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Effect of Coliform Bacteria on Various Environmental Factors: A Review

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ABSTRACT

Sewage sludge is a mud-like residue generated from wastewater treatment that contains pollutants such as heavy metals, fecal coliforms, Escherichia coli, Salmonella, and other harmful bacteria. Coliform bacteria are rod-shaped Gram-negative non-spore forming motile or non-motile bacteria that may ferment lactose with the production of acid and gas when grown at 35-37°C. The presence of coliform bacteria in sludge is a serious problem for both human health ranging from mild gastrointestinal complaints to more severe illnesses and, environmental safety. Controlling coliform bacteria demands proper sludge management, treatment, and disposal. Appropriate treatment processes, such as aerobic digestion and composting, can reduce the number of coliform bacteria in sludge. Several nanoparticles, including silver nanoparticles (AgNPs), titanium dioxide nanoparticles (TiO2NPs), and copper nanoparticles (CuNPs), play a significant role as anti-microbial agents and may be effective in the disinfection of E. coli. The United States Environmental Protection Agency (EPA) has set regulations governing the maximum allowable number of coliform bacteria in sludge. This review provides an overview of the origins of coliform bacteria in sludge, their health concerns, strategies for identification, and various degradation techniques along with their limitations.

Keywords: Coliform, Environment, Regulatory bodies, Degradation, Nanotechnology.

INTRODUCTION

Sludge is a semi-solid substance formed during wastewater treatment [1]. It is made up of organic particles, nutrients, and microbes such as coliform bacteria [2]. Coliform bacteria are frequently regarded as markers of fecal contamination which are frequently identified in association with enteric pathogens [3]. Several coliform bacteria, such as Erwinia and Enterobacter, are often part of the natural flora of many vegetables and usually do not indicate a potential public health problem [4]. Fecal coliforms, a similar subset of the coliforms, are frequently used to detect the presence of E. coli in water. The existence of this organism may indicate fecal contamination and be related to the use of polluted irrigation water, the presence of feces, or poor sanitation and hygiene practices [5]. Vegetables can, however, contain microbes other than E. coli that cause fecal coliform tests to be positive. For instance, only 29% of vegetables that tested positive for fecal coliforms contained recoverable E. coli [6]. False positive results for fecal coliform tests were caused by other bacteria such as Klebsiella pneumoniae, Enterobacter cloacae, Enterobacter agglomerans, and Enterobacter aerogenes. Hence, fecal coliform testing may be helpful when water quality or good hygiene is in question, but positive results may not necessarily point to a problem. Various methods and tools are required to detect the presence of fecal coliforms in food [7]. Prudent management of water resources towards a targeted level of drinking water quality is necessary for the security of a town's water supply. It is crucial to identify pollution sources and channels before putting effective mitigation techniques in place to reduce hazards to source water. Fecal bacteria are regarded as a health risk in sources of drinking water since they may be a sign of human viruses or parasites like Giardia or Cryptosporidia [8]. Risk levels for municipal water supply wells compare favorably about coliform detection in groundwater risk assessment research [9] employing a multi-barrier analysis technique. 142 of the 144 town water supply wells in South Australia showed coliform detection, with rates ranging from 1% in low-risk confined aquifers to 87% in high-risk unconfined aquifers in karst limestone. Also, E. coli has been found in shallow wells, but in low concentrations and at low frequency. The management of water quality has been concerned about the occurrence of coliforms in several of the low-risk, enclosed, and semi-enclosed deep wells. E. coli was found in 92.6% of samples from protected public water supply wells and 100% of those from unprotected wells [10]. In recent research, intestinal Enterococci and E. coli were reported to be present in 56.2% and 72.9%, respectively, of the studied drilled wells that had coliform bacteria contamination [11]. In the United States (US), illnesses brought on by pathogens, present in water continue to be a major cause of sickness. According to data from the US's waterborne disease surveillance program, groundwater sources were responsible for roughly 74% of confirmed outbreaks of waterborne diseases that occurred between 2001 and 2002 [12]. Regulations on the highest permissible concentrations of coliform bacteria in sludge have been established by the United States Environmental Protection Agency (EPA) [13]. Before it may be utilized for certain reasons, such as fertilizing farmland, sewage treatment plants must test their sludge for coliform bacteria and make sure it complies with these guidelines [14, 15]. Moreover, the development and spread of coliform bacteria can be reduced by careful treatment and storage of sludge. To reduce exposure to potentially hazardous microorganisms, sludge should be handled while wearing the proper protective clothing and kept in a safe area away from potential sources of contamination [16]. This review emphasizes the numerous issues, its management techniques with limitations, and the regulatory authorities involved with fecal pollution in the environment due to the presence of coliform bacteria in sewage sludge.

Brief details about coliform bacteria

Since the existence of coliform bacteria may indicate the presence of potentially harmful pathogens, they are frequently used as indicators of fecal contamination in water and soil [17]. Rainfall, temperature, pH, and the amount of organic matter can all impact their occurrence in soil. These have also been identified in both surface and groundwater [18]. They can infiltrate water sources through several channels, including agricultural runoff, sewage overflows, and faulty septic systems [19]. The coliform bacteria in water can suggest the presence of dangerous pathogens such as E. coli [20]. It is crucial to emphasize that coliform bacteria do not imply the presence of hazardous pathogens, but it suggests some possible risks [21].

Prevalence

Several factors, such as the wastewater source, the kind of treatment process, and the storage and handling conditions, affect the proportion of coliform bacteria in sludge. Yet since they are abundant in both human and animal faeces, which make up a sizeable portion of wastewater, coliform bacteria are frequently discovered in sludge. According to studies, the number of colony-forming units (CFU) of coliform bacteria per gram (CFU/g) in sludge can vary from less than 103 to over 108. According to WHO recommendations, sludge should include concentrations of fewer than 1,000 CFU/g and, fecal coliform bacteria concentrations of less than 1,000 CFU/g [22, 23]. It is critical to keep in mind that sludge is not always harmful just because it includes coliform bacteria. To make sure the sludge is suitable for disposal or beneficial use and to safeguard public health, regular testing and monitoring of the concentration of coliform bacteria and other pathogens in the sludge is crucial [24, 25].

Genetics

Coliform bacteria are a group of gram-negative, rod-shaped bacteria that are commonly found in the intestinal tract of humans and animals. These bacteria are used as indicators of fecal contamination in water, soil, and sludge [26]. The genetic makeup of coliform bacteria can vary depending on the specific species and strain. However, most coliform bacteria contain plasmids, which are small, circular pieces of DNA that can replicate independently of the bacterial chromosome. Plasmids often carry genes that confer antibiotic resistance, virulence, or other traits that can give the bacteria a selective advantage. In sludge, coliform bacteria can be present due to the presence of human or animal waste, as well as other sources such as food processing facilities [27]. The genetic makeup of these bacteria can be studied using various techniques, such as whole genome sequencing or PCR (polymerase chain reaction) amplification of specific genes. Understanding the genetic makeup of coliform bacteria in sludge can be important for several reasons. For example, it can help to identify potential sources of contamination and track the spread of antibiotic resistance genes [28]. In addition, some strategies might be useful for the safe and effective management of sludge as a waste product.

Furthermore, epigenetics is the study of changes in gene expression that occur without changes in the underlying DNA sequence. In coliform bacteria, epigenetic modifications can have a significant impact on their ability to survive and thrive in different environments, including sludge [29]. The epigenetic modifications in coliform bacteria in sludge can affect their ability to break down organic matter and survive in this environment [30]. One example of an epigenetic modification that may occur in coliform bacteria in sludge is DNA methylation, the addition of a methyl group to a cytosine base in the DNA molecule. This modification can affect gene expression by altering the accessibility of the DNA to transcription factors and other proteins involved in gene regulation [31]. In some cases, DNA methylation may be involved in regulating the expression of genes involved in the breakdown of organic matter in sludge. Another example of an epigenetic modification that may occur in coliform bacteria in sludge is histone modification. Histones are proteins that help package DNA into the compact structure of chromatin. Modifications to histones, such as acetylation or methylation, can affect the accessibility of the DNA and regulate gene expression [5]. In some cases, histone modifications may be involved in regulating the expression of genes involved in the breakdown of organic matter in sludge. However, the epigenetics of coliform bacteria in sludge is an area of active research, with potential implications for wastewater treatment and bioremediation [32].

IMPACT OF COLIFORM BACTERIA ON VARIOUS ENVIRONMENTAL FACTORS

When coliform bacteria are found in sludge, they can generate a variety of issues. If coliform bacteria-containing sludge is spread to soil or utilized as a fertilizer, it can pollute the soil and adjacent water sources [33]. This can endanger people’s health if they come into touch with polluted soil or water [34]. Coliform bacteria are a possible health risk since they are markers of fecal contamination and can transmit diseases that cause sickness in people and animals, such as Salmonella and E. coli. If coliform bacteria-containing sludge is not adequately treated or handled appropriately, it can endanger public health. As coliform bacteria degrade organic materials in the sludge, they emit foul odors that can be bothersome to neighboring inhabitants. Many nations have restrictions in place to limit the number of coliform bacteria in sludge. If sludge includes significant amounts of coliform bacteria, it can lead to regulatory noncompliance and, ultimately, fines or other penalties. Coliform bacteria can degrade sludge quality by emitting unpleasant aromas, lowering nutritional content, and making it more difficult to treat and manage [35]. Water supply has been a vital aspect of society since the birth of human civilization for a variety of functions including drinking, agriculture, industry, home, and so on. Many of the health issues in impoverished nations are caused by a lack of clean drinking water [36, 37]. As per the report of WHO, over 600 million episodes of diarrhea and dysentery are reported each year, with 46000 newborn deaths occurring as a result of dirty water and inadequate sanitation [38]. Water scarcity affects about 1.2 million people in developing nations, with the number predicted to rise to 1.8 million by 2025 due to a lack of sustainable legislation or a proper management plan for the reuse of treated wastewater in agricultural production [39]. There is a rising need for water in dry places, which has resulted in the use of wastewater in agriculture to minimize the pressure on freshwater resources. Around 70% of treated wastewater is utilized in agriculture [40], which can have negative environmental and health consequences. Determining the quantity of various microbiological pathogens in partially treated wastewater samples is critical and can allow for an accurate assessment of the treatment process. There are always concerns and precautions concerning the negative impact of using treated wastewater to irrigate food crops [41].

As a result, international and local organizations are concerned about establishing guidelines for the reuse of treated wastewater in agriculture [42]. Plant production of corn, potato, lettuce, olive trees, and alfalfa irrigation with treated wastewater increased compared to plants irrigated with natural water resources, which could be attributed to the presence of plant nutrients (primarily nitrogen and phosphorus) in the treated wastewater, but the risk due to the presence of some pathogens is still being considered [43, 44]. Fecal coli bacteria are found in human and animal feces and are mostly innocuous to people's intestines. The most prevalent type of fecal coli bacteria is E. coli. Streptococcus species can also cause pneumonia, ear infections, and meningitis [45]. Fecal streptococci, like fecal coli bacteria, are utilized as markers of water contamination and have been used for many years to assess the quality and safety of water for irrigation and human consumption [22]. Waterborne infections can cause gastrointestinal problems such as severe diarrhea, nausea, and perhaps jaundice, as well as headaches and exhaustion [46].

It is crucial to highlight, however, that these symptoms are not just connected with disease-causing organisms in drinking water. They might also be caused by a variety of other circumstances. In addition, not all persons will be impacted to the same degree; younger children and the elderly are frequently more sensitive [3, 47]. Coliform bacteria in sludge can have serious environmental, economic, and public health effects. In addition, it is critical to monitor and regulate the prevalence of these bacteria in sludge, as well as to guarantee that sludge is treated correctly and safely.

WHY EUROPEAN COMMISSION BANNED COLIFORM BACTERIA?

The European Commission has not imposed any ban on coliform bacteria [48]. The European Union has developed guidelines for tolerable coliform bacteria levels in drinking water and food. The European Drinking Water Directive, for example, limits the number of colony-forming units (CFU) of E. coli (a kind of coliform bacteria) to 0 per 100 milliliters of drinking water [21, 49]. Nonetheless, it is crucial to emphasize that the European Commission and national authorities in the EU take food and water safety seriously and periodically test for the presence of hazardous bacteria, including coliform bacteria, to protect public health [50]. If required, they may issue recalls or take other precautions to prevent the spread of hazardous microorganisms.

ADVERSE SIDE OF COLIFORM BACTERIA

The presence of fecal coliform bacteria in water sources, in particular, might suggest the presence of pathogens such as E. coli, which can cause gastrointestinal disease and other health issues [17]. Coliform bacteria are a worldwide problem because polluted water may cause epidemics of sickness in populations. The danger of coliform bacteria infection is especially significant in places with poor sanitation facilities or restricted access to clean water. The World Health Organization estimates that over 2 billion people worldwide lack access to adequate drinking water [51], and waterborne infections are responsible for an estimated 3.4 million fatalities per year [52]. Coliform bacteria exposure can have a substantial economic impact in addition to impacting human health. Waterborne infections can result in lost productivity and higher healthcare expenditures, as well as harm to businesses that rely on clean water supplies, such as agriculture and tourism. To address the dangerous feature of coliform bacteria, appropriate water management methods, such as frequent monitoring and treatment of water sources, as well as encouraging good hygiene and sanitation practices in communities, are essential. Governments, non-governmental organizations, and individuals may all help to ensure that everyone has access to clean drinking water [51]. In India, many initiatives have been implemented to mitigate the negative impact of coliform bacteria. The Indian government has set up a water quality monitoring program to guarantee that drinking water is safe and free of hazardous microorganisms. This approach includes frequent testing of water samples for coliform bacteria and other pollutants [53]. India has also made investments in water treatment facilities to eliminate toxins like coliform bacteria from drinking water. This covers the sterilization of water using chlorine, ozone, and UV light [54]. To raise awareness of the value of clean water and good hygiene habits, the Indian government has undertaken public education initiatives. This involves teaching people about the dangers of consuming water infected with coliform bacteria and the significance of boiling water before drinking it [55]. To lessen the quantity of human waste that enters rivers and facilitates the spread of coliform bacteria, the Indian government has invested in enhancing sanitary infrastructure, including public toilets [56]. The number of coliform bacteria that can be present in drinking water is regulated and subject to rules in India [57]. Nevertheless, these initiatives have helped to lessen the negative effects of coliform bacteria on public health in India, but there is still more work to be done to guarantee that all Indians have access to safe and clean drinking water.

DEGRADATION METHODS OF COLIFORM BACTERIA

Warm-blooded animals' faeces include coliform bacteria, and their presence in sludge implies contamination with human or animal waste. It is recognized that a mix of physical, chemical, and biological elements govern the process that lowers the population of pathogens and coliform in the water treatment process [58-60]. A mix of chemical, physical, and biological techniques can be utilized to remediate sludge contaminated with coliform bacteria. To disinfect and eliminate coliform bacteria, sludge can be treated with several chemicals, including chlorine, ozone, or hydrogen peroxide [61]. The environment must not be harmed by the chemicals utilized, and harmful by-products must also be avoided. Coliform bacteria can be eliminated with the potent disinfectant chlorine [62]. A chlorine solution may be used to treat the sludge; this will cause the bacteria in the sludge to react and die [63]. When treating sludge tainted with coliform bacteria, another potent disinfectant called ozone can be used. It is possible to kill bacteria by passing ozone gas through the sludge (Ozone Applications). Heat can be used to destroy coliform bacteria in sludge. The sludge can be heated to a temperature of at least 70°C for a length of time, which will eradicate the bacteria [64]. Filtration can be used to remove coliform bacteria from sludge. A sand or charcoal filter, for example, can be used to pass the sludge through a filter that can get rid of the bacteria [65]. Ultraviolet (UV) radiation is a non-chemical disinfection approach in which sludge is exposed to UV light. UV radiation can kill coliform bacteria by causing DNA damage [66]. Aerobic digestion is a biological process that breaks down organic matter in sludge by using oxygen. Because the bacteria will be destroyed by the microorganisms responsible for digestion, this approach can also be employed to kill coliform bacteria [67]. Anaerobic digestion is another biological approach that may be utilized to treat coliform bacteria-contaminated sludge. To break down organic content in the sludge, this procedure employs microorganisms that do not require oxygen [68, 69]. The bacteria that are responsible for anaerobic digestion will also devour coliform bacteria, killing them [70].

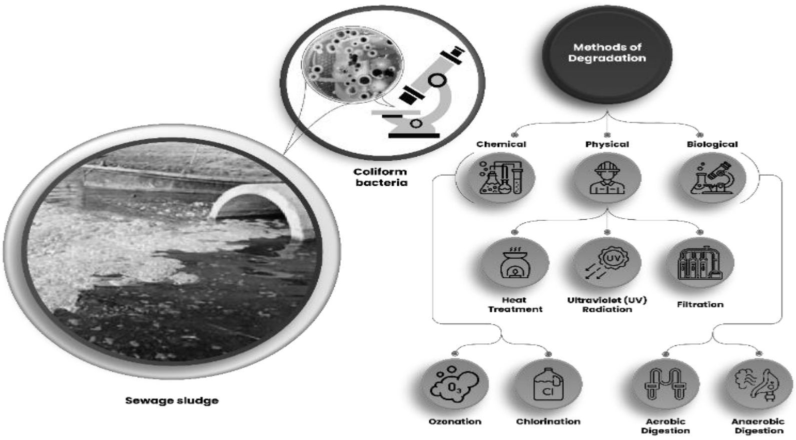

Fig. 1 Various methods for coliform bacteria degradation

It is crucial to note that these methods' efficacy can change depending on a variety of variables, including the type and quantity of coliform bacteria present in the sludge, its composition, and the conditions under which the treatment is conducted. Therefore, it is recommended to consult with experts or regulatory agencies to determine the most appropriate treatment method for specific situations [33].

Around the world, 1.1 billion people continue to drink water that has been tainted with fecal microorganisms [71]. Detecting each waterborne pathogen is complex; therefore, a standard reproducible microbial water quality test was developed by the International Organization for Standardization (ISO) to test the water quality. The detection of specific bacterial species serves as a fecal contamination indicator in this method [72]. The most extensively utilized markers are total coliform, Enterococci, and E. coli [73]. The water quality of a region is, however, influenced by several physicochemical factors in addition to bacterial pathogens. For the safe and sanitary water index, there are standardized recommendations from both WHO and BIS (Bureau of Indian Standards) [72, 74].

There are several ways already employed for coliform bacteria destruction in sludge, including physical, chemical, and biological treatments [75, 76], as illustrated in Figure 1. The efficiency of each approach may vary based on the exact characteristics of the sludge and the treatment procedure employed. Thermal treatment is the process of heating sludge to high temperatures to kill coliform bacteria. The most common thermal treatment method is the use of an anaerobic digester, which can operate at temperatures ranging from 35°C to 55°C [77]. Studies have shown that anaerobic digestion can reduce coliform bacteria by up to 99.9% [78-80]. The employment of chemicals to cleanse the sludge and kill coliform bacteria is known as chemical treatment. Chlorine is the most commonly utilized chemical for this purpose [63]. Chlorination has been proven in studies to eliminate coliform bacteria by up to 99.9%. UV radiation is the use of UV light to destroy coliform bacteria [81]. UV light has been demonstrated in studies to eliminate coliform bacteria by up to 99% [82]. Ozonation is the process of disinfecting sludge using ozone gas and killing coliform bacteria. According to research, ozonation can eliminate coliform bacteria by up to 99% [49]. Microorganisms are used in biological therapy to decompose coliform bacteria. The utilization of activated sludge systems is the most frequent biological treatment technology, which may eliminate coliform bacteria by up to 99% [83-85]. To summarise, all of the approaches discussed above are efficient in eliminating coliform bacteria in sludge, with various degrees of efficacy depending on the method and sludge conditions. The treatment technique chosen will be determined by criteria such as cost, efficacy, and environmental impact.

COLIFORM BACTERIA DEGRADATION VIA MECHANISM

Coliform bacteria can be eliminated by a variety of techniques, including biological treatment procedures such as activated sludge, trickling filters, and biofilm reactors [86]. These methods rely on the employment of microorganisms, such as coliform bacteria, to break down and absorb organic debris and nutrients in wastewater. Activated sludge is a popular biological treatment procedure that includes aerating wastewater in a reactor tank with a culture of microorganisms [87]. Microorganisms, such as coliform bacteria, eat organic materials and convert them to biomass and various by-products. Before release, the treated wastewater is separated from the biomass in a settling tank. A trickling filter is another biological treatment method that employs a bed of porous media, such as gravel or plastic media, as a substrate for microbial growth [68]. The effluent is sprayed over the medium, where microorganisms, notably coliform bacteria, break down the organic materials. Biofilm reactors include the formation of a microbial biofilm on a support medium, such as plastic media or membranes. The biofilm serves as a surface for microorganisms to adhere to and proliferate, resulting in a dense microbial population capable of breaking down organic materials in wastewater, including coliform bacteria [88]. Other strategies for coliform bacteria degradation, in addition to biological treatment procedures, include chemical oxidation, UV disinfection, and ozonation [89]. Chemical oxidation is the process of breaking down organic materials and killing coliform bacteria by using powerful oxidizing chemicals such as hydrogen peroxide or chlorine. UV disinfection uses high-energy UV radiation to damage coliform bacteria's DNA, stopping them from reproducing. Ozonation is the process of using ozone gas to break down organic debris and cleanse wastewater, eliminating coliform bacteria.

NANOTECHNIQUES: A FUTURISTIC DEVELOPING APPROACH

Nanotechnology is an advanced technique that may play a significant role in coliform bacteria degradation [90]. Some advanced techniques including photocatalysis, nanoscale sensors, nanomaterial filtration, nano biosensors, etc. might be beneficial to degrade the coliform bacteria from wastewater, as shown in Figure 2. Nanoparticles like AgNPs, titanium dioxide TiO_2NPs, and CuNPs have demonstrated antimicrobial properties. These nanoparticles can be used to coat or impregnate sludge materials, aiding in the disinfection and reduction of coliform bacteria. Also, nanoparticles can serve as carriers for antibiotics or antimicrobial agents, ensuring controlled and sustained release in sludge to combat bacterial growth [91]. An alternate approach that effectively kills E. coli from water is the use of inexpensive filter materials coated with AgNps [92]. Advanced oxidation processes, such as photocatalysis using nanomaterials like TiO_2 or ZnO, can generate reactive oxygen species (ROS) that effectively kill bacteria in sludge [93]. Further, nanomaterials like graphene oxide and carbon nanotubes can be used in water filtration systems to effectively remove coliform bacteria and other contaminants [94]. Although, nanomaterials have a high surface-to-volume ratio, high sensitivity and reactivity, high adsorption capacity, and ease of functionalization, making them ideal for coliform degradation in sludge [95]. Nanoscale photocatalysts, such as TiO_2NPs, can be employed in water treatment systems [96]. Nanofiltration and ultrafiltration membranes containing nanoscale pores can be used to physically separate and remove coliform bacteria from sludge, providing an effective means of purification [97]. When exposed to ultraviolet (UV) light, these nanoparticles generate reactive oxygen species that can break down and kill coliform bacteria [98]. Moreover, nano-sized delivery systems can encapsulate disinfectant agents, such as antimicrobial peptides or chemicals, and release them gradually to target and eliminate coliform bacteria in a controlled manner [91]. Nanotechnology has also led to the development of highly sensitive nanosensors that can rapidly detect and quantify coliform bacteria in water, allowing for early contamination monitoring and response [99]. Nanoscale biosensors can detect specific coliform bacteria strains, enabling precise targeting and treatment [100]. Nanotechnology can be used to design advanced membranes with nanoscale pores that effectively filter out coliform bacteria while maintaining high water flow rates [101].

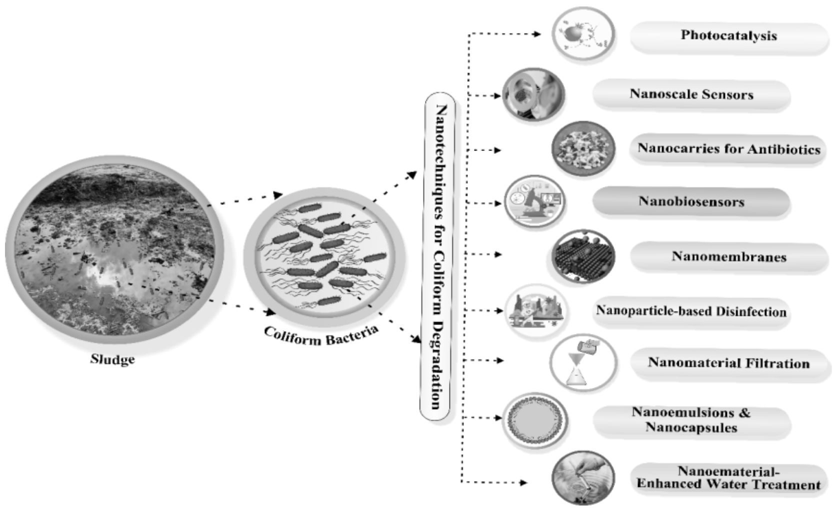

Fig. 2 Advanced techniques useful to degrade coliform bacteria in wastewater

Hence, these nanotechnology applications offer innovative and efficient approaches to tackle coliform bacteria contamination in various settings, including drinking water treatment, wastewater treatment, and healthcare facilities.

LIMITATIONS OF DEGRADATION TECHNIQUES

Coliform bacteria degradation is a crucial step in sludge treatment that is required to lower the risk of pathogen transmission and improve the end product quality. Yet, diverse strategies for coliform bacteria breakdown in sludge might have downsides. Anaerobic digestion is a widespread approach for sludge treatment, however, it has limits for the breakdown of coliform bacteria [102]. Also, composting is a natural process that may be used to decompose coliform bacteria, but it requires a specific combination of parameters, including optimal temperature, moisture, and oxygen levels. If these criteria are not satisfied, the procedure may not be successful, resulting in the partial destruction of coliform bacteria [103]. While decomposing coliform bacteria at high temperatures can be efficient, it can also be energy-intensive and costly. Furthermore, the technique may release odors and generate air pollution, which can be a significant negative. Chemical treatment degrades coliform bacteria using chlorine or ozone, which can be effective but also expensive and produce harmful by-products. Moreover, the usage of chemicals might hurt the environment [104]. Since each technique for coliform bacteria breakdown in sludge has advantages and disadvantages, it is important to consider several factors before selecting one. These factors include the kind of bacteria, the concentration of the sludge, and the available resources.

CONCLUSIONS

In conclusion, coliform bacteria are typically found in sludge and pose a concern to public health if not adequately managed. Several research has been conducted to explore the breakdown of coliform bacteria in sludge, and a range of treatment strategies have been utilized to eliminate or lower the bacterial burden. Physical, chemical, and biological approaches have been explored to remediate sludge, with encouraging results. Physical treatments including heat treatment, UV irradiation, and filtration have been shown to reduce coliform levels. Chemical treatments, such as the use of disinfectants such as chlorine, ozone, and hydrogen peroxide, have also demonstrated considerable decreases in coliform levels. Biological approaches such as aerobic and anaerobic digestion have proved successful in lowering coliform numbers in sludge. The process's efficiency, however, is affected by variables such as pH, temperature, and sludge retention time. Overall, treating coliform bacteria in sludge is an important step in protecting public health and environmental safety. The treatment technique used is determined by the sludge's individual features as well as the desired amount of coliform reduction. Future research can concentrate on the development of novel and more effective treatment strategies for coliform bacteria in sludge. Advanced oxidation processes (AOPs) such as the Fenton reaction, Photo-Fenton reaction, and electrochemical oxidation, for example, can be further examined. Additionally, the application of innovative technologies such as nanotechnology, membrane separation, and microbial fuel cells (MFCs) to lower coliform levels in sludge can be examined. Finally, continuing research and development of treatment methods will help to reduce the hazards associated with coliform bacteria in sludge while also protecting public health and the environment.

Declaration by Authors

Ethical Approval: Not Applicable

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REFERENCES

1. Demirbas A, Edris G, Alalayah WM. Sludge production from municipal wastewater treatment in sewage treatment plant. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2017 May 19;39(10):999-1006.
2. Fijalkowski K, Rorat A, Grobelak A, Kacprzak MJ. The presence of contaminations in sewage sludge–The current situation. Journal of environmental management. 2017 Dec 1;203:1126-1136.
3. Department of Health-Coliform Bacteria. 2022. Available from https://www.health.state.mn.us/communities/environment/water/factsheet/coliform.html
4. Taylor S. Postharvest handling: a systems approach. Academic Press; 2012 Dec 2.
5. Li E, Saleem F, Edge TA, Schellhorn HE. Biological indicators for fecal pollution detection and source tracking: A review. Processes. 2021 Nov 17;9(11):2058.
6. Splittstoesser DF, Corlett Jr DA. Aerobic plate counts of frozen blanched vegetables processed in the United States. Journal of food protection. 1980 Sep 1;43(9):717-719.
7. Mehlman IJ. Coliforms, fecal coliforms, Escherichia coli and enteropathogenic E. coli. Compendium of methods for the microbiological examination of foods. 1984;2.
8. Edberg SC, LeClerc H, Robertson J. Natural protection of spring and well drinking water against surface microbial contamination. ii. indicators and monitoring. parameters for parasites. Critical reviews in microbiology. 1997 Jan 1;23(2):179-206.
9. Somaratne N, Zulfic H, Ashman G, Vial H, Swaffer B, Frizenschaf J. Groundwater risk assessment model (GRAM): groundwater risk assessment model for wellfield protection. Water. 2013 Sep 18;5(3):1419-1439.
10. Opisa S, Odiere MR, Jura WG, Karanja DM, Mwinzi PN. Faecal contamination of public water sources in informal settlements of Kisumu City, western Kenya. Water Science and Technology. 2012 Dec 1;66(12):2674-2681.
11. Staradumskyte D, Paulauskas A. Non-fermentative gram-negative bacteria in drinking water. Journal of Water Resource and Protection. 2014 Feb 14;2014.
12. Hynds PD, Misstear BD, Gill LW. Development of a microbial contamination susceptibility model for private domestic groundwater sources. Water Resources Research. 2012 Dec;48(12).
13. Epa U. United States environmental protection agency. Quality Assurance Guidance Document-Model Quality Assurance Project Plan for the PM Ambient Air. 2001 Mar;2:12.
14. Reilly M. The case against land application of sewage sludge pathogens. Canadian Journal of Infectious Diseases and Medical Microbiology. 2001 Jul 1;12:205-207.
15. Al-Gheethi AA, Efaq AN, Bala JD, Norli I, Abdel-Monem MO, Ab. Kadir MO. Removal of pathogenic bacteria from sewage-treated effluent and biosolids for agricultural purposes. Applied Water Science. 2018 May;8:1-25.
16. CDC-Centers for Disease Control and Prevention. 2023. Available from https://www.cdc.gov/healthywater/emergency/sanitationwastewater/workers_handlingwaste.html
17. WSDH-Washington State Department of Health: Coliform Bacteria and Drinking Water. 2023. Available from https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs//331-181.pdf?uid=624aca46d7332
18. Campos Pinilla MC, Medina Córdoba LK, Piedad Fuentes N, García Montoya GI. Assessment of indicators of fecal contamination in soils treated with biosolids for growing grasses. Universitas Scientiarum. 2015 Aug;20(2):217-227.

19. NRDC-Water Pollution: Everything You Need to Know. 2023. Available from https://www.nrdc.org/stories/water-pollution-everything-you-need-know
20. Shmeis RM. Water chemistry and microbiology. InComprehensive analytical chemistry 2018 Jan 1 (Vol. 81, pp. 1-56). Elsevier.
21. New Nouveau Brunswick-Facts on Drinking Water Coliform Bacteria-Total Coliforms & E. coli. Available from https://www2.gnb.ca/content/dam/gnb/Departments/h-s/pdf/en/HealthyEnvironments/water/Coliforme.pdf
22. WHO-World Health Organization. 1989. Health guidelines for the use of wastewater in agriculture and aquaculture. Report of a WHO Scientific Group. Geneva, (Technical Report Series, No. 778).
23. WHO-World Health Organization. 2006. WHO guide lines for the safe use of wastewater, excreta and greywater: wastewater use in agriculture, vol. II. World Health Organization, France. Available from http://whqlibdoc. who.int/publications/2006/9241546832_eng .pdf.
24. WHO-World Health Organization. 2004. Guidelines for drinking-water quality (Vol. 1).
25. Boqvist S, Söderqvist K, Vågsholm I. Food safety challenges and One Health within Europe. Acta Veterinaria Scandinavica. 2018 Dec;60:1-13.
26. Chaudhry Q, Blom-Zandstra M, Gupta S, Joner EJ. Bacterial diversity and composition in different substrates and depths of sludge from a full-scale anaerobic wastewater treatment plant. Journal of Environmental Management. 2018;218:426-433.
27. Salles JF, Van Elsas JD, Van Veen JA. Effect of agricultural management regime on Burkholderia community structure in soil. Microbial Ecology. 2006 Aug;52:267-279.
28. Singh A, Grover A. Molecular detection and characterization of antibiotic resistant Enterococcus faecalis from municipal wastewater and sludge samples. Journal of Environmental Chemical Engineering. 2015;3:1583-1593.
29. Liao Y, Smyth WF, Yang X. Epigenetic regulation in bacteria. Current Opinion in Microbiology. 2017;36:126-131.
30. Singh BK, Bardgett RD, Smith P, Reay DS. Microorganisms and climate change: terrestrial feedbacks and mitigation options. Nature Reviews Microbiology. 2010 Nov;8(11):779-790.
31. Pecson BM, Triolo JM. What is the risk of infection from wastewater and sludge? Water Environment Research. 2016;88(3):184-205.
32. Duan Y, Zhou Z, Liu C, Chen J. Epigenetic regulation of bacterial pathogenesis and antibiotic resistance. Frontiers in Cellular and Infection Microbiology. 2019;9:116.
33. Edmonds RL. Survival of coliform bacteria in sewage sludge applied to a forest clearcut and potential movement into groundwater. Applied and Environmental Microbiology. 1976 Oct;32(4):537-546.
34. Srikullabutr S, Sattasathuchana P, Kerdsin A, Thengchaisri N. Prevalence of coliform bacterial contamination in cat drinking water in households in Thailand. Veterinary World. 2021 Mar;14(3):721-726.
35. EPA-Water: Monitoring & Assessment. 2012. Available from https://archive.epa.gov/water/archive/web/html/vms511.html
36. Gray NF. An introduction for environmental scientists and engineers. Water Technology p. 2000.
37. Bylund J, Toljander J, Lysén M, Rasti N, Engqvist J, Simonsson M. Measuring sporadic gastrointestinal illness associated with drinking water–an overview of methodologies. Journal of water and health. 2017 Jun 1;15(3):321-340.
38. Singh RK, Iqbal SA, Seth PC. Bacteriological pollution in a stretch of river Narmada at Hoshangabad, Madhya Pradesh. Pollution Research. 2001;20(2):211-213.
39. FAO (2007). Coping with water scarcity. Challenge of the twenty-first century. UN-Water. Available from https://www.google.com/search?q=Coping+with+water+scarcity.+Challenge+of+the+twenty-first+century.+UN-Water%2C+FAO%2C+2007&ie=utf-8&oe=utf-8
40. Cytryn E. Effect of treated wastewater irrigation on antibiotic resistance in agricultural soil bacteria. Environ. Health Problem. 2010.

41. Toze S. Reuse of effluent water—benefits and risks. Agricultural water management. 2006 Feb 24;80(1-3):147-159.
42. Mandi L, Abissy M. Utilization of Arundo donax and Typha latifolia for heavy metals removal from urban wastewater. Reuse of treated wastewaters for alfalfa irrigation. In3rd international symposium on wastewater, reclamation, recycling and reuse (Paris, 3-7 July 2000) 2000 (pp. 158-165).
43. Kouraa A, Fethi F, Fahde A, Lahlou A, Ouazzani N. Reuse of urban wastewater treated by a combined stabilisation pond system in Benslimane (Morocco). Urban water. 2002 Dec 1;4(4):373-378.
44. Lopez A, Pollice A, Lonigro A, Masi S, Palese AM, Cirelli GL, Toscano A, Passino R. Agricultural wastewater reuse in southern Italy. Desalination. 2006 Feb 5;187(1-3):323-334.
45. Ashraf MA. Persistent organic pollutants (POPs): a global issue, a global challenge. Environmental Science and Pollution Research. 2017 Feb;24:4223-4227.
46. World Health Organization. Escherichia coli diarrhoea. WHO Scientific Working Group. Bulletin of the World Health Organization. 1980;58(1):23-36.
47. SafeNest Environmental Testing. 2023 Available from https://safenestenviro.com/water-pollutants/bacterial-water-pollution/
48. Rock C, Rivera B. Water quality, E. coli and your health.
49. FWS-Fresh Water Systems. 2023. Available from https://www.freshwatersystems.com/blogs/blog/how-to-remove-bacteria-from-drinking-water
50. Figueras MJ, Borrego JJ. New perspectives in monitoring drinking water microbial quality. International journal of environmental research and public health. 2010 Dec;7(12):4179-4202.
51. WHO-World Health Organization. 2023. Available from https://www.who.int/news-room/fact-sheets/detail/drinking-water
52. WHO-World Health Organization. Water for Health. 2001. Available from http://lib.riskreductionafrica.org/bitstream/handle/123456789/936/6051%20%20Water%20for%20health.%20Taking%20charge.pdf?sequence=1
53. Zainurin SN, Wan Ismail WZ, Mahamud SN, Ismail I, Jamaludin J, Ariffin KN, Wan Ahmad Kamil WM. Advancements in monitoring water quality based on various sensing methods: a systematic review. International Journal of Environmental Research and Public Health. 2022 Oct 28;19(21):14080.
54. Varma VG, Jha S, Raju LH, Kishore RL, Ranjith V. A review on decentralized wastewater treatment systems in India. Chemosphere. 2022 Aug 1;300:134462.
55. Kingdon G. The quality and efficiency of private and public education: a case-study of urban India. Oxford bulletin of economics and statistics. 1996 Feb;58(1):57-82.
56. Ferguson B, Horsefield D. IMPROVING URBAN WATERWAYS IN EMERGING COUNTRIES: AN ACTION PLAN FOR MADRAS 1. JAWRA Journal of the American Water Resources Association. 1999 Aug;35(4):923-937.
57. Protocol MD. Uniform Drinking Water Quality Monitoring Protocol of Ministry of Drinking Water and Sanitation. Government of India. 2013.
58. Antunes S, Dionisio L, Silva MC, Valente MS, Borrego JJ, Lt E, Albufeira E. Coliforms as indicators of efficiency of wastewater treatment plants. InProceedings of the 3rd International Conference on Energy, Environment, Ecosystems and Sustainable development, IASME/WSEAS, Agios Nikolaos, Greece 2007 Jul (pp. 26-29).
59. Macedo SL, Araújo AL, Pearson HW. Thermo-tolerant coliform bacteria decay rates in a full scale waste stabilization pond system in Northeast Brazil. Water Science and Technology. 2011 Mar 1;63(6):1321-1326.
60. Tyagi VK, Kazmi AA, Chopra AK. Removal of fecal indicators and pathogens in a waste stabilization pond system treating municipal wastewater in India. Water environment research. 2008 Nov;80(11):2111-2117.
61. Collivignarelli MC, Abbà A, Benigna I, Sorlini S, Torretta V. Overview of the main disinfection processes for wastewater and drinking water treatment plants. Sustainability. 2017 Dec 31;10(1):86.
62. Von Sperling M. Modelling of coliform removal in 186 facultative and maturation

ponds around the world. Water research. 2005 Dec 1;39(20):5261-5273.

63. USEPA-US Environmental Protection Agency (1999). Wastewater Technology Fact Sheet: Chlorine Disinfection.
64. Yin F, Dong H, Shang B, Zhang W. Effect of time and mixing in thermal pretreatment on faecal indicator bacteria inactivation. International Journal of Environmental Research and Public Health. 2018 Jun;15(6):1225.
65. Verma S, Daverey A, Sharma A. Slow sand filtration for water and wastewater treatment–a review. Environmental Technology Reviews. 2017 Jan 1;6(1):47-58.
66. Lazarotto JS, Júnior EP, Medeiros RC, Volpatto F, Silvestri S. Sanitary sewage disinfection with ultraviolet radiation and ultrasound. International Journal of Environmental Science and Technology. 2021:1-8.
67. Digestion MSA. Biosolids Technology Fact Sheet. Environmental Protection Agency, Office of Water. 2006.
68. Appels L, Baeyens J, Degrève J, Dewil R. Principles and potential of the anaerobic digestion of waste-activated sludge. Progress in energy and combustion science. 2008 Dec 1;34(6):755-781.
69. Neyens E, Baeyens J, Dewil R. Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering. Journal of hazardous materials. 2004 Jan 30;106(2-3):83-92.
70. Agrivert-What is Anaerobic Digestion. 2023. Available from https://www.agrivert.co.uk/resources/anaerobic-digestion
71. Nations U. Department of Economic and Social Affairs, Population Division (2017). World population prospects: the 2017 revision, key findings and advance tables. InWorking Paper No ESA/P/WP/248 2017 (p. 46).
72. WHO-World Health Organization. 2017. Guidelines for Drinking-Water Quality. Geneva.
73. Saxena G, Bharagava RN, Kaithwas G, Raj A. Microbial indicators, pathogens and methods for their monitoring in water environment. Journal of water and health. 2015 Jun 1;13(2):319-339.
74. BIS-Bureau of Indian Standards. (2012). Drinking Water-Specification New Delhi.
75. Andreoli CV, Von Sperling M, Fernandes F. Lodo de esgotos: tratamento e disposição final. InLodo de esgotos: tratamento e disposiçao final 2001 (pp. 483-483).
76. CETESB R. Companhia de tecnologia de saneamento ambiental. Campos do Jordão, CETESB. 1983.
77. Li J, Li X, Wachemo AC, Chen W, Zuo X. Determining optimal temperature combination for effective pretreatment and anaerobic digestion of corn stalk. International Journal of Environmental Research and Public Health. 2022 Jun 30;19(13):8027.
78. Bisson JW, Cabelli VJ. Clostridium perfringens as a water pollution indicator. Journal (Water Pollution Control Federation). 1980 Feb 1:241-248.
79. Farrah SR, Bitton GA. Enteric bacteria in aerobically digested sludge. Applied and environmental microbiology. 1984 Apr;47(4):831-834.
80. Martin Jr JH, Bostian HE, Stern G. Reductions of enteric microorganisms during aerobic sludge digestion. Water Research. 1990 Nov 1;24(11):1377-1385.
81. ULTRAQUA-UV Disinfection Systems. 2023. Available from https://ultraaqua.com/blog/uv-light-and-water bacteria/#:~:text=How%20ultraviolet%20light%20kill%20viruses,unable%20to%20infect%20and%20reproduce.
82. Madge BA, Jensen JN. Ultraviolet disinfection of fecal coliform in municipal wastewater: effects of particle size. Water Environment Research. 2006 Mar;78(3):294-304.
83. Arceivala SJ. Wastewater treatment for pollution control. Tata McGraw-Hill Publishing Company Limited; 1986.
84. James MM. Wastewater Treatment Principles and Design. Willey-Inter Science Publication, New York. 1985.
85. Koivunen J, Siitonen A, Heinonen-Tanski H. Elimination of enteric bacteria in biological–chemical wastewater treatment and tertiary filtration units. Water research. 2003 Feb 1;37(3):690-698.
86. AES-Akruthi Enviro Solutions 2023. Available from https://neoakruthi.com/blog/biological-treatment-of-wastewater.html

87. Sugarprocesstech. 2023. Available from https://www.sugarprocesstech.com/activated-sludge-process/
88. Qureshi N, Annous BA, Ezeji TC, Karcher P, Maddox IS. Biofilm reactors for industrial bioconversion processes: employing potential of enhanced reaction rates. Microbial cell factories. 2005 Dec;4:1-21.
89. Abdel-Raouf N, Al-Homaidan AA, Ibraheem I. Microalgae and wastewater treatment. Saudi journal of biological sciences. 2012 Jul 1;19(3):257-275.
90. Mandeep, Shukla P. Microbial nanotechnology for bioremediation of industrial wastewater. Frontiers in Microbiology. 2020 Nov 2;11:590631.
91. Li X, Hu M, Ren H. Epigenetic regulation of bacterial adaptation to environmental stress. Frontiers in Microbiology. 2021;12:640749.
92. Mpenyana-Monyatsi L, Mthombeni NH, Onyango MS, Momba MN. Cost-effective filter materials coated with silver nanoparticles for the removal of pathogenic bacteria in groundwater. International journal of environmental research and public health. 2012 Jan 18;9(1):244-271.
93. Puri N, Gupta A. Water remediation using titanium and zinc oxide nanomaterials through disinfection and photo catalysis process: A review. Environmental Research. 2023 Mar 31:115786.
94. Soni R, Pal AK, Tripathi P, Lal JA, Kesari K, Tripathi V. An overview of nanoscale materials on the removal of wastewater contaminants. Applied water science. 2020 Aug;10(8):189.
95. Jain K, Patel AS, Pardhi VP, Flora SJ. Nanotechnology in wastewater management: a new paradigm towards wastewater treatment. Molecules. 2021 Mar 23;26(6):1797.
96. Zahra Z, Habib Z, Chung S, Badshah MA. Exposure route of TiO2 NPs from industrial applications to wastewater treatment and their impacts on the agro-environment. Nanomaterials. 2020 Jul 27;10(8):1469.
97. Hairom NH, Soon CF, Mohamed RM, Morsin M, Zainal N, Nayan N, Zulkifli CZ, Harun NH. A review of nanotechnological applications to detect and control surface water pollution. Environmental Technology & Innovation. 2021 Nov 1;24:102032.
98. Lin N, Verma D, Saini N, Arbi R, Munir M, Jovic M, Turak A. Antiviral nanoparticles for sanitizing surfaces: A roadmap to self-sterilizing against COVID-19. Nano Today. 2021 Oct 1;40:101267.
99. Swierczewska M, Liu G, Lee S, Chen X. High-sensitivity nanosensors for biomarker detection. Chemical Society Reviews. 2012;41(7):2641-2655.
100. Abdelhamied N, Abdelrahman F, El-Shibiny A, Hassan RY. Bacteriophage-based nano-biosensors for the fast impedimetric determination of pathogens in food samples. Scientific Reports. 2023 Mar 1;13(1):3498.
101. Sayan B, Indranil S, Aniruddha M, Dhrubajyoti C, Uday CG, Debashis C. Role of nanotechnology in water treatment and purification: potential applications and implications. Int J Chem Sci Technol. 2013;3(3):59.
102. Poudel RC, Joshi DR, Dhakal NR, Karki AB. Anaerobic digestion of sewage sludge mixture for the reduction of indicator and pathogenic microorganisms. Scientific World. 2010;8(8):47-50.
103. Erickson MC, Liao J, Ma L, Jiang X, Doyle MP. Inactivation of Salmonella spp. in cow manure composts formulated to different initial C: N ratios. Bioresource technology. 2009 Dec 1;100(23):5898-5903.
104. Mukai S, Oyanagi W. Decomposition characteristics of indigenous organic fertilisers and introduced quick compost and their short-term nitrogen availability in the semi-arid Ethiopian Rift Valley. Scientific Reports. 2019 Nov 5;9(1):16000.

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