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Factors Affecting the Quality of Drinking Water in the United States of America: A Ten-Year Systematic Review

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Abstract Safe drinking water is a product that is free of contaminants which pose short and long-term risks to the consumers' well-being. It is an indispensable resource that safeguards public health and engenders sustainable economic development. We conducted a systematic review of journal article published between 2010-2020 to (a) identify, appraise, and synthesize the best available evidence for the factors that affect the quality of drinking water in the United States of America (b) make appropriate recommendations to improve the quality of drinking water. Eligible studies were systematically reviewed and selected for analysis from searches of 21,042 publications identified from six databases. We analyzed factors affecting quality of ground water, surface water, water treatment plants, water distribution systems, tap water and bottled water. 201 studies were included in this review, and more than half were published between 2016-2020. The major water contaminant identified from this review was chemical waste from industries (33.3%), followed by pathogens (32.3%), metals and naturally occurring substances (23.9%), pharmaceuticals (9.0%), natural gas and oil (1.0%) and biogenic substance (0.5%). Therefore, factors affecting the quality of water include industrial activities, pathogens especially from fecal contamination of water, agricultural practices, naturally occurring substances, pharmaceutical substances, and natural disasters. There is need to enforce regulations that protect all sources of drinking water from pollution by industrial effluents and other anthropogenic sources. Improvements in water treatment processes and continuous water monitoring, especially in the rural areas, will help to improve the quality of drinking water in the United States. Systematic review registration: The systematic review protocol was registered (CRD42021271183) and is published on PROSPERO.

Keywords: *factors, quality, safe drinking water, contaminants, pathogens*

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1. Introduction

Water is an important substance to human beings and other living organisms on earth [1]. It is an indispensable natural resource that is critical for human health, functioning ecosystems, and sustainable socioeconomic development [2]. It covers two-thirds of the earth's surface in a form that is largely unsafe for human consumption because it contains microbial, chemical, and other contaminants that are inimical to human health. The freshwater which human beings process for drinking is 2.7% of the available water on earth and only 1% of this is accessible to humans because it is hidden in deep aquifers and glaciers [3]. The various sources of water humans use for drinking purposes include groundwater, rainwater, streams, aquifers, glaciers, and natural springs. The knowledge of these sources of water and pragmatic efforts towards protecting them from all kinds of pollution are germane to the management of water resources and provision of safe drinking water for consumers [4].

Safe drinking water emanates from public water systems, private wells or bottled water factories and is delivered to consumers in a manner suitable for drinking, domestic use, and personal hygiene [5]. According to the World Health Organization (WHO) 2020 report, safe drinking water is a form of water that has undergone treatment and does not pose any significant risk to the health of consumers in the immediate or long term [6]. It is the outcome of a multistage process that ensures the removal of contaminants from freshwater, leading to the production of high-quality water that is safe for human consumption [7]. Public and private water systems take raw water through the processes of screening, chemical addition, coagulation, flocculation, sedimentation, filtration, disinfection, storage, and distribution to the consumers [8]. These processes require appropriate techniques and modern technologies that can enhance the capacities of water treatment plants to produce safe water in quantities that meet the community needs and qualities that measure up to regulatory requirements [9]. Safe drinking water has characteristics that usually fall within three categories: physical, chemical, and microbiological. Physically, water must be odorless, tasteless, colorless, and turbid free. Chemically, safe water is required to be free from toxic substances, contaminants, excess minerals, divalent ions, organic matters, and a pH of 6.5-8.5. It must be free of pathogens and radioactive substances The Table 1 below shows the standard values for safe drinking water according to the WHO and United States Environmental Protection Agency [10,11] (USEPA).

Table 1. International standards for quality drinking water

S/N	Parameter	WHO standards	US EPA Standards
1	PH	6-8.5	6-8.5
2	Electrical conductivity	1,000	2,500
3	Color	15 TCU	
4	Turbidity	5NTU	0.5-1
5	TDS	500mg/l	500mg/l
6	Nitrate	10mg/l	50mg/l
7	Nitrite	1mg/l	3mg/l
8	Ammonia	1.5,35mg/l	-
9	Phosphate	0.3mg/l	1.5mg/l
10	Calcium	75mg/l	---
11	Fluoride	1.5mg/l	2-4mg/l
12	Chloride	250mg/l	250mg/l
13	Arsenic	0.7mg/l	10microg/l
14	Sulphate	400mg/l	250mg/l
15	Iron	1mg/l	300microg/l
16	Total hardness	300mg/lCaC03	300mg/lCaC03
17	Sodium	200mg/dl	-
19	Manganese	0.1mg/l	50microg/l
20	Magnesium	150mg/l	-
21	Alkalinity	200mg/lCaC03	-
22	Bicarbonate	150 -350 mg/l	

There is a plethora of literature describing factors that affect the quality of safe drinking water. These factors are events and situations that result in the contamination of water from the water source to the water treatment plants, through decaying water distribution infrastructures and household water storage facility [12]. For example, the improperly disposed of industrial chemicals, animal wastes, pesticides, human wastes, and naturally occurring substances can all contaminate ground and surface water [13]. Long and colleagues reported that surface and underground water sources are often polluted during the rainy season due to increase in the soil table water and human activities. This would lead to an increase in the level of water contaminants like nitrates, pesticides, and fecal coliforms which are then transferred to the treatment plant [14]. The water treatment plants are designed to eliminate harmful substances, contaminants, and disease-carrying pathogens from the raw water [15]. However, a breach in the integrity of the processes mentioned earlier can result in the distribution of water contaminated with antibiotics, pesticides, and other unacceptable elements to the community [16].

Furthermore, the distribution of treated water using ageing pipeline often cause deterioration in taste, color, odor, and turbidity which compromise the quality of water pumped into the community from the treatment plants [17]. A recent and typical example is the Flint, Michigan water crisis in 2014. This resulted in leaching of lead and other metals from the city's aging pipes into the water supplied into homes and businesses thereby exposing around 100,000 residents to elevated lead levels with their health consequences [18]. Household water storage systems and plumbing facilities can also constitute a potential source of water contamination. A cross-sectional household survey of 800 households was conducted across three informal peri-urban neighborhood which reported that most households drinking water sample had fecal contamination (67%), defined by the presence of colony forming units of the fecal indicator bacteria enterococci [19].

The unwavering determination and efforts of the United State government to provide safe drinking water for the citizens have brought some remarkable progress across the States but the momentum must be sustained. Globally, disparities and inequalities exist in access to safe drinking water between towns and cities, developing and developed countries, the gap is reducing gradually. In Sub-Saharan Africa, where the rate of access is lowest, household access to safe drinking water is increasing steadily [20] The United Nation General assembly sustainable development goals in 2010 and 2015 recognized the rights of individuals to safe, acceptable, affordable, and accessible water for both domestic and personal use [21]. Despite these interventions, studies show that 140 million are exposed to unsafe levels of arsenic element and 2 billion people drink water source contaminated with feces, which poses significant health risk by increasing the occurrence of water borne diseases such as poliomyelitis and dysentery with estimated 829,000 diarrheal deaths annually.

In view of the foregoing, this research is imperative because safe drinking water is critical to human survival and a major factor affecting human health. According to WHO, poor access to safe drinking water, improper hygiene practices, and unimproved sanitation account for four percent of all deaths and 5.7 percent of all ill health and disabilities in the world. In addition, there are communities and individuals who are unaware of their exposure to health risks from water contaminated with lead, toxic chemicals, microbes, and others. This review focused on factors affecting the quality of drinking water in the United States. Therefore, the objectives of this review are to (i) identify, appraise, and synthesize the best available evidence for the factors that affect the quality of safe drinking water in the United States of America (ii) make appropriate recommendations to improve the quality of drinking water.

2. Materials and Methods

2.1. Protocol and Registration

We followed the reporting guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis for Protocols 2015 and guidance for dissemination of results [23]. The study protocol was registered in the International Prospective Register of Systematic Reviews Database (PROSPERO) (available at https://www.crd.york.ac.uk/prospero) in August 2021 with registration number CRD4202127118.

2.2. Search Strategy and Keywords

This study systematically reviewed journal articles on factors affecting the quality of drinking water in the United States published between 2010 and 2020. A University Librarian developed the search strategy in MEDLINE Complete. The initial search strategy was tested and refined by sampling search results and applying proposed inclusion and exclusion criteria. Once completed, the search strategy was translated to five other databases. Final searching was completed in MEDLINE Complete (Ebsco interface), CINAHL Complete (Ebsco interface) Web of Science Core Collection, ABI/INFORM (ProQuest interface), ProQuest Agricultural & Environmental Science Collection, and COMPENDEX (Engineering Village interface). Search terms related to drinking water and water quality were used and an extensive list of foreign countries were used as excluding keywords. The searching of databases and screening of articles were conducted between November 2021 and February 2022. The list of complete search strategy (Table 2), list of databases that were searched (Table 3) and Prisma flow diagram for this study (Figure 1) are presented below.

2.3. Inclusion Criteria and Exclusion Criteria

Retrieved articles were imported into Zotero where duplicates were removed. The deduplicated set of articles was then uploaded to Rayyan where two authors performed title and abstract screening and removed ineligible articles. The remaining papers were downloaded for eligibility assessment and data extraction. The inclusion criteria include (i) peer reviewed primary studies published in English language from the United States of America. (ii) Investigation time: 2010–2020 (iii) studies that focused on drinking water and reported factor(s) affecting quality of safe drinking water (iv) study design such as randomized controlled trials RCTs, quasi-RCT, and experimental design were considered.

Exclusion criteria included: (i) studies not related to the research topic (ii) studies not published within the year 2010-2020 (iii) Commentaries, case-controls, cohort study, reviews, opinion pieces, proceedings of conferences, editorials, and non-peer reviewed reports.

Table 2. A table showing the full search strategy used for the review

MEDLINE Complete Search Strategy
S1. (MH “Drinking Water+”) OR (SU “Drinking Water”) OR “potable water” OR “bottled water”
S2. Purification OR quality OR safety OR pollutants OR pollution OR contaminant* OR microbiology* OR “water chemistry” OR toxicity
S3. S1 AND S2
S4. Argentina OR Australia OR Bangladesh OR Brazil OR Bulgaria OR Canada OR Chile OR China OR Colombia OR Denmark OR Ethiopia OR Finland OR France OR Germany OR Ghana OR Greece OR Haiti OR India OR Iran OR Italy OR Japan OR Kenya OR Korea OR Malaysia OR Mexico OR Netherlands OR Nigeria OR Norway OR Pakistan OR Peru OR Poland OR Portugal OR Romania OR Russia OR Saudi Arabia OR South Africa OR Sri Lanka OR Spain OR Sweden OR Taiwan OR Thailand OR Tunisia OR turkey OR Uganda OR Afghanistan OR Africa OR Algeria OR Asia OR Austria OR Belgium OR Benin OR Bolivia OR “British Isles” OR “Burkina Faso” OR Cambodia OR Cameroon OR Chad OR “Costa Rica” OR Croatia OR Cyprus OR “Czech Republic” OR “Danube River” OR Ecuador OR Egypt OR Eire OR England OR Estonia OR Europe OR Europe OR “European Union” OR “Gaza Strip” OR Guatemala OR Honduras OR Hungary OR Indonesia OR Iraq OR Ireland OR “Irish Republic” OR Israel OR Jordan OR Kazakhstan OR Kuwait OR “Latin America” OR Lebanon OR Libya OR Lithuania OR Malawi OR “Middle East” OR Mongolia OR Morocco OR Nepal OR “New Zealand” OR Nicaragua OR Oman OR Ontario OR Palestine OR Philippines OR “Puerto Rico” OR Qatar OR Quebec OR Rwanda OR Scotland OR Scotland OR Serbia OR “Sierra Leone” OR Singapore OR Slovakia OR Slovenia OR “Southeast Asia” OR Sudan OR Switzerland OR Syria OR Tanzania OR “United Arab Emirates ” OR “United Kingdom” OR Uruguay OR Vietnam OR Wales OR Zambia OR Zimbabwe
S5. S3 NOT S4
From: 2010-2020
Source Types: Academic Journals
Language: English

Table 3. A table showing the list of databases searched

Search Tool	Number of Results	Date Searched
MEDLINE Complete (Ebsco)	1,396	11/19/2021
CINAHL Complete	1,110	11/19/2021
Web of Science Core Collection	5,841	11/19/2021
ABI/INFORM (ProQuest)	724	11/19/2021
ProQuest Agricultural & Environmental Science Collection	9,300	11/19/2021
COMPENDEX (Engineering Village)	2,671	11/19/2021
Unduplicated Total	21,042	
Duplicates	(8,320)	
De-duplicated Total	**12,722**	

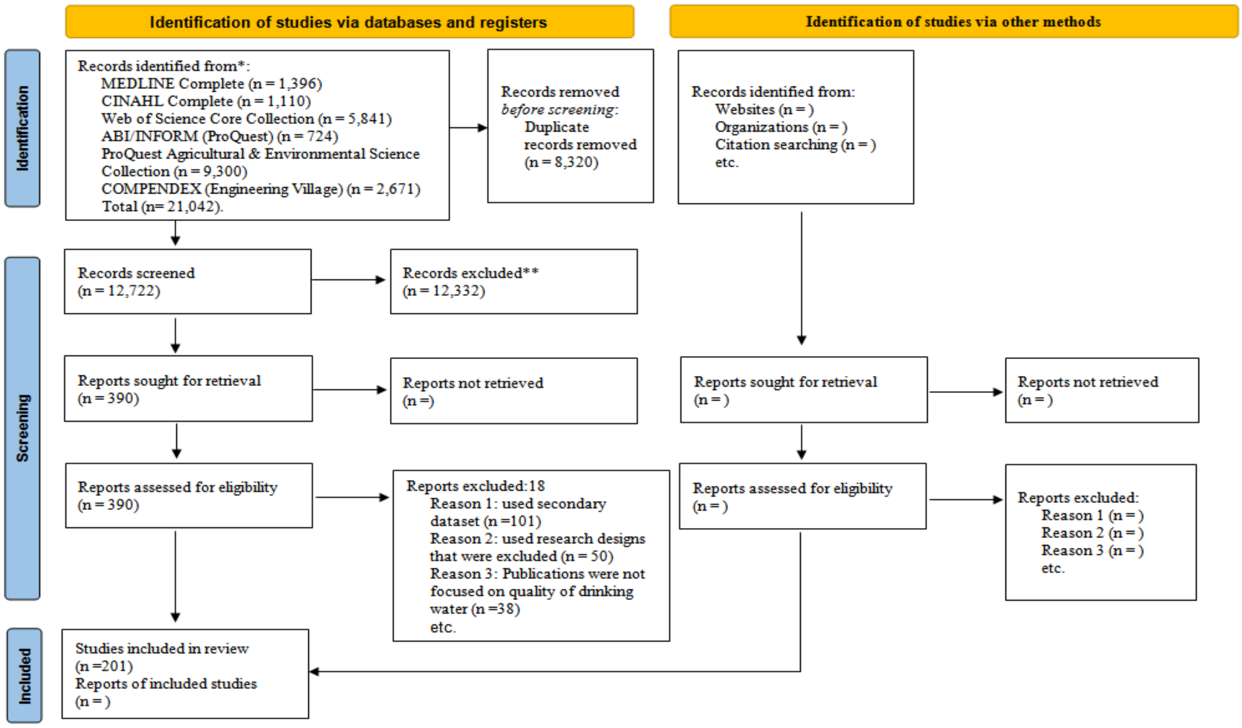

Figure 1. Prisma 2020 flow diagram for new systematic reviews which included searches of databases, registers, and other sources (Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers). (**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools. *From:* Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/)

2.4. Eligibility Assessment

Titles and abstracts of search results were screened by two independent reviewers for methodological validity prior to inclusion in the review using standardized critical appraisal instruments from the Joanna Briggs Institute (JBI) Critical appraisal checklist for systematic review and research synthesis [24]. Disagreements that ensued between them were resolved through discussion with a third reviewer.

2.5. Data Extraction

Data extractions were conducted independently by two authors and disagreements resolved by a third author. The Data extracted covered the following parameters: author, year of publication, study aim, sampling site/location, rural/urban, State, sampling year/period, study design, water contaminants, sampling point, author and reviewers' conclusions, and factors affecting quality of drinking water.

2.6. Data Analysis

The information listed in section 2.5 above were entered into a Microsoft Excel database. The main outcomes from quantitative evaluations were extracted, summarized, and discussed.

3. Results

3.1. Search Results

A total of 21,042 publications were identified from six databases, out of which 8,320 were duplicates and 12,332 were excluded based on title and abstract. A total of 390 articles were selected for full text review. The most common reasons for exclusion were that the study used secondary or existing dataset for analysis (n=101), used research designs like reviews, case controls or retrospective cohort studies (n= 50) and did not focus on quality of drinking water (n=38). Finally, 201 publications were included in this systematic review. The results of this review are organized into characteristics of literature included, factors affecting the quality of surface water, groundwater, water at the treatment plants, water during distribution and at household levels.

3.2. Characteristics of Literatures Included

Table 4 and Table 5 below summarized the characteristics of the 201 articles and the excel sheet containing the list of the articles reviewed in this study. All the included articles identified one or more contaminants affecting the quality of water in the United States. More than half of the articles (55.7%) were published between 2016-2020. The articles sampled and reported water situation in the Northeast (24.4%), Midwest (22.9%), West (16.4%) and South (14.9%) regions of the United States. Figure 2 below present a map of the United States showing sampling sites, location, and States. In this review, the states with the highest number of publications were Pennsylvania (6.5%), California (5.5%) and Colorado (5.0%) while 20.9% of the articles sampled water across multiple states. The setting reported most by the authors was urban (71.1%), followed by urban & rural (17.5%), and rural (11.4%). The study design used by most of the authors was inductively coupled plasma spectrometry, ICP-MS (23.4%), followed by liquid chromatography mass tandem spectrometry (20.4%), quantitative polymerase chain reaction (16.9%), gas chromatography capillary column (7.0%), DNA Sequencing (12.0%), culture-based method (3.0%) and other methods (17.3%).

Table 4. Characteristics of the included articles

Characteristics	**Number of articles**	**Percent**
1) Year of publication		
2010-2015	89	44.3
2016-2020	112	55.7
2) Regions of the United States		
Northeast	49	24.4
Midwest	46	22.9
West	33	16.4
South	30	14.9
Multiple States	42	20.9
Undisclosed state	1	0.01
3) Settings		
Rural	23	11.4
Urban and rural	35	17.5
Urban	143	71.1
4) Study design		
Alpha spectrometry technique	1	0.5
Arsenic analysis	1	0.5
Cadmium Reduction Flow Injection Method	1	0.5
Catalytic oxidation	1	0.5
Coagulation/flocculation combined with sedimentation (CFS)	1	0.5
Compartment bag test and membrane filtration with agar	1	0.5
Culture based method	6	3.0
Detection limits	1	0.5
DNA Sequencing	12	6.0
Electron diffraction and X-ray analyses	1	0.5
Enzyme Linked Immuno Sorbent Assay	2	1.0
Experimental Nitrate analysis	1	0.5
Gamma spectrometry methods	1	0.5
Gas Chromatography capillary column	14	7.0
Headspace solid phase microextraction	10	5.0
Immunofluorescence microscopy to detect infections in cell culture	1	0.5
Immuno-Magnetic Separation (IMS) was preformed using a Dynal Bead Retrieve	1	0.5
Immunomagnetic separation (IMS), stained, and examined by microscopy as described in EPA Method	1	0.5
Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	47	23.4
Inductively Coupled Plasma Optical Emission spectrometer	1	0.5
Inductively Coupled Optical Emission Spectroscopy (ICP-OES)	2	1.0
Ion chromatography	1	0.5
Ion column chromatograph	1	0.5
Ion exchange resins	2	1.0
Isotopic analysis of samples from drinking water wells	1	0.5
Liquid chromatography–mass spectrometry	1	0.5
Liquid chromatography-tandem mass spectrometry	41	20.4
Manometer: fluorescence spectrometry (CVAFS)	1	0.5
Method detection limits	1	0.5
Preconcentration with FeOH3, separation on TRU resin	1	0.5
Quantitative polymerase chain reaction (QPCR)	34	16.9
Standard membrane filtration techniques	1	0.5
Surface-enhanced Raman spectroscopy (SERS)	1	0.5
SUVA254 (specific ultraviolet absorbance at 254 nm)	1	0.5
The alpha-spectrometry technique	1	0.5
The enzyme substrate test	1	0.5
The enzyme substrate test	1	0.5
UV-visible spectrophotometer	1	0.5
X-ray diffraction and scanning electron microscopy (SEM) analyses,	1	0.5
X-ray fluorescence spectrometry	1	0.5
X-ray photoelectron spectroscopy	1	0.5
5) Sampling points		
Surface water	67	27.8
Ground water	76	31.5
Water treatment plant	22	9.1
Distribution system	1	0.4
Tap water	69	28.6
Bottled water	6	2.5
6) Water contaminants		
Biogenic substance	1	0.5
Chemicals	67	33.3
Metals	48	23.9
Natural gas and oil	2	1.0
Pathogens	65	32.3
Pharmaceuticals	18	9.0

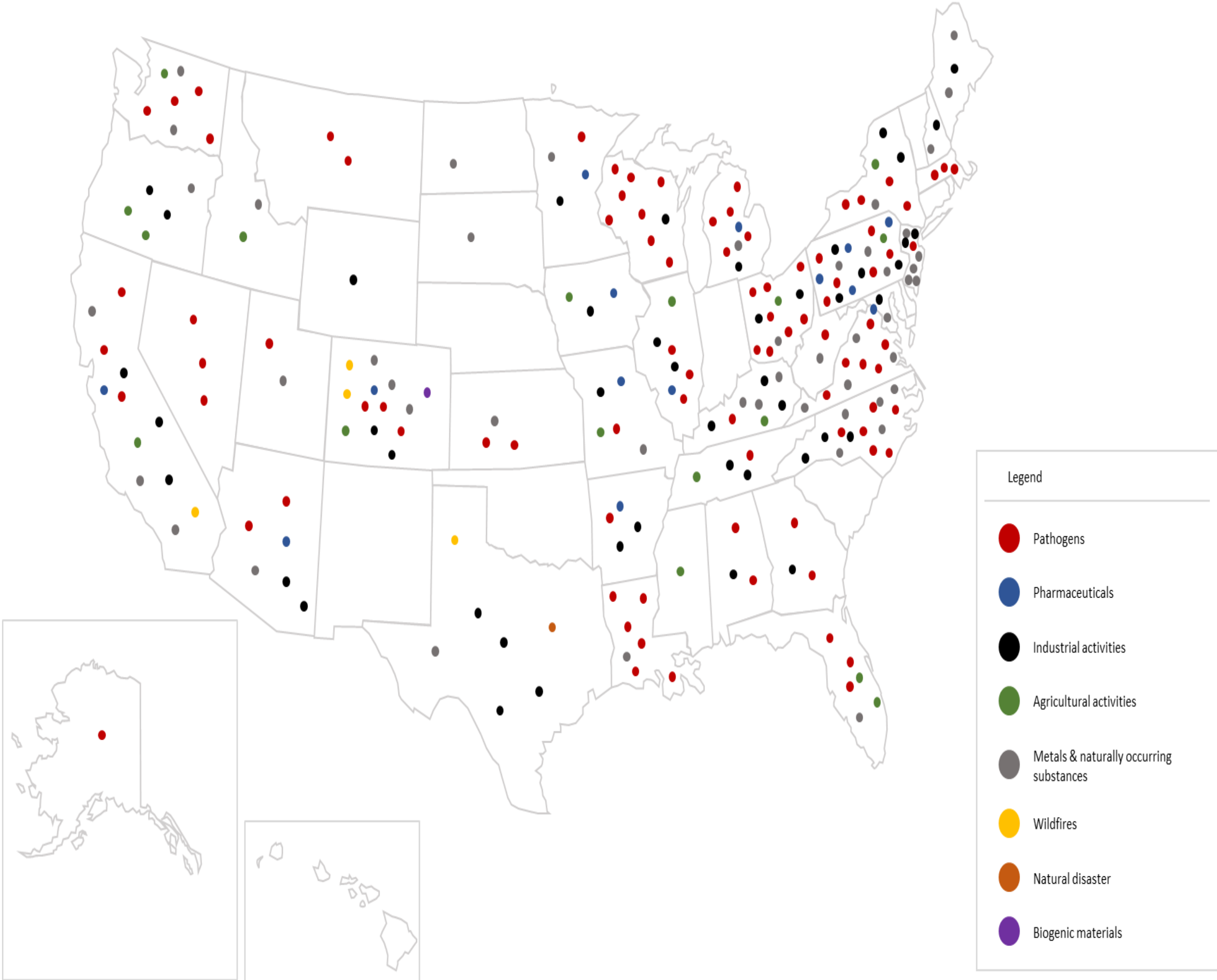

Figure 2. Map of the United States showing sampling sites, location, and States

Majority of the articles sampled and analyzed water from ground water (31.5%), followed by tap water (28.6%), surface water (27.8%), water treatment plant (9.1%), bottled water (2.5%) and distribution system (0.4%). The contaminants that were identified can be categorized into chemicals (33.3%), pathogens (32.3%), metals (23.9%), pharmaceuticals (9%), natural gas and oil (1%) and biogenic substance (0.5%).

3.3. Factors Affecting the Quality of Surface Water

Seventy-one articles sampled and analyzed surface water such as streams, rivers, lakes, reservoirs, and creeks. The factors affecting the quality of surface water as identified from these studies are pathogens (26.8%), industrial wastes (23.9%), metals and naturally occurring substances (22.5%), pharmaceuticals (12.7%), agricultural wastes (7.0%), wildfire (5.4%), biogenic (1.4%). Table 6 below shows these factors and examples from the study.

3.4. Factors Affecting the Quality of Groundwater

Eighty-eight articles sampled and analyzed ground water which permeates below the soil and stored in the tiny spaces (pores) between rocks and particles of soil. The factors affecting the quality of ground water from the articles reviewed are industrial wastes (32.9%), metals and naturally occurring substances (25%), pathogens (25%), pharmaceuticals (7.9%), agricultural wastes (7.9%), and biogenic (1.1%). Table 7 below shows these factors and examples of the contaminants.

Table 6. Table showing the factors affecting the quality of surface water

Factors affecting surface water	Examples	No of articles	%
Pathogens	Bacteria (Escherichia coli, Enterobacteriaceae), Protozoans (Cryptosporidium and Giardia), Virus (Hepatitis E) etc.	19	26.8
Industrial wastes	Polyfluoroalkyl substances (PFAS), dissolved organic compounds and tri-haloacetic acids	17	23.9
Metals and naturally occurring substances	Arsenic (As), nitrate (NO) and uranium (U)	16	22.5
Pharmaceuticals	Acetaminophen, ampicillin, atrazine, bisphenol-A, caffeine etc.	9	12.7
Agricultural wastes	Nitrate, chloride, and sulfate	5	7.0
Wildfire	Total suspended sediment, dissolved organic carbon	4	5.6
Biogenic	Estrogen, androgen, progesterone	1	1.4
Total		71	

Table 7. A table showing the factors affecting the quality of groundwater

Factors affecting groundwater	Examples	No of articles	%
Industrial wastes	Methane, 1,2,3-Trichloropropane (1,2,3-TCP)	29	32.9
Pathogens	Total coliforms (TCs) and Escherichia coli	22	25
Metals and naturally occurring substances	Arsenic, Manganese (Mn) and Hexavalent chromium, Cr (VI)	22	25
Pharmaceuticals	Acetaminophen, caffeine, carbamazepine	7	7.9
Agricultural wastes	Major and minor inorganic constituents, nutrients, pesticides, and volatile organic compounds VOCs	7	7.9
Biogenic	Estrogen, androgen, progesterone	1	1.1
Total		88	

3.5. Factors Affecting the Quality of Drinking Water at Water Treatment Plants

Twenty-five articles sampled and analyzed water at the water treatment plants before water treatment processes occurred. The leading factor identified was pathogens (28 %) followed by pharmaceuticals (24%), industrial wastes (24%), metals and naturally occurring substances(12%), agricultural wastes (4%), wildfire (4%) and natural disaster (4%). Table 8 below shows the factors affecting the quality of water at the water treatment plants.

3.6. Factors Affecting the Quality of Drinking Water during Water Distribution

One study sampled water in the water distribution network. It assessed the concentrations of halide compounds in the distribution system.

3.7. Factors Affecting the Quality of Tap Water

Seventy-one articles sampled and analyzed tap water. The most observed factor affecting the quality of tap water was pathogens (42.3%) followed by metals and naturally occurring substances (31%), industrial products (12.7%), pharmaceuticals (8.5%), and agricultural wastes (5.6%). Table 10 below shows the factors affecting tap water and examples.

3.8. Factors Affecting the Quality of Bottled Water

Five studies sampled and analyzed bottled water. The factors affecting the quality of bottled water are industrial wastes (40%), metals and naturally occurring substances (40%) and pathogens (20%). Table 11 below shows the factors affecting the quality of bottled water.

Table 8. A table showing the factors affecting the quality of water at the treatment plants

Factors at water treatment plants	Examples	No of articles	%
Pathogens	Aeromonas hydrophilia, L. pneumophila	7	28
Pharmaceuticals	Naproxen, acetaminophen, trimethoprim, and tramadol	6	24
Industrial wastes	Tri(2-butoxyethyl) phosphate, Polychlorinated biphenyls (PCBs)	6	24
Metals and naturally occurring substances	Total organic chlorine (TOCl), bromine (TOBr) and iodine (TOI)	3	12
Agricultural wastes	Nitrate, sulphates	1	4
Wildfire	perfluoro carboxylic acids, perfluoro sulfonates and fluorotelomers.	1	4
Natural disaster	TOC, dissolved organic carbon	1	4
Total		25	

Table 9. A table showing the factors affecting the quality of water during distribution

Factors affecting quality of water during distribution	Examples	No of articles	%
Metals and naturally occurring substance	Total organic chlorine (TOCl), bromine (TOBr) and iodine (TOI) species and collectively total organic halide (TOX) concentrations	1	

Table 10. Factors affecting the quality of tap water

Factors affecting quality of tap water	Examples	No of articles	%
Pathogens	Mycobacterium spp., Escherichia coli and total coliform, algae, Legionella spp. etc.	30	42.3
Metals and naturally occurring substances	Lead, Strontium, Arsenic, Boron, and manganese, Antimony, Chromium, cobalt (Co), Cu, iron (Fe), Pb, Mn, nickel (Ni), Se, Sr, tin (Sn), uranium (U), vanadium (V), and zinc (Zn)	22	31.0
Industrial wastes	Trichloroethylene (TCE), Polyfluoroalkyl substances (PFAS), Vinyl Chloride	9	12.7
Pharmaceuticals	Antibiotics, hormones, analgesics, stimulants, antiepileptics, and X-ray contrast media	6	8.5
Agricultural wastes	Atrazine, pesticides	4	5.6
Total		71	

Table 11. Factors affecting the quality of bottled water

Factors affecting the quality of bottled water	Examples	No of articles	%
Industrial wastes	Fluorobenzene, 1,4-dichlorobenzene, bromodichloromethane	2	40
Metals and naturally occurring substances	Silver, arsenic, barium, beryllium, cadmium, cobalt, chromium, copper,	2	40
Pathogens	Escherichia Coli and coliforms	1	20
Total		5	

4. Discussion

This systematic review highlights some of the factors that affect the quality of drinking water in the United States by reviewing 201 articles published between 2010-2020. We observed that the highest number of articles were from Pennsylvania State and northeast region of the United States. In 2017, Pennsylvania state faced enormous water crisis from lead-contaminated drinking water in Pittsburgh, to sick and dying fish in the Susquehanna, to rainwater runoff contaminated with industrial pollutants in Delaware. The rivers and streams are stressed with many showing signs of ecological decline [25]. Similarly, the whole of the northeast region had its share of water crisis as well during this period. Some of these problems include the presence of lead, iron, manganese, and other metals that give source and tap water in some counties in this region its characteristic smell/odor, color, and hardness. The increasing industrial activities and ageing water distribution pipes have been implicated to be responsible for the challenges in water supply and contamination [26]. Therefore, it is plausible that research and publications on water issues are likely to emanate from region with serious water challenges compared with those with moderate to mild problems.

Majority of the articles sampled and analyzed water from urban settings. Urban areas are hub for commercial activities and the United States Census Bureau states that 80.7% of the U.S. population resides in the urban areas [27]. Also, public water distribution system that supply drinking water to 90% of Americans are also situated there. Urban waters usually carry-on substantial pollution from industrial effluents, commercial wastewater and polluted stormwater runoff which have negative impact on the ecosystems and water quality [28]. However, the unpleasant occurrence of water pollution in an urban area is usually matched with adequate attention and response by the media, civil society, researchers, and government agencies. These may account for the high percentage of water sampling from urban areas among the articles reviewed.

The methodology used in the articles reviewed varied in sampling, study design and analysis because of the heterogeneity of these articles and focus on different factors that affect quality of water. However, the most common study design observed was inductively coupled plasma mass spectrometry. This technique atomizes water sample easily, highly sensitive in detecting metals & non-metals at low concentrations and simultaneously detect multiple trace elements [29]. It can quickly differentiate isotopes of the same element and this characteristic makes it a procedure of choice for identifying undesirable elements in drinking water.

Furthermore, the most common contaminant identified in this study was chemical waste, followed by pathogens. The discharge of chemical wastes into the environment and water bodies is one of the aftermaths of industrialization. Some of these chemical wastes, unfortunately, often find their ways to the tap and consumers' table. Evans et al., observed that the cumulative risk analysis of contaminant occurrence in United States drinking water for the period of 2010-2017 indicated that over 100,000 lifetime cancer cases could be due to carcinogenic chemicals in tap water. Most of this risk is due to the presence of arsenic, disinfection byproducts and radioactive contaminants [30]. Similarly, Andrew and colleagues observed that chemicals like per- and polyfluoroalkyl substances are nearly ubiquitous in surface water, the predominant source of drinking water for the U.S. population. It was estimated that 18–80 million people in the U.S. receive tap water with 10 ng/L or greater concentration of perfluorooctanoic acid and perfluoro-octane sulfonate combined, and over 200 million people likely receive water with a PFOA and PFOS concentration at or above 1 ng/L [31].

4.2. Factors Affecting the Quality of Surface Water

Surface water is any body of water found on the earth's surface, including the saltwater in the ocean and the freshwater in rivers, streams, and lakes. It is highly susceptible to pollution because it runs on earth's surface and easily contaminated by stormwater run-off, human and animal excreta which introduce micro-organisms such as Escherichia Coli and other particulate matter into it. This study identified the following as the factors affecting the quality surface water; pathogens, industrial wastes, metals and naturally occurring substances, pharmaceuticals, agricultural wastes, wildfire, and biogenic substance. Industrial waste is one of the major factors identified that affect the quality surface water. This is in tandem with James et al observation during a multi-agency study of organic and inorganic chemicals in urban stormwater from 50 runoff events at 21 sites across the United States. It was reported that stormwater transports substantial mixtures of polycyclic aromatic hydrocarbons, bioactive contaminants (pesticides and pharmaceuticals), and other organic chemicals known or suspected to pose threat to surface water quality and safety of the environmental [32].

Similarly, per- and poly-fluoroalkyl substances have been recognized as surface water contaminants of emerging concerns by the United States Environmental Protection Agency (USEPA) due to their environmental impact. They have been observed to be several folds higher than the US EPA health advisory level of 70 ng/L for lifetime exposure from drinking water. Direct discharge and atmospheric deposition were identified as primary sources of PFAS in surface water and cryosphere respectively [33]. Agricultural activities such as fertilizers, pesticides and fungicides applications to a farmland also cause contamination of contiguous surface water. Glinski et al., in a study titled, "Analysis of pesticides in surface water, stemflow, and throughfall in an agricultural area in South Georgia" observed that the most frequently detected pesticide in surface water and stemflow samples was met alachlor (0.09–10.5μg/L) and the most detected pesticide in throughfall samples was biphenyl 0.02–0.07μg/L [34]. The presence of these substances makes surface water unfit for swimming, fishing, and drinking purposes due to the negative health effects on human beings.

4.3. Factors Affecting the Quality of Groundwater

Groundwater is the part of rainfall that seeps down through the soil until it reaches rock material that is saturated with water. It is stored in the spaces between rock particles. It is very important because it provides 25% of the fresh water used in the United States and many rural communities depend on it as their source of drinking water [35]. It becomes polluted when contaminants leached from landfills and septic systems into aquifers making it unsafe for human consumption. This study identified industrial wastes, metals and naturally occurring substances, pathogens, pharmaceuticals, agricultural wastes, and biogenic substances as factors affecting the quality of groundwater.

The increasing contamination of ground water by metals and naturally occurring substances, such as arsenic, manganese, and hexavalent chromium was observed to be widespread among the articles reviewed. This is in consonance with McMahon et al observation in a study titled, "Elevated manganese concentrations in United States groundwater, role of land surface–soil–aquifer connections". They reported that an estimated 2.6 million people consume groundwater with elevated manganese concentrations, the highest densities of which occur near rivers and in areas with organic carbon rich soil [36]. Also, Coyte et al., in a study on groundwater titled, "Occurrence and distribution of hexavalent chromium in groundwater from North Carolina, USA", identified several areas in the Piedmont region where chromium Cr (VI) concentrations in groundwater was above health guidelines which posed high human health risks to large populations in the eastern united states [37]. Furthermore, the first large-scale, systematic assessment of hormone and pharmaceutical occurrence in groundwater used for drinking across the United States revealed that at least one compound was detected at 5.9% of 844 sites representing the resource used for public supply across the entirety of 15 Principal Aquifers and detections were most common in shallow wells [38].

4.4. Factors Affecting the Quality of Drinking Water at Water Treatment Plants

Water treatment plants employ processes and modern techniques to treat wastewater until it is clean and safe again for human use. The United States has over 16,000 wastewater treatment plants that treat wastewater that is collected from homes, businesses, and industries. This study identified the following factors that affect the quality of water in treatment plants; pathogens, pharmaceuticals, industrial wastes, metals and naturally occurring substances, agricultural wastes, wildfire, and natural disaster. King et al, obtained drinking water at 25 treatment plants across the United States and screened for nine pathogens. They observed that pathogens are widespread in source waters, but that treatment is generally effective in reducing them to below detection limits. The one exception is the mycobacteria, which were commonly detected in treated water, even when not detected in source waters [39]. Natural disaster is another factor that affects the quality of water depending on its magnitude. The catastrophic destructions that trail events such as hurricane often affect water infrastructure making clean water a serious challenge for the affected communities.

Water treatment plants are very important to reducing human exposure to contaminants and outbreak of diseases. The prevalence of waterborne diseases would be reduced to the barest minimum if water emanating from the treatment plants conform to US EPA regulatory requirements. The Safe Drinking Water Act sets maximum contaminant levels or enforceable standards for some pathogens, which are published in the Code of Federal Regulations (CFR) under Title 40 CFR §141 subpart [40].

4.5. Factors Affecting the Quality of Drinking Water during Distribution

Water distribution system infrastructure comprises the pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, and other components that connect treatment plants or well supplies to consumers' taps. This system is made up of 2.2 million miles of underground pipes called water mains, that deliver safe, reliable water to millions of people.

In this study, only one article sampled water in the water distribution network. It assessed the concentrations of halide compounds in the distribution system. Total organic chlorine (TOCl), bromine (TOBr) and iodine (TOI) species and collectively total organic halide (TOX) concentrations were quantified quarterly at 11 US drinking water treatment plants (WTPs) and distribution systems. It observed increase in TOCl as the intake of dissolved organic chlorine increased in some plants [41].

The challenges with the distribution systems are the ageing infrastructure and breakage along the distribution pipes. In 2020, the average age of water pipes in the U.S. was 45 years old -- an increase in average age from 25 years old in 1970. Each year, 250,000 to 300,000 main breaks occur in the U.S., disrupting supply and risking contamination of drinking water [42].

4.6. Factors affecting the Quality of Tap Water

In this study, the most common factor affecting the quality of tap water was pathogens followed by metals and naturally occurring substances, industrial products, pharmaceuticals, and agricultural wastes. The drinking water is regulated by State and federal laws that stipulate maximum contaminant levels and treatment requirements for some pollutants and naturally occurring constituents. Tap water is safe for drinking in most parts of the United State. However, there is growing distrust among citizens to the extent that some prefer bottled to tap water. Rosinger et al., in a nationally representative U.S. trends analysis of in-home tap water avoidance between 2007 and 2016 observed that younger children, Hispanic, non-Hispanic black, and those from low socioeconomic status backgrounds had consistently higher probability of avoiding tap water over time. Children who avoided tap water had 92% higher prevalence of drinking bottled water. In 2015–2016, 78% of non-Hispanic black children who avoided tap water drank bottled water on a given day [43]. Similarly, Leila et al in a water consumption survey with 1,171 participants, observed that 48% of the respondents reported drinking tap water daily compared with 58% who reported drinking bottled water daily. The reason they cited for not drinking tap water was perceived health risks [44].

4.7. Factors Affecting the Quality of Bottled Water

Over the last decade, annual bottled water consumption increased by 40 percent, reaching a total of almost 44 gallons per person in 2019. This increase may be due to the notion that bottled water is safer than tap water especially among the Hispanic and Black households [45]. Bottled water sometimes contains contaminants that are unsafe for human consumption. This study identified industrial wastes, metals and naturally occurring substances and pathogens as some of the factors that affect the quality of bottled water. This is similar with Chowdhury et al findings in a study titled, "Spectrochemical Analysis of Bottled and Tap Water from Selected Counties of Middle Tennessee, USA. A total of 37 elements were observed in tap and bottled water samples from six counties of Middle Tennessee (USA) by Inductively Coupled Plasma Optical Emission Spectrometry [46].

Chow et al., in a study titled, "detection of ultrashort-chain and other per- and polyfluoroalkyl substances (PFAS) in U.S. bottled water", investigated the occurrence of PFAS and related factors in 101 uniquely labelled bottled water products for sale in the United States. Ultrashort-chain measured for the first time in bottled water, accounted for the greatest individual fraction of detected PFAS mass (42%) and was found almost exclusively in products labeled as Spring water [47].

5. Strength and Limitation

This review was based on a protocol that was created beforehand and outlined the methodology used throughout. Also, a comprehensive search strategy helped to capture large numbers of studies. Blinding during selection and screening of articles helped to reduce bias. This review was limited to studies conducted only in the United States, so it may not be generalizable. However, we made efforts to search relevant databases and retrieved 12,722 articles and reviewed 201 articles in detail Secondly, we did not cover gray literature. Since gray literatures are not published in peer-reviewed journals, we may not have captured all the available literatures on this subject. Third, it was also limited to a narrative analysis and did not include a meta-analysis due to high sample, experimental and statistical plurality.

6. Recommendation and Conclusion

This systematic review highlighted some of the factors that affect the quality of drinking water in the last decade in the United States. It is evident from these literatures that the factors include wastes from industrial activities, pathogenic micro-organisms especially from fecal contamination of water, agricultural practices, naturally occurring substances, pharmaceutical substances, and natural disasters. The consequences of these factors on human health and ecosystems can be reduced to the barest minimum by taking specific action to address them. We therefore want to make the following recommendations

a) Unites States Environmental Protection Agency (US EPA) should be given more human and material resources to enforce the Safe Drinking Water Act (SDWA) and synergize with states in enforcing their own drinking water standards
b) Regulation of discharge of industrial effluents into the environment or water bodies
c) Routine testing of private and public water supplies for various contaminants on a periodic basis to ascertain changes in contaminant levels.
d) Communities and individuals should take more active roles in protecting drinking water sources from pollution.
e) Refurbishing ageing water infrastructure

In conclusion, drinking water sources are contaminated by natural substances in the environment and human activities. Such contaminated water is not only injurious to human health and other living organisms, but it also kills. In fact, globally it caused 1.8 million deaths in 2015 and makes about 1 billion people sick every year [48]. The burden of waterborne diseases in the United States show that every year, waterborne diseases cause 7.15 million illnesses and 6,630 deaths and cost our healthcare system more than $3.3 billion [49]. Therefore, to mitigate the negative impact of contaminated drinking water on humans, there must be concerted effort to implement appropriate water policies, protect water sources and invest in water infrastructure for an enduring and sustainable future.

Conflicts of Interest

The authors declare no conflicts of interest exist

Authors' Contributions

KO conceived and designed the study under the supervision of SK. LC is a University Librarian who designed the search strategy and extracted the articles from the databases. KO and PJ independently screened and assessed the articles for eligibility. KO and PJ extracted the results from the excel sheet. KO drafted the manuscript. All authors critically reviewed the manuscript and approved the final version.

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Table 5. An Excel sheet showing all the articles included in this study (supporting documents)