Bandyopadhyaya [21] also used fluorescence spectroscopy for enumeration. Guo et al [25] also used both plate count and direct count for enumeration of *E. coli*.

Table 2: Description of Measurement Tools, Outcomes and Conclusions

Author	Disinfection Method	Type of Water Used	Comparison Group	Method of Disinfection	Source of Disinfection	E. Coli Enumeration Method	Duration of Disinfection or Equalization of Duration /s	Type of E. coli used	Number of E.coli /		Conclusion
									Before Disinfection	After Disinfection	
Huang et al (2013)	UV only	Phosphate-buffered saline (PBS)	Control Group	UV irradiation	Low Pressure UV light source (253.7 nm, UVC)	Plate Count	386.7	Tetracycline resistant E. coli (CGMCC 1.1595)	10^7	10	Inactivation of E.coli is significant, but is not effective enough if *E.coli* present is high in concentration
Timmerman et al (2015)	UV only	Mineral Water	No Intervention	UV irradiation	LED (254 nm, UVC)	Plate Count	90	E. coli (ATCC 25922)	3 x 103	0 (if agitated) 173 (if stagnant)	Highly effective if water is agitated
Vilhunen et al (2009)	UV only	Ultrapure Water, Water with nutrient, Water with Humic Acid	No Intervention	UV irradiation	LED (269 & 276 nm, UVC))	Plate Count	20 minutes	*E.coli* K12	107	-0 (ultrapure water) -10 (nutrient water) -103 (water with humic acids)	more effective when turbidity of water is low and when wavelength of UV is at 269 nm

Nyanganresi et al (2018)	UV only	Deionised Water	No Intervention	UV irradiation	LED (267,275, 310, 267/275, 275/310 267/310 nm, UVC and UVB)	Plate Count	21.6 seconds	*E. coli* (CGMCC 1.3373)	106	-100 (267 nm) -103 (275 nm) -105 (310 nm)	Significantly effective at UV wavelength of 267 nm, but is not effective enough if *E.coli* present is high in concentration
Sommer et al (2000)	UV only	Sterile 0.9 % Saline Water	No Intervention	UV irradiation	Low Pressure Mercury UV Lamp (253.7 nm, UVC)	Plate Count	204.2 seconds	Pathogenic : - EHEC - ETEC Nonpathogenic	106 to 107	1	Effective, as reduction is 6log, but only if wavelength of UV is 253.7 nm and UV dose is 400 J/m2
Lui et al (2016)	UV only	0.05 M NaCl water solution	No Intervention	UV irradiation	LED (270, 310, 365, 385, 405, 430, 455, 525, 590, 623, 660 and 740 nm [UVC, UVB, UVA and Visible light spectrum])	Plate Count	-180 (3 minutes) for 270 nm UVC -21600 (6 hours) for 310 nm UVB -3600-7200 (1 to 2 hours) for 365 to	E. coli K12	106	- 10 (270 nm UV A) - 105 (310 nm UVB) - 10 (365-405 nm UVA)	Inactivation is much more effective with UV of wavelength 270 nm, but is not effective enough if *E.coli* present is high in concentratio

							405 nm UVA				n
Mbonimpa et al (2012)	UV only	Deionized Water with Sodium Carbonate	No Intervention	SODIS	Solar Disinfection enhanced with Compound Parabolic Collector (CPC)	Plate Count	21 600 (6 hours) (sample taken for counting in one-hour intervals)	*E. coli* (from the Wabash River in Indiana, USA)	3 x 104	30-35	Inactivation is significant, but not effective enough
Ubomba Jaswa et al (2010)	UV only	Natural Well and Turbid Water	Control Group	SODIS	Solar Disinfection enhanced with Compound Parabolic Collector (CPC)	Plate Count	18 000 (5 hours)	E. coli K12	106	-Sunny Days: Below detection limit -Cloudy Days: 103	Effective especially in sunny weather
Ireland et al (1993)	Combination (UV Combined with other method)	Dechlorinated Tap Water	Control Group	TiO2 Photocatalytic Oxidation	TiO2 photoreactor (with 300-400 nm UVB to UVA lamp)	Plate Count	3600	Not Stated	103 – 107	Dechlorination with thiosulfate : 1.7 x 10^7 Dechlorination with UV : <1	Method is effective and feasible, but with caution as ‘sulfurous’ scent was present when tap water was dechlorinated with thiosulfate
Zhao et al (2020)	Combination (UV	•	Filtration using	Photocatalytic and Filtration	Photocatalytic and	Double Staining	3600	*E. coli*	105	100 CFU/mL	Method is effective,

	Combined with other methods)		undecorated porous ceramic disk filter (PCDF)		Filtration using porous ceramic disk filter (PCDF) coated with Fe/TiO2 nanocomposites			(ATCC 25922)			but light conditions are important (both visible and UV light must be present)
dos Santos et al (2017)	Combination (UV Combined with other methods)	Water with 0.08N of Sodium Sulfate	Photolytic oxidation (UV-A radiation only)	Electrochemically assisted photocatalysis	Electro-chemically Assisted Photocatalysis with Ti/TiO2 thermal electrode doped with Ag	Plate Count	600	*E. coli (CCT145)*	3 X 102	0	Method is effective
Duffy et al (2004)	Combination (UV Combined with other methods)	Sterile filtered water	SODIS (UV-A radiation only)	Catalytic SODIS	Solar photocatalytic disinfection (SPC-DIS) using Coated or Inserted TiO2 with Glass or PET container	Plate Count	Glass + SPC = 6300 (105 minutes) Glass + SPC coating = 11700 (195 minutes) - Plastic + SPC insert = 10800	E. coli K12 (ATCC 10798)	106	Below detection limit of 4CFU/mL	Method is effective and fastest when using a glass container with a TiO2 SPC insert

							(180 minutes)				
Harding and Schwab (2012)	Combination (UV Combined with other methods)	Sterilized Dechlorinated Tap Water	Control Group	SODIS with Lime Juice, Lime Slurry and Synthetic Psoralens	Lime Juice, Lime Slurry and Synthetic Psoralens	Plate Count	1800 (30 minutes) and 9000 (150 minutes)	Nalidixic Acid-resistant E. coli CN-13 (ATCC 70009)	106	1.SODIS + Lime Slurry -30 minutes: under limit of detection - 150 minutes: under limit of detection (700609) contaminan t 2. SODIS + Synthetic Psoralen - 30 minutes: no value - 150 minutes: under limit of detection	Method is effective especially with addition of lime slurry, as *E.coli* number reaches under limit of detection in 30 minutes
Guo et. al (2016)	Other Disinfection Methods (Non UV)	Deionized water	Control Group	Electrochemical disinfection with Reactive Electrochemical Membrane, Electrolysis	Electro-chemical disinfection with Reactive Electro-chemical Membrane	- Plate Count - Direct Count	7200 (2 hours)	*E. coli* (ATCC 25922)	- Membrane Filtration ~ 10^4 CFU mL^{-1} - Batch Inactivation. ~ 10^5 CFU mL^{-1}	- Membrane filtration: 1log removal - Batch inactivation: E.coli are all inactivated	Electrochemical disinfection with Reactive Electrochemical Membrane (REM) and

					(REM)						electrolysis is effective at inactivation of E.coli, but electrolysis has a more definite efficacy in inactivating E. coli
Pathak and Gopal (2012)	Other Disinfection Methods (Non UV)	Autoclaved tap water	No Intervention	Silver Ionization	Silver electrodes (cathode and anode)	Plate Count	3600 (60 minutes)	Not stated	1.75 × 10^3 CFU mL^{-1}	0 (1 to 20 ppb is 100%bactericidal for *E. coli* with 60–20 min of contact time)	Silver ionization is effective in inactivation of *E.coli*
Huang et al (2019)	Other Disinfection Methods (Non UV)		No Intervention	Photocatalytic and Non-Photocatalytic Filtration	Ceramic Disk Filter coated with Ag/ZnO Nanocomposites and Light Illumination	Plate Count	-	Not stated	Varies	0 (For initial concentration of E.coli = 10^3 CFU mL^{-1} + LUX 7000)_	Highly Effective as long as initial concentration of E.coli = 10^3 CFU mL^{-1} + LUX 7000. Higher light intensity will decrease E.coli concentration, but not until 0
Jin et al (2019)	Other Disinfection	Neutral low	Control Group	Electrochemical disinfection	Modified Reticulated Vitreous	Plate count	14400 (4 hours)	*E. coli* (ATCC	10^6 CFU mL^{-1}	0 (Under detection	Electrochemical disinfection

	Methods (Non UV)	electrolyte water solution (up to China's drinking water standards)			Carbon Cathode			25922)		limit = 4 CFU mL^{-1})	is effective in inactivation of *E.coli*
Chang, He and Ma (2008)	Other Disinfection Methods (Non UV)	Deionized water	Control Group	Catalytic Disinfection	Ag/Al2O3 and AgCl/Al2O3	Plate count	Ag/Al_2O_3 1800 (30 minutes (Ag/Al_2O_3 and) 3600 (60 minutes (Ag/Al_2O_3)	*E. coli* K 12 (ATCC 8099)	6 × 10^7 CFU mL^{-1}	0	Catalytic disinfection is highly effective in inactivation of *E.coli*
Biswas and Bandyopadhyaya (2016)	Other Disinfection Methods (Non UV)	•	Control Group	Silver nanoparticle impregnated activated carbon	Silver nanoparticle impregnated activated carbon	- Fluorescence spectroscopy -Plate count	25 minutes (batch) 16 days (continuous)	*E. coli* K 12 (MTCC 1302)	10^4 CFU mL^{-1}	0	Silver nanoparticle impregnated activated carbon is highly effective in inactivation of *E.coli*
Huang et. al. (2013)	Other Disinfection Methods (Non UV)	Phospate buffered saline	Control Group	Chlorination	Chlorine	Plate count	10 minutes	Tetra-cycline-resistant *E. coli* (CGMC C 1.1595)	10^7 CFU mL^{-1}	100	Inactivation of *E.coli* is significant, but is not effective enough

Description of Water Used in Experiments

Some experiments such as those of Vilhunen et al [29] or Ubomba-Jaswa et al [26] test on two or more different types of drinking water at once, so total number of type of water used for sample is greater that the number of journals chosen. Types of water sample obtained were either unspecified (*n* = 4), from natural sources such as well water (*n* = 1) and turbid water (*n* = 1), are store brand so had to be bought like ultrapure water (*n* = 1), deionized water (*n* = 4) and mineral water (*n* = 1), from tap water (*n* = 3) or had to be prepared in a lab for instance water with nutrient (*n* = 1), water with humic acid (*n* = 1), saline water (*n* = 1), phosphate-buffered saline (PBS) (*n* = 2), sterile filtered water (*n* = 1) and neutral low electrolyte water solution (*n* = 1).

A few water samples were subjected to an autoclave before experimental procedures [16,16,17,24] to ensure sterilization. Ireland et al [20] and Harding and Schwab [17] chose to dechlorinate their water sample which is obtained from tap water to ensure that effect of disinfection will not be affected by the prior chlorination. Mbonimpa et al [31] also chose to add sodium carbonate to the water sample to act as a buffer so that water sample will stay relatively neutral and any accidental acidic or basic additions to the water sample can be neutralised.

Type of *E. coli* used

A lot of the researchers choose to experiment with *E. coli* K12 or other similar strains of E. coli often used for laboratory purposed (n = 13), even though they are manufactured in different labs in different countries. Some, such as Huang et al [15] and Ireland et al [20] choose to not specify and disclose the type and strain of E.coli they used in their experiments (n = 2). One in particular, Mbonimpa et al [31], chose to isolate and culture their own *E.coli* sample from water sample collected in a river called Wabash River located in Indiana, USA. Others choose to use *E.coli* strains that are specifically pathogenic or resistant towards a particular substance (n = 3). Huang et al [15] chose to use tetracycline-resistant *E. coli* (CGMCC 1.1595) and an antibiotic sensitive *E. coli* strain (CGMCC 1.3373) for control in their experiment, and Harding and Schwab [17] opted to use Nalidixic Acid-resistant *E. coli* CN-13 (ATCC 700609). Sommer [16] experimented with seven pathogenic *E.coli* strains and one nonpathogenic strain, with three being enterohaemorrhagic strains. The seven pathogenic strains used are *E. coli* O157:H7 (CCUG 29197; isolated from a hamburger during an outbreak in the United Kingdom), O157:H7 (CCUG 29199; isolated from a haemolytic-uremic syndrome patient in North Carolina), O50:H7 (CCUG 29198; isolated from a patient with haemorrhagic colitis), O157:H7 (CCUG 29193; isolated from human faeces), O78:H11 (ATCC 35401; isolated from human faeces), O25:K98:NM (ATCC 43886; isolated from a human during an outbreak on a ship), and O25:K80:H12 (ATCC 43896; isolated from a child with diarrhoea). The non-pathogenic *E. coli* strain used by Sommer [16] is ATCC 11229.

Intervention

Control Group

The comparison groups used in the studies included no intervention group (n = 8)[15,17,20–23,25,26] [9,16,24,27–31], control group (n = 8)[15,17,21–23,25,26] and other methods (n = 3) [18,19,32] with the methods being filtration using undecorated porous ceramic disk filter (PCDF), photolytic oxidation (UV-A radiation only), and SODIS (UV-A radiation only) respectively.

Selection of Disinfection Methods

UV

In total, there are seven researchers that choose to find out the disinfection effect of UV on *E. coli* [16,26–32]. And from these seven experiments, the UV source used are either low-pressure UV light source (n = 2), light-emitting diode (LED) (n = 3), solar UV from the sun (n = 2) or UV light source type not clearly defined (n = 1).

All the low-pressure UV light sources used emitted UV of wavelength 253.7 nm [15,16]. LED used in the experiments irradiated UV light of varying wavelengths ranging from 265 nm to 740 nm, which is a range of UV-C to UV-A (100-400 nm), and some until beyond UV light spectrum [27–29]. Solar UV used in experiments by Mbonimpa [31] and Ubomba-Jaswa [26]have fluctuating wavelengths, as source of UV is the sun, and exposure of UV to the water sample is bound to fluctuate with the varying amount of clouds blocking the UV rays from the sun depending on the time of the day. But, Mbonimpa's [31] experiment, the UV exposure are mostly in the range of UV-B (280-315 nm), and in Ubomba-Jaswa's [26] experiment, the UV exposure are mostly in the range of UV-A (315-400 nm). Timmerman [30] did not specify what their instrument for UV light source was made of, but it is portable, light and battery operated, so it can be either LED or low-pressure UV light source.

UV in Combination with Other Methods

In total, there are five journals chosen that use methods of disinfection that also involves irradiation with UV in order for the disinfection method to work more optimally [17–20,32].

Four out of the five journals chosen included the method of photocatalysis aided by titanium dioxide (TiO_2) as a catalyst. Ireland et al (1993) experimented with TiO_2 photocatalytic oxidation and used UV lamp (300- 400 nm) covered with fiberglass mesh sleeve that is coated with a firmly bonded layer of TiO2 for disinfection. Zhao et al [32] chose to experiment with photocatalytic filtration by using a porous ceramic disk filter (PCDF) made from rice and husk coated with Fe/TiO2 nanocomposites, and then shone with UV light and visible light. UV light wavelength used by Zhao [32] is undisclosed. dos Santos et al [19] chose to test on efficacy of electrochemically assisted photocatalysis on the disinfection of water using non-doped Ti/TiO2 either Ag-doped electrodes under UV-A irradiation. Duffy et al [18] experimented on a different variation of SODIS, which is solar photocatalytic disinfection (SPC-DIS). Duffy [18] used coated or inserted TiO_2 with glass or PET container.

Harding and Schwab [17] also experimented on a variation of traditional SODIS, with the addition of lime juice, lime slurry and synthetic psoralens.

Disinfection Methods Other than UV

There is a total of seven journals that explore the use of non-UV means for disinfection of water [9,15,21–25].

Filtration method for water disinfection was further explored in two journals, with one using an electrochemical filtration method with a reactive electrochemical membrane (REM) [25] and the other one using a ceramic disc filter coated with Ag/ZnO nanocomposites [9]. Other disinfection methods are chlorination [15], silver ionization [24] electrochemical disinfection [23] catalytic disinfection [22] and disinfection using silver nanopartical impregnated activated carbon [21].

Quality Assessment

Quality assessment of the included studies was appraised by the 2018 version of Mixed Methods Appraisal Tool (MMAT). The MMAT is a critical appraisal tool that is designed for the appraisal stage of systematic mixed studies reviews, i.e., reviews that include qualitative, quantitative and mixed methods studies [33].

Four studies [17,18,26,31] received an all 'Yes' on all categories of questions. This is attributed to the fact that the confounding factor is clearly stated, which is weather for all studies . Other studies (n = 15) received a 'Can't tell' under the category 'Are the confounders accounted for in the design and analysis?' because confounders in the studies were not disclosed.

Table 3: Quality assessment of studies included according to the MMAT

Quality assessment of methodology based on MMAT scale					
Reference	Are the participants representative of the target population?	Are measurements appropriate regarding both the outcome and intervention (or exposure)?	Are there complete outcome data?	Are the confounders accounted for in the design and analysis?	During the study period, is the intervention administered (or exposure occurred) as intended?
[15]	Yes	Yes	Yes	Can't tell	Yes
[30]	Yes	Yes	Yes	Can't tell	Yes
[29]	Yes	Yes	Yes	Can't tell	Yes
[28]	Yes	Yes	Yes	Can't tell	Yes
[16]	Yes	Yes	Yes	Can't tell	Yes
[27]	Yes	Yes	Yes	Can't tell	Yes
[31]	Yes	Yes	Yes	Yes	Yes
[26]	Yes	Yes	Yes	Yes	Yes
[20]	Yes	Yes	Yes	Can't tell	Yes
[32]	Yes	Yes	Yes	Can't tell	Yes
[19]	Yes	Yes	Yes	Can't tell	Yes
[18]	Yes	Yes	Yes	Yes	Yes
[17]	Yes	Yes	Yes	Yes	Yes
[25]	Yes	Yes	Yes	Can't tell	Yes
[24]	Yes	Yes	Yes	Can't tell	Yes
[34]	Yes	Yes	Yes	Can't tell	Yes
[23]	Yes	Yes	Yes	Can't tell	Yes
[23]	Yes	Yes	Yes	Can't tell	Yes
[22]	Yes	Yes	Yes	Can't tell	Yes
[21]	Yes	Yes	Yes	Can't tell	Yes

* Responds are either Yes, No, Not Sure

Discussion:

Objective of this Systematic Review

This systematic review wishes to cover the efficacy on several disinfection methods, some of which are novel, in comparison to that of UV only on the inactivation of *E. coli* found in drinking water. 19 journals were chosen to be reviewed. The other disinfection methods included are both that do not use UV as a mean of disinfection and also methods that incorporate UV light as one part of the modalities of the disinfection. To the author's knowledge, this is the first systematic review done on the efficacy of disinfection of *E. coli* by UV disinfection and other methods, both non-UV disinfection methods and methods combined with UV.

Efficacy of Methods

A variety of disinfection methods were used by the 19 studies reviewed in this systematic review. Discrepancy in the result of *E. coli* inactivation in the water samples after exposure to the disinfection methods is apparent, especially since different types of water are used, and also protocols of disinfection procedure differs greatly between each study. Different types of *E.coli* strains used may also be a factor to the efficacy of disinfection. Water movement also varies, as in some studies water samples are contrived to be flowing such as Ireland et al's [20] and Zhao et al's [32], whereas in studies by Duffy et al (2004), water are left stagnant.

But all in all, all methods of disinfection are shown to be able to significantly inactivate *E.coli*, albeit in some studies *E.coli* removal are not as effective and end result of water disinfection does not satisfy the maximum threshold of *E.coli* number by MPN of Indonesia as stated by Ministry of Health Indonesia , which is the total *E. coli* number per100 mL must be 0, or at least below the detection limit of 1 MPN [3]. It must be taken into account that in all of the studies, very high amounts of *E. coli* were incorporated into water samples measured for the initial concentration with most being around 10^4 to 10^7, which is significantly higher than the data author obtained regarding E. coli found in water samples from DAMs located in Manukan Kulon and Sawahan district of Surabaya, Indonesia, which is only around 5 – 100 MPN/100 mL in contaminated sources. This data is obtained from author's first preliminary data when author conducted research in Manukan Kulon & Sawahan district in Surabaya, which is used to compare the situation with the one in Surabaya.

UV only methods

In the present systematic review, 8 out of 19 studies used UV only disinfection as a modality of *E. coli* inactivation. Three uses LED as an UV light source, two uses low-pressure UV lamp with one using a low-pressure mercury lamp, two uses SODIS method with a tube and enhanced with a CPC, and one lamp source is unspecified. All of the UV only disinfection modalities are appropriate for disinfection of point of use (POU) drinking water found in homes or in communities, and one is catered for mobility [30] .

All of these modalities achieved 4-log reduction target recommended by WHO for household POU treatment [1]. Based from the studies, experiments that result in *E. coli* reduction larger than 4-log and with some being 0 CFU mL^{-1} after disinfection are those irradiated with UV light of wavelength 253.7 nm [15,16] and 267-270 nm [27–29]. These range of UV wavelength is included in UV- C. All of these studies use either LEDs or low- pressure UV lamps as a UV light source. This observation is coincides with statement from ISO [35], in which ultraviolet germicidal irradiation at a wavelength of 253,7 nm is the most germicidal. Percival [36] also stated that UV-C is the part of the UV radiation that is most effective in destroying organisms, with 254 nm being the peak of inactivation for bacteria. This is also supported by studies that show that wavelength around 265 nm have a relatively higher inactivation of microorganisms than other wavelengths in the UVB and UVC (200-300 nm) range [37,38].

This statement is contradicted in the observations done by Setlow [39] and Green et al [40] , in which wavelengths between (roughly) 300-310 nm had the greatest effect on disinfection efficacy. The reason as stated is that wavelengths below this range, the incident fluence rate is generally too low to bring about substantial inactivation. At wavelengths above this range, available energy from UVB radiation is ineffective at producing damage in DNA.

Mbonimpa et al [31]and Ubomba-Jaswa et al [26] uses SODIS as a modality of disinfection. This method relies heavily on the presence of the sun, how sunny the day is, and how much cloud is covering the sun, thus UV wavelength fluctuates. Results from study Mbonimpa [31] agrees with statement of Setlow [39] and Green et al [40], in which for their study, the UV wavelength that results in the most inactivation of *E.coli* is around the range of 300-310 nm. But this maximum efficacy is still not effective enough, as only 3-log removal is performed. This is the same case with study done by Ubomba-Jaswa et al [26] on cloudy days, in which only 3-log removal of *E.coli* is done. But on days where it is sunny, complete removal of *E.coli* was performed. Reasoning behind this is that even though UVC is the most bactericidal, all UVC is completely absorbed by the ozone before reaching the earth (WHO, 2020), thus the next most bactericidal is the UV with wavelength around 300-310 nm (UVB).

Huang et al [15] and Sommer et al [16] used specialised strains of *E.coli* which are tetracycline resistant and pathogenic respectively. Efficacy of the modalities done might be different when more 'normal' or strains of *E.coli* usually used in laboratories are used, but these disinfection modalities are still proven to be effective against these particular specialised strains.

It can be summarised that both UV disinfection can yield total removal of *E.coli*, as long as UV light wavelength emitted by LED or low-pressure UV lamp is set at around 254 nm and SODIS is done during sunny days, meaning that SODIS is much more fitting to be implemented in sunny countries such as Indonesia, and effective at disinfecting a large volume of water, like in the case of Ubomba-Jaswa et al [26] in which the volume of water sample is 25L. It is highly possible and beneficial to utilise SODIS in more rural parts of Indonesia that has less access to electricity and more advanced materials.

Disinfection Methods Combined with UV Light Exposure

In the present systematic review, 4 out of 19 studies used combination with UV disinfection as a modality of *E. coli* inactivation. Four studies use photocatalysis by TiO2 as a mean of disinfection, with three studies using LED lights and one using the sun as a source of UV light [18–20,32]. Out of those four studies, one also incorporates filtration with a porous ceramic disk filter (PCDF), and another one is assisted with electrodes. One study uses a SODIS method the addition of lime juice, slurry and synthetic psoralens into the water sample. All of the UV only disinfection modalities are appropriate for disinfection of point of use (POU) drinking water found in homes or in communities.

All of these modalities achieved 4-log reduction target recommended by WHO for household POU treatment [1], and are very effective, with almost all end result of disinfection being 0 CFU mL^{-1} or under detection limit of 1 CFU mL^{-1} [20] or 4 CFU mL^{-1} [18][17]. End result of disinfection in study by Zhao et al (2020) is not 0, but still inactivated *E. coli* by 4-log.

Ireland, Duffy and Harding and Schwab [17,18,20] tested on larger volumes of sample water, which are 12L, 1L and 2L respectively. All of their methods yielded really good results, especially since all of their studies used an initial *E.coli* concentration of around 10^6 in their water samples.

A worthy mention is study by Harding and Schwab [17], in which in his study, the addition of lime slurry in water sample subjected to SODIS allows end result of *E.coli* to be under limit of detection in just 30 minutes, even though initial *E.coli* concentration placed in water sample is 10^6 CFU mL^{-1}. This method proves to be extremely past, unlike the traditional method of SODIS where it has to be kept under the sun for six hours if sunny or two days if cloudy [41].

It can be summarised that all methods above can yield total removal of *E.coli*, with the exception of photocatalytic filtration done by Zhao [32]. Zhao [32] still yielded a removal of more than 4-log, so their disinfection method is still significant and can still be accounted for, as it still follows the guideline set by WHO regarding POU water disinfection method.

Non-UV Disinfection Methods

In the present systematic review, 7 out of 19 studies used methods without the use of UV light as a modality of *E. coli* inactivation. Guo et al [25] used electrochemical filtration with reactive electrochemical membrane (REM), Jin et al [23] used electrochemical disinfection with reticulated vitreous carbon (RVC), Pathak and Gopal [24] used silver ionization, Huang et al [9] used photo-catalytic and non-photo catalytic filtration with ceramic disk filter coated with Ag/ZnO nanocomposites, Chang He and Ma [22] used catalytic disinfection with Ag/Al2O3 and AgCl/Al2O3, Biswas and Bandyopadhyaya [21] used silver nanoparticle impregnated activated carbon and Huang et al [15] used chlorination in their studies. These methods possible to be used at home, but are more suited to be used by drinking water manufacturers such as DAMs or plants.

All methods of disinfection shows significant results, with almost all yielding 0 *E.coli* concentration after disinfection, in exception for chlorination by Huang et al [15] and filtration of 800 mL by Guo et al [25]. For Huang et al [15], it must be noted that end result is 100 CFU mL^{-1} from an initial concentration of 10^7 CFU mL^{-1}, meaning that disinfection method is still considered efficient.

A worthy mention is study by Biswas and Bandyopadhyaya [21] in which they ran their study of silver nanoparticle impregnated activated carbon as a method of water disinfection for 16 days straight with 624L of water sample. Their study was also proven very effective, as end result of *E. coli* concentration in their water sample is 0 CFU mL^{-1}, from an initial of 10^4 CFU mL^{-1}.

Choice of Water Sample

This systematic review includes 19 studies with water samples from a number of sources, which are well water, turbid water, ultrapure water, deionized water, mineral water and tap water. Some water samples had to be prepared in a lab for instance water with nutrient, water with humic acid, saline water, phosphate-buffered saline (PBS), sterile filtered water and neutral low electrolyte water solution.

Some are more turbid than others, and in the study by Vilhunen et al [29], it was shown that disinfection is more effective in clearer or less turbid waters.

Cost

In this systematic review, only two out of 19 studies talks about the spendings associated with the disinfection method. Huang et al [9] talked about the price of the equipment used in their study, which is a ceramic disk filter coated with Ag/ZnO nanocomposites. They explained that it only costs a few dollars. Zhao et al [32] also only said that the disinfection equipment used in their study, which is porous ceramic disk filter (PCDF) made from rice and husk coated with Fe/TiO2 nanocomposites, has a low cost. Exact pricing were not mentioned in both studies.

Reactivation of *E. Coli*

It is known that some microorganisms, particularly bacteria including *E. coli* is able to undergo reactivation by photoreactivation or dark repair after being subjected to UV irradiation. This is because the bacteria is able to repair their damaged DNA.

Reactivation is not much discussed and experimented in the studies included in this systematic review, except in that of Nyangaresi et al [28] and Sommer et al [16], in which they also experimented with photoreactivation. Nyangaresi et al [28] used a non-pathogenic *E. coli* strain, whereas Sommer et al [16] used both pathogenic and non-pathogenic *E. coli* strains.

Photoreactivation is a process where microorganisms utilize light in the wavelength range of 330-480 nm to reactive. Dark repair is when no light is needed for the reactivation of the microorganism. [42][43]

Nyangaresi et al's [28] study showed that reactivation occurred in dark repair, but not in photoreactivation for a period of 9 h. This result contrasted with results from Sommer et al [16], in which no reactivation happened in dark repair except in one pathogenic strain O50:H7, and up to 3 log reactivation under conditions with light.

Reactivation of *E.coli* should be accounted for in further experiments regarding inactivation of *E.coli*, especially if UV light is used as a modality of disinfection.

Implementation of Water Disinfection Method in Indonesia

All of the methods included in this systematic review shows significant results and are beneficial in inactivation of *E. coli*. From all these methods, SODIS assisted with CPC can be very beneficial for use in more rural parts of Indonesia with limited access to electricity and more advanced substances and technology, as SODIS mostly only rely on sunlight, and materials needed for manufacture of appliance are easily obtainable.

Limitations

1. This research reviews existing journals only.

2. In quality assessment done using MMAT, almost all of the studies are not clear on whether confounding factors in the studies are accounted for, as authors do not specify on what those factors are.

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Conclusion

UV treatment could significantly reduce *E. coli* found in drinking water.

Recommendation

1. In future researches, production and usage costs of the modalities should be taken into account and stated in their studies.
2. *E. coli* reactivation should also be accounted for in future researches regarding bacteria subjected to UV irradiation.
3. Modalities mentioned in this systematic review can actually be implemented in Indonesia, as perhaps in more rural parts of Indonesia or in DAMs in order for drinking water disinfection to be more effective.

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