Environmental Health Engineering and Management Journal 2024, 11(3), 371-384
http://ehemj.com
doi 10.34172/EHEM.2024.36
Environmental Health Engineering and Management Journal
Review Article
Open Access Publish Free

Review on dry toilet and management: Brown water (feces) characteristics, composition, and management

Firomsa Bidira[1*], Mamuye Busier Yesuf[1], Nina Schaefer[2], Matthias Friedle[2], Esayas Alemayehu[1]

[1]Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, P.O. Box 378, Jimma, Ethiopia
[2]University of Applied Forest Science, Rottenburg, Department of Water Resource Management, Rottenburg, Germany

Abstract

Background: An essential component of environmental sustainability and sanitation is the management of dry toilets, especially waste disposal. Understanding the composition of the brown water from dry toilets, putting the proper composting technique in place, and guaranteeing safe disposal and reuse procedures are all necessary to handle the waste successfully. It has been discovered that brown water, sometimes known as feces, can be used for brick-making, fuel, fertilizer, and other purposes.
Methods: This review focuses on dry toilet technology, management processes, and sanitation systems in Ethiopia and other underdeveloped nations. It utilizes secondary information and searches from Google scholars, Library catalogs, and Researchers to comprehend dry sanitation systems, including their implementation, use, and maintenance. Keywords used in the search include "in-situ treatment," "fecal sludge treatment," "fecal slurry management," and "brown water treatment."
Results: The review used a total of 108 articles and books, agricultural research, and reports on the feces' physical, chemical, and biological characteristics. It also discussed risks associated with the mismanagement of feces, including parasitic diseases in exposed humans. The main aim of the review was to develop an understanding of brown water uses, composition, and management and select the proper method of composting with dry toilets.
Conclusion: Dry toilets in developing countries are utilized for ecological sanitation and agriculture, with feces potentially used as fertilizer. Utilizing feces as fertilizer is a sustainable, eco-friendly, and environmentally responsible practice that can increase productivity while maintaining a clean environment.
Keywords: Agriculture, Developing countries, Feces, Fertilizer, Nutrients
Citation: Bidira F, Yesuf MB, Schaefer N, Friedle M, Alemayehu E. Review on dry toilet and management: brown water (feces) characteristics, composition, and management. Environmental Health Engineering and Management Journal 2024; 11(3): 371-384 doi: 10.34172/EHEM.2024.36.

Article History:
Received: 30 December 2023
Accepted: 16 June 2024
ePublished: 26 August 2024

***Correspondence to:**
Firomsa Bidira,
Emails: bidiraabdi84@gmail.com and firomsa.bidira@ju.edu.et

Introduction

Sanitation systems that do not require water for feces flushing are called dry toilets, sometimes referred to as non-flush or waterless toilets (1). Dry toilets are waterless sanitary systems appropriate for places with scarce water supplies or where centralized sewage systems are prohibitively expensive (2). They provide responsiveness, low prices, sustainability, and water-saving. The management of human waste is a crucial aspect of everyday life that significantly influences the comfort of individuals (3). Sustainable sanitation services in developing countries face serious challenges due to the inadequate management of fecal sludge, a result of rapid urbanization and population growth (4). The methods and techniques used to collect and take away human excreta have evolved and vary by location (5).

In 2015, 82% of the world's urban population and 51% of its rural population (8 billion people) had access to improved sanitation facilities (6). Out of the 5 billion people, 2.8 billion (or 38%) use a piped sewer system, 0.9 billion use septic tanks or pit latrines, and 1.3 billion use vented improved pit, pit with slab, or composting toilets, respectively. In areas with inadequate sewage disposal and an ineffective or non-existent hydraulic network, dry composting toilets are being used more frequently as practical sanitation technologies (7). The leftovers of these systems are increasingly used as organic fertilizer in semi-urban agriculture, often without any assessment of hygienic quality, which poses a serious risk to human health (8).

The term "bio-toilet" refers to a dry toilet or composting toilet that uses sawdust as a synthetic soil substrate for the bioconversion of human feces into compost. This compost can then be used as a soil conditioner or an organic fertilizer rich in nitrogen (N), phosphorus (P), and potassium (K) (9). The bio-toilet mainly consists of a toilet bowl, composting reactor, ventilation, and mixing systems (8). After using the toilet, a button activates a mixer that blends sawdust in the compost reactor. The toilet paper and other human waste are quietly and odorlessly mixed into the sawdust matrix, where aerobic biodegradation occurs (10). 2.4 billion people still lacked access to better sanitation facilities in 2015, forcing them to share toilets, use primitive toilets (pit latrines without a slab or platform, hanging latrines, and bucket latrines), or use open defecation (3). Given that the essential components of artificial fertilizer will eventually be depleted, it would be more logical to utilize human waste for agricultural purposes (6). Using human waste for agricultural purposes is not new (11). There are primarily two methods of use: collecting and using urine and feces, or separating them (12). The sustainable development goals and national sanitation management regulations provide a framework for sanitation in Ethiopia's towns and cities. However, implementation is minimal and largely relies on customary traditions (13).

In locations with poor sewage disposal and water scarcity, the dry-composting toilet, which requires neither water nor sewage facilities, is a viable solution (14). The physical and mental health of the populations living in low-income nations, as well as the prevention of environmental contamination, critically depend on the safe disposal or sanitation methods used for human waste (15). In low-income countries like Ethiopia, on-site sanitation (OSS) systems are the most prevalent method for managing excreta (16). These facilities can provide a hygienic and efficient method of waste disposal by treating human waste at its source (17).

The current open-site sanitation (OSS) systems, however, need improvement and require further research and development (8). The process of composting is not an innovation; it simply regulates a natural decomposition process (18). Composting offers the advantage of producing less mass, volume, and water than fresh dung, thereby requiring less transportation (19). Pathogens, parasites, weed seeds, and odor emissions are all eliminated, providing concurrent advantages for land application (20). Using composting toilets, human waste is transformed into safe humus. It is crucial to ensure low prices, minimized risks, and bulk discounts beforehand (21,22). When organic waste is placed in the ground and allowed to decompose under controlled aerobic conditions, it undergoes a process that results in a mature, stable, and sterilized final product that is free of pollutants and foreign materials, with no negative effects on the environment. However, composting is associated with carbon and nitrogen losses, as well as the release of greenhouse gases. Nutrient release is delayed after soil addition because composting stabilizes the nutrients (19). Compost also improves the biological and physical properties of soil and has a disease-suppressing effect (22).

The purpose of the review was to understand the physical, chemical, and biological properties of brown water and different types of dry toilet design systems. These insights are critical for developing successful management solutions. It also aids in comprehending the possible health risks, such as disease transmission and contaminated water sources, that may arise from inappropriate feces management. The study also evaluated how brown water management techniques affect the environment, specifically how they affect microbiological pollution, nutrient loading, and groundwater contamination. To support well-informed decision-making, it assesses both current and developing solutions for treating and getting away from brown water. The review also provides evidence-based recommendations for sustainable and safe sanitation practices that are later used as fertilizers by composting methods, which in turn informs policy formulation and regulation. It also encourages creativity and investigation, pointing out knowledge gaps and areas needing improvement in sanitation and waste management.

Materials and Methods

Search techniques used

The systematic review, search, and information-gathering process utilized most articles, journals, and books related to dry toilet management and sanitation in Ethiopia, other underdeveloped nations, and developed countries. The search was conducted between July 1, 2023 and November 28, 2024. A review was conducted to gain a further understanding of dry sanitation systems, including their implementation, use, and maintenance. The relevant technologies for this review were searched using databases such as Web of Science, Scopus, Google Scholar, Research Gate, and other catalogs using keywords "in-situ treatment," "fecal sludge treatment," "fecal slurry management," "on-site sanitation," "dry toilet systems in underdeveloped countries," "utilization of feces and management," and "brown water treatment." These terms are significant in the context of dry toilet technology. Further search terms included the primary WHO classification of pathogen treatment and control methods, such as "anaerobic digestion," "fecal composting," "utilization of feces as fertilizer," and "utilization of feces as energy," as well as references from books, journals, Wikipedia, and other online publications and encyclopedias. Finally, by identification and screening, a total of about 93 articles and 15 books were selected and included in the manuscript depending on the similarity with the title, objective, and time of publication.

Results

The review on dry toilets and their management considered functionality, durability, user experience, environmental impact, cost-effectiveness, health and safety, and comparative analysis to make informed decisions about toilet options. A total of about 210 papers and reviews have been searched and identified. As shown in Figure 1, after excluding duplicates and papers irrelevant to the review, a total of 93 articles and books were included. Among these articles and books, papers reported on dry toilet management and the use of feces as fertilizers in different localities, especially in developing countries like Africa and Asia. Other papers included reports on feces' physical, chemical, and biological characteristics and procedures for composting and using it as fertilizer. Additionally, risks associated with the mismanagement of feces and problems for humans, water bodies, and soil were discussed by measuring the prevalence of parasitic diseases in exposed humans. The ways of contamination in water, soil, and vegetables, as well as data regarding the measured health effects of contamination from brown water and the contents of useful nutrients in brown water that plants, use to improve crop production, were reported by different researchers. Generally, many researchers use brown water rather than disposing of it first as environmental mitigation, and then, as a useful material, energy, and nutrient.

Composition of brown water

The physical-chemical and biological parameters along with the composition of brown water with their respective concentration are in (Table 1) understanding these parameters was essential for determining the suitability of brown water for various applications

Management of brown water

Figure 2 depicts the management of brown water, which includes collection, storage, transportation, and finally reuse or disposal. Furthermore, the diverse approaches to handling brown water with different kinds of dry toilets, as shown in Figures 3-6, have been thoroughly reviewed and discussed inexpensively."

Uses of brown water

Brown water can be used to create a nutrient-rich compost that enhances soil structure and enriches agricultural land, as shown in Figure 7. Additionally, Figure 8 illustrates how biogas, a renewable energy source, is produced through the anaerobic digestion of excrement.

Discussion

Physicochemical characteristics of brown water (feces)

The solid or semisolid remains of food that the human small intestines are unable to digest are known as human feces (33). it contains bacteria, and a small number of metabolic byproducts, including bacteria-modified bilirubin, dead intestinal epithelial cells, and bacteria. It is eliminated during the process of defecation (4). Comparable to the feces of other animals, human feces differ substantially in size, color, and texture depending on the food, digestive system, and overall state of health (34). Depending on diet and health, the appearance of human feces varies greatly (35).

Another physical characteristic of feces is temperature, which may influence their use. The surrounding air

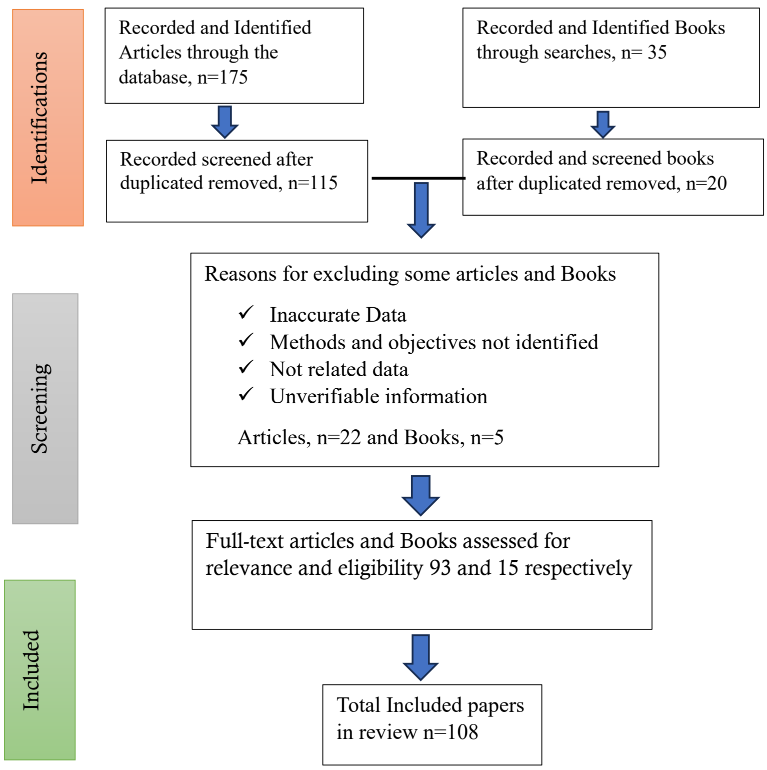

Figure 1. Searching process of studies, evaluation, and selection

Table 1. Chemical composition of feces (8)

Parameter	Concentration
Moisture content (%)	80.0±5.0
pH	5.3±0.2
Electrical conductivity (mho/cm)	60.0±15
Organic matter (% dry weight)	82.0±5.0
Carbon-C (% dry weight)	42.5±2.5
Nitrogen-N (% dry weight)	4.1±0.4
C: N ratio	12.0±1.0
Phosphorous-P_2O_5 (% dry weight)	1.1±0.2
Potassium-K_2O (% dry weight)	2.8±0.17
Calcium-CaO (% dry weight)	4.5±0.80
Magnesium-Mg (mg/g dry weight)	8.2±1.5
Sodium-Na (mg/g dry weight)	8.5±1.3
Iron-Fe (mg/g dry weight)	3.8±0.9
Zinc-Zn (mg/g dry weight)	0.24±0.04
Copper-Cu (mg/g dry weight)	0.004±0.005
Manganese-Mn (mg/g dry weight)	0.27±0.05
Nickel-Ni (mg/g dry weight)	0.009±0.002

temperature was consistent with the average temperature, which was 25 °C. About 75% of fresh feces is water, and the remaining 7%-16% of the solids consist of organic materials (36). These organic solids contain between 25%-54% bacterial biomass, 2%-5% nitrogenous matter or protein, 25% carbohydrates or undigested plant material, and 1%-2% fat. Variations in the physiological odor of feces can be attributed to diet and overall health (8). A fecal pH test includes characterizing a sample of feces by detecting its acidity or basicity (9). The pH of the raw feces ranged from 6.5 to 8.5. This pH range backs up the idea that sludge's pH could be somewhat acidic and/or quite basic(5) Research shows that employing acidic detergents to clean toilets may cause the sludge in public toilets to have a lower pH value (37). Despite the presence of waste, between 50% and 80% of feces (excluding water) consist of bacteria, which are present in your intestines during digestion and are then expelled (3,38). Increased fecal coliform levels are often used as a warning indicator for inadequate water treatment. Break in the integrity of the distribution system, and probable pathogen contamination (16). Both animals and humans excrete a vast number of viruses (8); human excreta contains diverse viruses, including coronaviruses, enteroviruses, and hepatitis A (7). Rotavirus is the most common cause of acute non-bacterial gastroenteritis in infancy and childhood(39). Intestinal protozoa cause severe health problems in children, the elderly, and people who drink contaminated water or food (40).

Chemical composition of brown water

Excreta mass and composition are heavily influenced by people's dietary choices (41). Table 1 shows the composition of feces as investigated by previous researchers. Fresh feces contain around 75% water, with the remaining contents consisting of 84%-93% organic substances (18). These organic solids consist of 25%-54% bacterial biomass, 2%-25% protein or nitrogenous material, 25% carbohydrate or undigested plant tissue, and 2%-15% other materials. Proteins and lipids are produced in the colon through secretion, epithelial shedding, and the activity of gut microorganisms. These proportions vary significantly and are influenced by various factors, including nutrition and body weight (8). The remaining solids include calcium, iron, phosphates, oxygen, nitrogen, lead, magnesium, and other elements.

Environmental issues, feces management, and applications of feces

Environmental issues with inadequate feces management

Environmental sanitation aims to develop and maintain a clean, healthy, and functional physical and natural environment (42). Toilets with septic tanks and pit latrines are examples of OSS systems that are crucial for providing access to toilets in both rural and urban areas (14). Microbial contamination is an increasing environmental issue that poses a threat to human health (43,44). Access to improved sanitation is critical for sustaining human health (45). Personal and private sanitation is a fundamental human right, yet universal access is a significant issue in many nations (17). Despite all the advances made in wastewater disposal over the past century in Western cultures, sewage still has several detrimental effects on the environment (33). Excessive use of water, resources, and money can lead to damage to aquatic ecosystems and contamination of sewage sludge by microorganisms (33). Some problems related to the unhygienic sanitation system will be as follows.

Problems in human and animals health

Improper processes and disposition of human waste are significant causes of dangerous diseases (46). These illnesses can affect people, plants, and animals. Untreated human waste poses a hazard to the health of all living beings on the planet, leading to the killing of animals (47). In low- and middle-income nations, animals living near people often carry a variety of viruses that can infect humans and spread through their feces (48). Contact with human waste poses a significant risk to human health (49).

Contamination of surface water bodies

Water is essential for life; however, many people lack access to clean, safe drinking water and die as a result of waterborne diseases (50). Open defecation threatens the safety of the water supply because human waste in the open environment can be carried into water bodies during rainstorms. These bodies of water are the main sources of

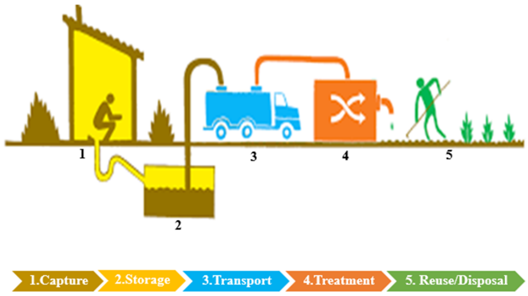

Figure 2. Brown water management by collection, storage, transport, and use (23,24)

Figure 3. Bucket toilet (25)

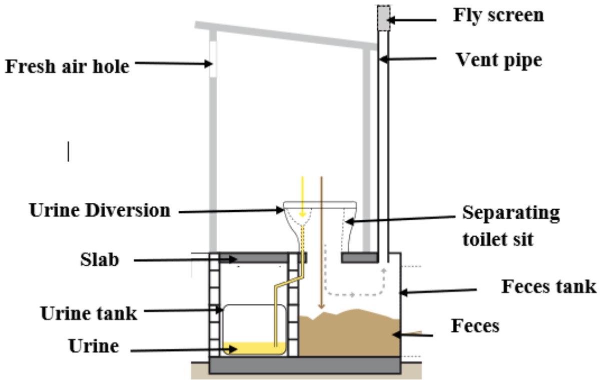

Figure 5. Urine-diverting dry toilet (27)

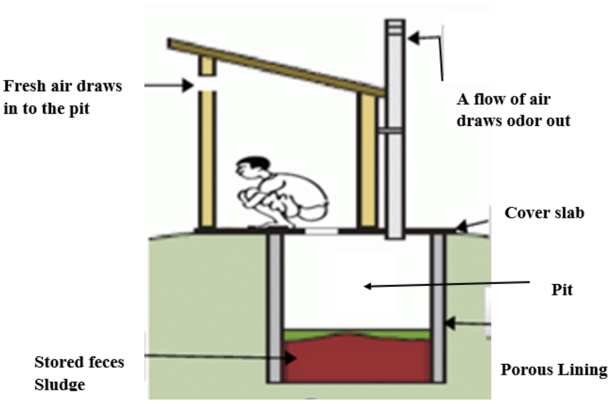

Figure 4. Pit latrine (26)

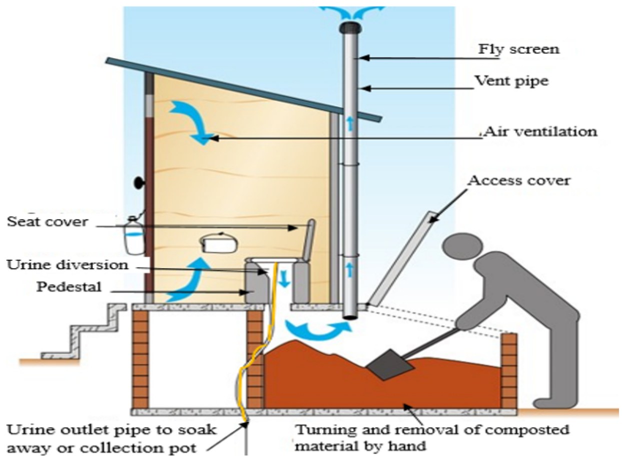

Figure 6. Composting toilet (28)

drinking water for humans and livestock (51). According to research conducted in Ethiopia, uncontrolled waste management practices, insufficient sanitary services, and improper fertilizer management are all problems aquifers contribute to aquifers contamination (52). Numerous protozoa, bacteria, viruses, and parasites can be found in human feces (53). One of the major global challenges for the aquatic environment is water pollution caused by microorganisms (7). A water body's bacterial load is increased by fecal waste, hospitals, industries, and cow farms (54). Coliform bacterial groups have traditionally been associated with public health security and have long been used as indicators of microbial contamination in water. *Escherichia coli*, a type of coliform bacteria, is an indicator of fecal contamination among coliform bacteria (55). The multiple-tube fermentation method has been traditionally used to identify coliform in water samples by fermenting lactose sugar, leading to the production of acid and gas (16). Fecal contamination, which primarily originates from human waste or the excrement of warm-blooded animals, introduces disease-causing germs into recreational water (9).

Contamination of soil

The term "soil pollution" refers to the presence of a chemical or material in the soil that is out of place, present at a higher-than-normal concentration, and has negative

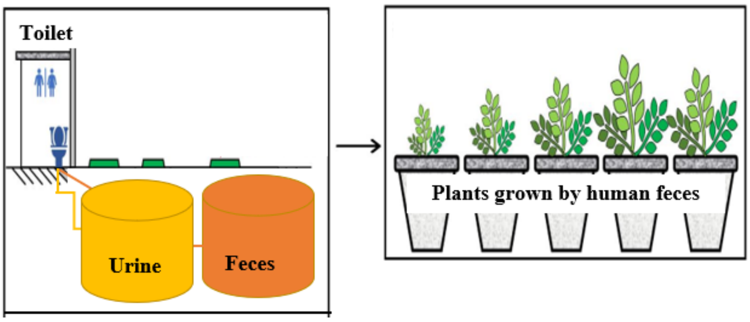

Figure 7. Uses of human feces as fertilizer (29,30)

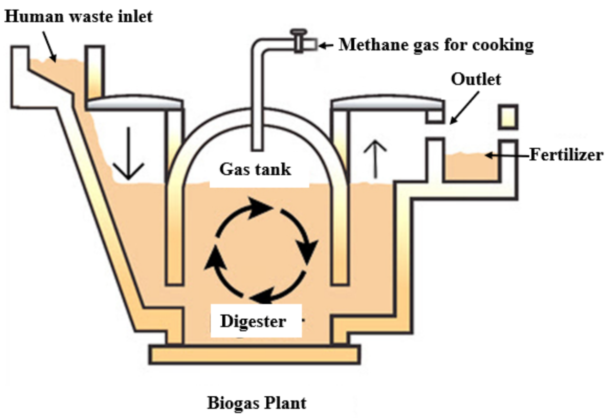

Figure 8. Biogas production from human waste (31,32)

effects on any organism that is not the intended target (56). Soil pollution is a concealed threat because it is often challenging to measure or detect. Microbes from human feces were found in high numbers in soil and stored water, but not in source water (20).

Management of brown water (feces)

Collection, storage, transport, and use

Lack of access to sanitary facilities may be a factor in the pollution of the environment and its social effects (49). Human excrement may build up outside residences, in surrounding drains, and in waste dumps in unsanitary conditions, causing contamination of the environment (57) As shown in Figure 2 fecal sludge management is also known as the process of safely using or

disposing of fecal sludge after it has been stored, collected, transported, and treated. The "value chain" or "service chain" of fecal sludge management is made up of the collection, transportation, treatment, and final use of feces (4). Fecal sludge is commonly defined as the waste that accumulates in onsite sanitation systems, such as pit latrines, septic tanks, and container-based solutions, and is not specifically transported through a sewer (58). Septage is the term for the fecal sludge removed from septic tanks. Best practices for fecal waste storage, collection, and transportation are available for use by a range of service providers, from small businesses with a single cart to large enterprises with multiple transport vehicles operating in densely populated urban areas (17). Sludge collection methods must be emptied and transported to a designated treatment facility once they are full (59). Depending on the type of material recovered by the procedure used to treat feces, several products can be made (60). The reuse of fecal sludge adds value to its treatment and has the potential to generate income by harnessing the inherent resources in the waste (18). Fecal sludge collected from OSS systems is treated to prevent any negative impact on the environment or public health, both from its solid and liquid components (40). Finally, it is crucial to ensure the safe disposal of treated sludge, especially the portion that cannot be used to recover resources for reuse (61). Regenerating items for reuse is essential to ensure that waste is kept away from people and the environment. Reusing the treatment plant's internal resources nutrients, electricity, and water, all of which have inherent value could result in financial gain (55).

Brown water (feces) management techniques using dry toilets

Almost half of the world's population lacks access to basic sanitation (62). By 2020, just 54% of the world's population will have access to properly run sanitation services (57). In poor nations where most of the population defecates in open or public spaces, building a latrine is the first step on the sanitation ladder. Excreta disposal that involves burial is practically always safe (63). Only 16% of people in Ethiopia live in cities. In urban Ethiopia, 14% of families use upgraded toilets that are not shared with other households, while 32% use communal toilets. Urban families use unimproved toilet facilities in the vast majority (54%). An open-pit latrine is the most prevalent type of unimproved toilet, being utilized by 37% of households in towns and cities (61). Urban people suffer from a lack of urban constructions and, more frequently, water, sanitation, and hygiene services in many African nations, including Ethiopia. In city slums and densely populated urban areas, the situation is more severe (17). There are different types of dry toilets types to manage feces and control pollution (64), some of which are discussed below.

Bucket toilet

A bucket (pail) is utilized to collect feces in a basic dry toilet referred to as a bucket toilet (14). Typically, excrement and urine are combined in one bucket, leading to odor issues (65). The bucket could be located inside a house or in other small nearby construction(65). An unimproved bucket toilet may be a better option than open defecation in situations where people lack access to adequate sanitation, especially in low-income urban areas in developing countries (6). They may provide temporary assistance with emergency sanitation, such as after earthquakes. In contrast to an improved sanitation system, the unimproved bucket toilet could pose serious health risks (18). In the past, several nations used the bucket toilet system, along with municipal collection services. The basic bucket toilet evolves into a variety of other systems that are more appropriately referred to as container-based sanitation systems, composting toilets, or urine-diverting dry toilets (UDDTs) (1).

As shown in Figure 3, a bucket toilet, also known as a composting or portable toilet, is a simple and efficient alternative to traditional flush toilets when water or sewage infrastructure is unavailable or as a temporary solution. The components include a bucket, seat, lid, absorbent material, biodegradable bags (optional), ventilation system, and working mechanism of

a bucket toilet. This involves preparation, usage, adding absorbent material, maintenance, composting, and cleaning.

Pit latrine

Pit toilets are the most fundamental and cost-effective type of sanitation for better hygiene. A pit latrine is a basic type of sanitation system commonly used in areas that lack access to conventional flush toilets (17). According to studies by Mihelcic et al (66) and Zhang et al (67), a pit latrine, also known as a pit toilet, collects human waste in a hole in the ground. A drop hole in the floor, which may be connected to a toilet seat or squatting pan for user comfort, enables urine and waste to enter the pit. When constructed properly, pit latrines can effectively separate human waste from human contact and minimize the transmission of fecal-oral diseases (5). Pit latrines can be designed with a water seal (pour-flush pit latrine) or without a water seal (dry toilet) (46). When constructed and maintained correctly, pit latrines can reduce the transmission of illness by minimizing the amount of human waste released into the environment through open defecation (68). This reduces flies' ability to spread viruses from dung to food (69). Regular emptying is required for the pits to stay functional and avoid overflows. The process of manually emptying pit latrines, which involves removing fecal sludge with implements like buckets and shovels and other is the most popular one (60) As shown in Figure 4, pit latrines consist of components like a pit or digester, superstructure, ventilation pipe, seat or squat plate, and cover material (63).

The working mechanism of a pit latrine involves a combination of decomposition and natural processes such as waste collection, decomposition, evaporation, filtration, filling, or emptying (70). As the pit fills up with waste or reaches its maximum capacity, it needs to be either emptied or closed off, and a new pit is constructed (65). It is important to note that proper maintenance and hygiene practices, such as regular pit emptying, avoiding groundwater contamination, and implementing safety precautions, play a crucial role in ensuring the effectiveness and safety of pit latrines (71).

Urine diverting dry toilet

New environmentally sustainable and financially feasible sanitation technologies, such as waterless systems with source separation of human waste, have been developed in response to the current environmental issues that the majority of middle- and low-income nations, like Ethiopia, have been experiencing (72). A toilet that diverts urine separates it from solid waste (73). The UDDT is designed so that feces fall through a sizable hole in the back of the toilet, while urine is collected and emptied from the front area (3). Following defecation, drying material such as lime, ash, or soil should be placed in the same hole, depending on the collection and storage/treatment technology that will be used next (74). In urine-diversion dry toilets, human waste can serve as beneficial soil conditioners.

A successful application in agriculture requires effective pathogen elimination with no adverse effects on vegetation (55). The toilet has a fan installed that removes moisture and air, rendering the toilet odorless in the area (75). Since there is no need for a drain, heated room, or water, a urine-diverting toilet operates in any setting (76). The solid waste is placed in compostable bio bags made of corn starch, which can later be composted, while the urine is discharged into a collection vessel or infiltrated (77). UDDT is a sustainable and innovative sanitation technology that provides an alternative solution to traditional flush toilets. As indicated in Figure 5 the UDDT aims to separate urine and feces to promote proper waste management and minimize water usage. The major components of a UDDT toilet include the toilet bowl, urine diverting system, solid waste container, ventilation pipe, and urine collection system (57)

The working mechanism of UDDT includes usage, diversion, collection, solid waste decomposes, emptying, and maintenance (75). UDDT toilets offer several advantages, including water conservation, nutrient recycling, and improved sanitation in areas with limited access to water and centralized sewage systems. They contribute to sustainability by minimizing water usage and providing an eco-friendly approach to waste management. The primary facilitator of adoption is the collection and reuse of human waste as fertilizer; however, this may be incompatible with existing beliefs (46). Providing continuing instruction on safe emptying or establishing an emptying/reuse service is critical to UDDT use success (62). Having enough ash or dry material enables the implementation of dry sanitation. UDDT propagators should concentrate on the economic, water, user experience, and health advantages at the home level (57).

Composting toilet

A composting toilet is a form of dry toilet that uses the biological process of composting to treat human waste (64,78). A composting toilet operates through a combination of physical, biological, and chemical processes (79). While the primary focus is on the decomposition of organic waste, chemical reactions also play a significant role in breaking down waste and transforming materials within the composting toilet system (14). The primary chemical reaction that occurs in a composting toilet is called aerobic decomposition or aerobic digestion (80). This process involves the decomposition of organic materials in the presence of oxygen. When waste, such as human excreta is added to the composting toilet, aerobic bacteria, and other microorganisms begin to break down the organic matter (81). Microorganisms which are mainly bacteria, need oxygen to live and break down the waste (82). The organic substance is broken down into simpler chemicals as they ingest it and release enzymes. Additional chemical processes, such as oxidation and hydrolysis, result in the generation of carbon dioxide (CO_2), water (H_2O), and different leftover organic molecules from these components (83). In a process known as ammonification, bacteria transform ammonia into ammonium (NH_4^+), a type of nitrogen that plants may use (84). The compost created can be used as fertilizer by this conversion, which also makes nutrient cycling easier. It is noteworthy that composting toilets may also utilize additives to aid in the composting process (85). These additives can include substances like sawdust, peat moss, or coconut, which help maintain the proper carbon-to-nitrogen ratio and provide additional sources of organic matter for the microorganisms (19). These additives may also contribute to chemical reactions by providing essential nutrients and creating an optimal environment for microbial activity (34). Overall, the chemical reactions in a composting toilet play a crucial role in the decomposition and transformation of organic waste into usable compost. The proper balance of oxygen, organic materials, and microorganisms allows for the efficient breakdown of waste and the production of nutrient-rich compost for gardening or other purposes (20). Human waste is converted into compost-like material during this process, which results in the decomposition of organic matter (86). Diet, activity, age, sex, social standing, and anal cleansing techniques all have an impact on the creation and chemical makeup of human feces compost. 3.0%-5.4% P_2O_5, 1.0%-2.5% K_2O, and 4.8%–7% N make up feces. 15.0%–19.2% N, 2.5%–0% P_2O_5, and 3.0%–4.5% K_2O are the main components of urine (11). Composting toilets are promoted as waterless systems for treating human waste that are suitable for use by the general population in remote areas. Most compost toilet constructors aim to enable human feces to decompose without depending on surrounding soils, and to ensure that the final products can be safely disposed of on-site without requiring additional treatment (82). According to research, microorganisms, mostly bacteria and fungi, carry out composting under carefully regulated aerobic conditions (87).

Figure 6 shows the key components of a composting toilet, which include the toilet bowl, ventilation system, composting chamber, separator, compost drainage system, and the working mechanisms of separation, decomposition, temperature and moisture control, and compost maturation (6,79)

Factors affecting human feces composting

Human feces composting is a process that involves the breakdown of organic matter into simpler forms through the activity of microorganisms (88,89). The ideal temperature for composting is in the range of 40 to 60 °C, which promotes the growth of beneficial microorganisms and accelerates the breakdown of organic matter (5). Adequate moisture content is crucial for composting, with a balance of 25 to 30 being ideal (6,86). The composting process takes time, typically requiring several months to a year for it to mature fully (82). Regularly turning or aerating the compost every few weeks helps to mix materials, improve aeration, and accelerate decomposition. Proper composting is essential to ensure the destruction of pathogens present in human feces. This includes maintaining the compost pile at a temperature of at least 55 °C (131 °F) for a minimum of three days (44). Time plays a significant role in feces composting, with decomposition resulting from the activity of microorganisms breaking down complex organic compounds into simpler forms (37). This decomposition is essential for the transformation of feces into nutrient-rich compost. Over an extended period, the nutrients present in feces become more readily available for plants, leading to the breakdown of organic matter into nutrient-rich compounds like nitrogen, phosphorus, and potassium (7). Stability and maturity are also important aspects of feces composting, with longer composting periods allowing the compost to reach a stable and mature state (90,91).

Incinerations toilet

An incinerating toilet is a type of dry toilet that burns human feces instead of flushing them away with water (92).

Incinerating toilets are used only for niche applications, which include:

- Apartments with limited or difficult access to waste plumbing.

Houses without access to drains, and where building a septic tank would be difficult or uneconomic.

On canal barges, as an alternative to a blackwater holding tank, which needs to be pumped out occasionally.

On mobile homes, recreational vehicles, and caravans/(trailers).

Incinerating toilets may be powered by electricity, gas, dried feces, or other energy sources (6). Incinerating toilets gather excrement in an integral ash pan, and then, incinerate it, reducing it to pathogen-free ash. Some will also incinerate "grey water" created from showers and sinks (93).

An incineration toilet, also known as a self-combusting toilet, is a modern and sanitary alternative to traditional toilets that uses a combustion process to dispose of human waste (58). It consists of several components that work together to efficiently and safely incinerate the waste like a toilet bowl, incinerator chamber, burner, exhaust system and working mechanism waste disposal, incineration cycle, initiation, combustion process, waste incineration, ventilation and odor control, ash collection, cleaning, and maintenance (94).

Uses of brown water (feces)

Fertilizer

The use of human feces as fertilizer can increase agricultural productivity. Excreta from people makes for excellent organic fertilizer (63,65). They have a larger capacity for fertilizing than animal feces. The improvement of the organic and humus component of the soil, preservation of moisture and air regulation, and an increase in nutrient storage and release are all long-term advantages of using human waste (11). However, it is advised that the waste be processed at least once before being applied to the farm (22). Human excreta contains organic matter which, if applied to poor soils, can improve its biophysical characteristics such as water-retention capacity (11,52).

Mechanisms (procedures) of using feces as fertilizer will be collection, treatment, composting vermicomposting, and maturation (9,73). Proper sanitation is crucial for the collection of human feces, also known as "night soil," to prevent contamination and the spread of hazardous bacteria. Proper treatment of human waste eliminates pathogens and contaminants through methods such as composting, anaerobic digestion, and vermicomposting (using worms) (55). Composting involves combining feces with organic materials like straw, leaves, or wood chips, which must be managed and maintained at specific temperatures and moisture levels (20). Anaerobic digestion breaks down trash in an oxygen-free environment, producing biogas (CH_4 and CO_2) as a by-product (95). The remaining sludge can be further composted or used as fertilizer. Vermicomposting utilizes earthworms to decompose waste, resulting in nutrient-rich vermicompost that can be used as soil fertilizer. After treatment, the human waste undergoes a maturation phase to achieve complete pathogen destruction. The duration of the fertilization process varies, but it is recommended to last for several months to a year to eliminate harmful microorganisms and ensure safety. Feces can be matured and used as a nutrient-rich fertilizer in agriculture (79). Figure 7 shows that the safe use of human feces as fertilizer for plants ensures the mitigation of health risks, improved sanitation, and the adoption of appropriate technologies (95). Following local regulations for sanitary, sustainable practices, public acceptance, and awareness are crucial for successful implementation (83). Agricultural usage of sludge endangers nearby communities with its smell and may have negative health effects on farm workers (8).

Production of biogas

The need for alternative sources of energy is being driven by the rising cost of fossil fuels and the dangers posed by environmental contamination (96). In particular, the creation of more HN_3, which is a greenhouse gas due to its low C: N ratio, needs to be reduced through studies to produce biogas from human waste (97). It is possible to capture and utilize the methane gas produced by human waste to create biogas. According to the study by Adjama et al (98), biogas might be utilized to generate energy, heat water for domestic or commercial use, and cook food. This is done using a procedure that involves gathering methane in a confined, oxygen-free container (97). Organic stuff can decompose more easily at high temperatures. When biogas is burned with oxygen present, it reacts and releases energy (99). The process is presented in detail as follows.

Collection and pre-treatment: Human feces are collected and undergo pre-treatment, which may include the removal of large solids, such as toilet paper, to ensure a more efficient digestion process. For fertilizer to be safe and effective, human excrement must be collected and pre-treated properly(55,100). This includes taking hygienic precautions to prevent the spread of pathogens and treating or composting the waste in a manner that reduces health risks (101).

Anaerobic digester: The feces are then fed into an anaerobic digester, a sealed container where digestion occurs. The digester can be either a batch or continuous flow system (102). Anaerobic digesters are devices that break down organic materials, such as human waste, in the absence of oxygen. These systems utilize specialist bacteria to break down complex molecules found in human excrement into simpler materials such as methane gas and organic fertilizer (103). To ensure optimal conditions, the procedure requires careful monitoring of the temperature, pH levels, and retention duration. The design of the digester and the properties of the input material can affect the duration of the process (20).

Bacterial activity: Inside the digester, anaerobic bacteria break down the organic matter found in the feces. These bacteria convert complex organic compounds, such as carbohydrates, fats, and proteins, into simpler compounds (27). Anaerobic digesters break down organic matter, including human feces, in an oxygen-free environment using specialized bacteria. These bacteria convert complex compounds into simpler substances, such as methane gas and organic fertilizer. The process requires careful monitoring of temperature, pH levels, and retention time (89). Anaerobic digestion can generate biogas for energy production and nutrient-rich fertilizer for agriculture. However, it is crucial to adhere to proper safety protocols and local regulations for the sake of public health and environmental protection (104).

Biogas production: Bacterial activity results in the production of biogas. Biogas is primarily composed of methane (CH_4) and carbon dioxide (CO_2), along with small amounts of other gases, such as hydrogen sulfide (H_2S) and trace elements(105,106). Anaerobic digestion is a process where human feces is broken down by bacteria in an oxygen-free environment, producing biogas primarily composed of methane and carbon dioxide (7). This process involves collecting fecal matter and introducing it into a sealed digester, where bacteria grow and produce biogas. Monitoring factors like temperature, pH, and retention time are crucial for safety. Biogas production can contribute to sustainable energy production and waste management (5).

Storage and utilization: The biogas produced can be stored and utilized for various applications. It can be utilized as a source of renewable energy for cooking, heating, or even electricity generation. The remaining materials after digestion, known as digestates, can be used as fertilizer because of their nutrient-rich composition (55). Excrement can be stored in anaerobic digesters and biogas plants, which create an oxygen-free environment for microorganisms to decompose organic materials and generate biogas. This biogas can be used as a renewable energy source to generate electricity, provide heat, and for cooking (55). Pre-treatment steps include removing non-biodegradable materials and adjusting the levels of moisture and nutrients to enhance the process. Biogas can be used for heating or cooking, or it can be converted into energy using biogas generators. The digestate can also be utilized as a nutrient-rich agricultural fertilizer. Respecting local laws is essential for environmental compliance and safety (54,57)

Biogas production from human feces is influenced by factors such as temperature, pH, retention time, and feedstock composition. It contributes to waste management by reducing the volume of fecal sludge and harnessing renewable energy resources. Figure 8 shows the components of the biogas chamber and parts.

As a renewable energy source, biogas offers numerous benefits, such as reducing deforestation for energy production and minimizing environmental pollution (99,107,108). By capturing methane that would have otherwise been released into the atmosphere, biogas helps to mitigate environmental impacts (4).

Conclusion

In conclusion, the implementation of dry toilets and effective feces management in Ethiopia and other developing countries offers numerous benefits. These include promoting sustainable sanitation practices, decreasing water usage, and generating valuable compost for use in agriculture, environmental conservation, and energy production. Ultimately, these measures improve hygiene, enhance food security, and stimulate economic development. Nevertheless, it is crucial to address existing challenges. Addressing these issues will require a comprehensive approach that includes education and awareness campaigns, investments in sanitation infrastructure and technology, improved waste management techniques, and community engagement. This review aimed to gain an understanding of dry toilets and feces management by promoting methods that can be used for sanitation and processing feces (brown water), which can be utilized as fertilizer and biogas through composting and preparation. There are several types of dry toilets with different designs for managing human feces, but toilets that can separate feces and urine, such as composting toilets and urine-diverting toilets, are the most suitable for utilizing excrement as fertilizer and increasing output. In impoverished nations like Ethiopia, various methods have been developed to manage human waste. However, society's perception of using excrement for various purposes is extremely negative. Implementing pilot projects such as urine-diversion toilets and composting toilets was beneficial for training purposes. This study on brown water literature aimed to raise awareness and establish a comprehensive understanding of the management and utilization of brown water in various toilet systems and urban and rural sanitation technologies. The overall purpose of the review was to analyze existing information on brown water and identify knowledge gaps related to feces management, toilet selection, challenges caused by uncontrolled brown water, and societal perspectives on excrement management and utilization. In Ethiopia, dry toilet systems and feces management play a crucial role in ensuring proper sanitation and reducing the spread of diseases.

Acknowledgments

The authors would like to express their gratitude to

Jimma University, Jimma Institute of Technology, and the University of Applied Forest Science of Rottenburg for their invaluable assistance during the review process.

Authors' contributions

Conceptualization: Esayas Alemayehu, Matthias Friedle.
Data curation: Mamuye Busier Yesuf, Firomsa Bidira.
Formal analysis: Niña Schaefer, Esayas Alemayehu.
Funding acquisition: Matthias Friedle, Esayas Alemayehu.
Investigation: Firomsa Bidira, Mamuye Busier Yesuf.
Methodology: Mamuye Busier Yesuf, Nina Schaefer.
Project administration: Esayas Alemayehu, Nina Schaefer.
Resources: Firomsa Bidira, Matthias Friedle.
Supervision: Esayas Alemayehu, Mamuye Busier Yesuf.
Validation: Mamuye Busier Yesuf, Nina Schaefer.
Visualization: Niña Schafer, Firomsa Bidira.
Writing–original draft: Firomsa Bidira, Esayas Alemayehu.
Writing–review & editing: Esayas Alemayehu, Nina Schaefer.

Competing interests

The authors declare that there is no conflict of interest.

Ethical issues

This review includes articles, data from books, journals, and citations, making it a unique type of review that has not been previously published.

Funding

The project has no funding.

References

1. Nasri B, Brun F, Fouché O. Evaluation of the quality and quantity of compost and leachate from household waterless toilets in France. Environ Sci Pollut Res Int. 2019;26(3):2062-78. doi: 10.1007/s11356-017-0604-z.
2. Anand C, Apul DS. Economic and environmental analysis of standard, high efficiency, rainwater flushed, and composting toilets. J Environ Manage. 2011;92(3):419-28. doi: 10.1016/j.jenvman.2010.08.005.
3. Matheka RM, Raude JM, Murunga SI, Riungu JN, Wandera SM. Effect of fecal matter co-digestion with kitchen waste on *Hermetia illucens*' larval weight and protein content. J Water Sanit Hyg Dev. 2021;11(5):746-57. doi: 10.2166/washdev.2021.077.
4. Zewde AA, Li Z, Xiaoqin Z. Improved and promising fecal sludge sanitizing methods: treatment of fecal sludge using resource recovery technologies. J Water Sanit Hyg Dev. 2021;11(3):335-49. doi: 10.2166/washdev.2021.268.
5. Saxena S, Den W. In situ treatment technologies for pit latrines to mitigate groundwater contamination by fecal pathogens: a review of recent technical advances. J Water Sanit Hyg Dev. 2021;12(1):102-15. doi: 10.2166/washdev.2021.184.
6. Nagy J, Zseni A. SWOT analysis of dry toilets. In: WIT Transactions on Ecology and the Environment. WIT Press; 2016. p. 257-68.
7. Gunnarsdóttir R, Jenssen PD, Erland Jensen P, Villumsen A, Kallenborn R. A review of wastewater handling in the Arctic with special reference to pharmaceuticals and personal care products (PPCPs) and microbial pollution. Ecol Eng. 2013;50:76-85. doi: 10.1016/j.ecoleng.2012.04.025.
8. Rose C, Parker A, Jefferson B, Cartmell E. The characterization of feces and urine: a review of the literature to inform advanced treatment technology. Crit Rev Environ Sci Technol. 2015;45(17):1827-79. doi: 10.1080/10643389.2014.1000761.
9. Rose EK, Issouf O, Nouho OK, Louis K. Ecological sanitation in tropical environments: quantifying the inactivation rates of microbiological parameters during a feces-based composting process. Eur Sci J. 2017;13(29):290-305. doi: 10.19044/esj.2017.v13n29p290.
10. Devkota GP, Pandey MK, Maharjan SK. Urine diversion dry toilet: a narrative review on gaps and problems and its transformation. Eur J Behav Sci. 2019;2(3):10-9.
11. Timmer L, Visker C. Possibilities and Impossibilities of the Use of Human Excreta as Fertilizer in Agriculture in Sub-Saharan Africa. The Netherlands: Royal Tropical Insitute, University of Amsterdam; 1998. p. 1-60. Available from: https://www.ircwash.org/sites/default/files/352.2-98PO-16640.pdf.
12. Lamichhane KM, Babcock RW Jr. Survey of attitudes and perceptions of urine-diverting toilets and human waste recycling in Hawaii. Sci Total Environ. 2013;443:749-56. doi: 10.1016/j.scitotenv.2012.11.039.
13. Adugna D. Challenges of sanitation in developing counties - evidenced from a study of fourteen towns, Ethiopia. Heliyon. 2023;9(1):e12932. doi: 10.1016/j.heliyon.2023.e12932.
14. Rao KC, Velidandla S, Scott CL, Drechsel P. Business models for fecal sludge management in India. International Water Management Institute (IWMI); 2020. p. 13-184.
15. Amisi B, Nojiyeza S. Access to Decent Sanitation in South Africa: The Challenges of Eradicating the Bucket System. Durban: AfriSam; 2008. p. 1-23. Available from: https://ccs.ukzn.ac.za/files/amisi%20nojiyeza.pdf.
16. Redlinger T, Graham J, Corella-Barud V, Avitia R. Survival of fecal coliforms in dry-composting toilets. Appl Environ Microbiol. 2001;67(9):4036-40. doi: 10.1128/aem.67.9.4036-4040.2001.
17. Donacho DO, Tucho GT, Soboksa NE, Faro MH, Hailu AB. Qualitative analysis of onsite sanitation challenges in an urban setting: the case of Jimma town, Ethiopia. Environ Health Insights. 2023;17:11786302231154421. doi: 10.1177/11786302231154421.
18. Cofie O, Nikiema J, Impraim R, Adamtey N, Paul J, Koné D. Co-Composting of Solid Waste and Fecal Sludge for Nutrient and Organic Matter Recovery. International Water Management Institute (IWMI); 2016. p. 52. Available from: http://www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_3.pdf.
19. Larney FJ, Sullivan DM, Buckley KE, Eghball B. The role of composting in recycling manure nutrients. Can J Soil Sci. 2006;86(4):597-611. doi: 10.4141/s05-116.
20. Larney FJ, Olson AF. Windrow temperatures and chemical properties during active and passive aeration composting of beef cattle feedlot manure. Can J Soil Sci. 2006;86(5):783-97. doi: 10.4141/s06-031.

21. Mohamadkhani K, Sadeghi M, Mohammadkhani S. The globalization of Iranian universities in the internet & virtual spaces. Adv Environ Biol. 2013;7(13):4095-102.
22. Lalander CH, Hill GB, Vinnerås B. Hygienic quality of faeces treated in urine diverting vermicomposting toilets. Waste Manag. 2013;33(11):2204-10. doi: 10.1016/j.wasman.2013.07.007.
23. Minier P, Esculier F, Tassin B, Chatzis K. Can sewerage be considered safe management of human feces? City Environ Interact. 2023;19:100107. doi: 10.1016/j.cacint.2023.100107.
24. Cruz Espinoza LM, Yeh D, Vinnerås B, Rajaram L, Whiteford L, Corvin J, et al. Inactivation of *Ascaris suum* by ammonia in feces simulating the parameters of the solar toilet. Journal of Applied Sciences in Environmental Sanitation. 2012;7(3):173-82.
25. Koetlisi KA, Muchaonyerwa P. Biochar types from latrine waste and sewage sludge differ in physico-chemical properties and cadmium adsorption. Am J Appl Sci. 2017;14(11):1039-48. doi: 10.3844/ajassp.2017.1039.1048.
26. Magri ME, Philippi LS. Inactivation of pathogens in feces by desiccation and urea treatment for application in urine-diverting dry toilets. Appl Environ Microbiol. 2013;79(7):2156-63. Doi: 10.1128/aem.03920-12.
27. Niwagaba CB. Treatment Technologies for Human Faeces and Urine [dissertation]. Uppsala: Swedish University of Agricultural Sciences; 2009. p. 1-91. Available from: https://pub.epsilon.slu.se/2177/1/niwagaba_c_091123.pdf.
28. Geldreich EE, Litsky W. Fecal coliform and fecal streptococcus density relationships in waste discharges and receiving waters. Crit Rev Environ Control. 1976;6(4):349-69. doi: 10.1080/10643387609381645.
29. Tibebu T. Evaluation the Impact of World Vision Ethiopia, Water, Sanitation and Hygiene Project on the Community: The Case of Amhara Region, West Gojam Zone, Jabi Tehnane Woreda [dissertation]. Addis Ababa, Ethiopia: School of Continuing Education; 2016. Available from: http://197.156.93.91/handle/123456789/2679.
30. Abd Ellatif N, Mohamed M, El-Taweel H, Hamam M, Saudi M. Intestinal protozoa in diarrheic children in an Egyptian rural area: role of water contamination and other possible risk factors. Parasitol United J. 2018;11(2):82-9. doi: 10.21608/puj.2018.16317.
31. Zseni A. Human excreta management: human excreta as an important base of sustainable agriculture. Proceedings of the 4th Multidisciplinary Academic Conference. 2015. Available from: https://www.researchgate.net/publication/273382957_Human_excreta_management_human_excreta_as_an_important_base_of_sustainable_agriculture.
32. Giwa AS, Sheng M, Zhang X, Wu Y, Bo H, Memon AG, et al. Approaches for treating domestic wastewater with food waste and recovery of potential resources. Environ Pollut Bioavailab. 2022;34(1):501-17. doi: 10.1080/26395940.2022.2137061.
33. Abudulai I, Aziz TA, Ofori B, Adjei GA. The menace of open defecation in Ghanaian communities: the case of Gambaga and Nalerigu communities in North East region. Int J Environ Prot Policy. 2021;9(2):16-26. doi: 10.11648/j.ijepp.20210902.11.
34. Nuha ZU, Nurwijayanti. Analysis of factors affecting the improvement of open defecation free (ODF) behavior in communities in Kerta Timur village, Dasuk district, Sumenep Regency. J Qual Public Health. 2022;5(2):480-8. doi: 10.30994/jqph.v5i2.344.
35. Krause A, Häfner F, Augustin F, Udert KM. Qualitative risk analysis for contents of dry toilets used to produce novel recycling fertilizers. Circ Econ Sustain. 2021;1(3):1107-46. doi: 10.1007/s43615-021-00068-3.
36. Busienei P, Ogendi G, Mokua M. Latrine structure, design, and conditions, and the practice of open defecation in Lodwar town, Turkana county, Kenya: a quantitative methods research. Environ Health Insights. 2019;13:1178630219887960. doi: 10.1177/1178630219887960.
37. Fujioka RS, Solo-Gabriele HM, Byappanahalli MN, Kirs M. U.S. Recreational Water Quality Criteria: A Vision for the Future. International Journal of Environmental Research and Public Health. 2015; 12(7):7752-7776. doi:10.3390/ijerph120707752.
38. Mumbi TL, Wilberforce C. An assessment of open defecation among residents of Thika East Sub-County, Kiambu county, Kenya. Int J Med Res. 2017;2(3):9-20.
39. Mulat C. Analyzing the Effect of Wastewater on Groundwater Quality in case of Bahir Dar City, Amhara Region, Ethiopia [dissertation]. Bahir Dar, Ethiopia: Bahir Dar University; 2020. p. 1-14. Available from: http://hdl.handle.net/123456789/11078.
40. Giribabu D, Bharadwaj P, Sitiraju R, Burra M, Rao PP, Reddy CS. Combating open defecation through community-led sanitation. Dr Sulaiman Al Habib Med J. 2019;1(3):45-51. doi: 10.2991/dsahmj.k.190626.001.
41. Kumie A, Zeru K. Sanitary conditions of food establishments in Mekelle town, Tigray, north Ethiopia. Ethiop J Health Dev. 2007;21(1):3-11.
42. Andreev N, Ronteltap M, Boincean B, Lens PNL. Treatment of source-separated human feces via lactic acid fermentation combined with thermophilic composting. Compost Sci Util. 2017;25(4):220-30. doi: 10.1080/1065657x.2016.1277809.
43. Han SH, An JY, Hwang J, Kim SB, Park BB. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. Forest Sci Technol. 2016;12(3):137-43. doi: 10.1080/21580103.2015.1135827.
44. Sun S, Han J. Open defecation and squat toilets, an overlooked risk of fecal transmission of COVID-19 and other pathogens in developing communities. Environ Chem Lett. 2021;19(2):787-95. doi: 10.1007/s10311-020-01143-1.
45. Griffith JF, Weisberg SB, McGee CD. Evaluation of microbial source tracking methods using mixed fecal sources in aqueous test samples. J Water Health. 2003;1(4):141-51. doi: 10.2166/wh.2003.0017.
46. Domingo JL, Nadal M. Domestic waste composting facilities: a review of human health risks. Environ Int. 2009;35(2):382-9. doi: 10.1016/j.envint.2008.07.004.
47. Wikipedia. Sanitation. Available from: Https://en.wikipedia.org/wiki/Sanitation.
48. Oishi W, Vinnerås B, Sano D. Resource recovery technologies as microbial risk barriers: towards safe use of excreta in agriculture based on hazard analysis and critical control point. Environ Sci Water Res Technol. 2023;9(4):1008-29. doi: 10.1039/d2ew00832g.
49. Thye YP, Templeton MR, Ali M. A critical review of technologies for pit latrine emptying in developing countries. Crit Rev Environ Sci Technol. 2011;41(20):1793-

819. doi: 10.1080/10643389.2010.481593.
50. Mondal S. Faecal Sludge Management in Khulna City: An Approach for Safe Emptying [dissertation]. Khulna, Bangladesh: Khulna University of Engineering & Technology (KUET); 2018.p. 1-111. Available from: http://hdl.handle.net/20.500.12228/96.
51. Kebede HA, Ayenew WA. Solid waste disposal site selection analysis using geospatial technology in Dessie city Ethiopia. Heliyon. 2023;9(8):e18865. doi: 10.1016/j.heliyon.2023.e18865.
52. Nur S. Microbial contamination of drinking water and community water in Bangladesh: a review. 2023:1–44. Available from: https://dspace.bracu.ac.bd/xmlui/handle/10361/226
53. Drangert JO. Fighting the urine blindness to provide more sanitation options. Water SA. 1998;24(2):157-64.
54. Conroy KM, Mancl KM. Understanding the adoption of urine-diverting dry toilets (UDDTs) in low- and lower-middle-income countries using the diffusion of innovation framework. J Water Sanit Hyg Dev. 2022;12(12):905-20. doi: 10.2166/washdev.2022.154.
55. Ashebir Y, Rai Sharma H, Alemu K, Kebede G. Latrine use among rural households in northern Ethiopia: a case study in Hawzien district, Tigray. Int J Environ Stud. 2013;70(4):629-36. doi: 10.1080/00207233.2013.835533.
56. Gebru H, Deyissia N, Medhin G, Kloos H. The association of sanitation and hygiene practices with intestinal parasitic infections among under-14 children in rural Dire Dawa, eastern Ethiopia: a community based cross-sectional study. Environ Health Insights. 2023;17:11786302231180801. doi: 10.1177/11786302231180801.
57. Aburto-Medina A, Shahsavari E, Khudur LS, Brown S, Ball AS. A review of dry sanitation systems. Sustainability. 2020;12(14):5812. doi: 10.3390/su12145812.
58. Van Der Geest S. The night-soil collector: bucket latrines in Ghana. Postcolonial Stud. 2002;5(2):197-206. doi: 10.1080/1368879022000021092.
59. Schouw NL, Danteravanich S, Mosbaek H, Tjell JC. Composition of human excreta--a case study from Southern Thailand. Sci Total Environ. 2002;286(1-3):155-66. doi: 10.1016/s0048-9697(01)00973-1.
60. Wikipedia. Bucket Toilet. Available from: Https://en.wikipedia.org/wiki/Bucket_toilet.
61. Chaggu EJ. Sustainable Environmental Protection Using Modified Pit-Latrines [dissertation]. The Netherlands: Wageningen University and Research; 2004. Available from: https://www.proquest.com/openview/b3e49d5278712e72761948cca272c451.
62. Still DA. After the Pit Latrine is Full… What Then? Effective Options for Pit Latrine Management. Biennial Conference of the Water Institute of Southern Africa. 2002. Available from: https://sswm.info/sites/default/files/reference_attachments/still20200220after20the20pit%20latrine20is20full.pdf.
63. Mihelcic JR, Fry LM, Shaw R. Global potential of phosphorus recovery from human urine and feces. Chemosphere. 2011;84(6):832-9. doi: 10.1016/j.chemosphere.2011.02.046.
64. Zhang W, Xiao X, An T, Song Z, Fu J, Sheng G, et al. Kinetics, degradation pathway and reaction mechanism of advanced oxidation of 4-nitrophenol in water by a UV/H2O2 process. J Chem Technol Biotechnol. 2003;78(7):788-94. doi: 10.1002/jctb.864.
65. Orner KD, Mihelcic JR. A review of sanitation technologies to achieve multiple sustainable development goals that promote resource recovery. Environ Sci Water Res Technol. 2018;4(1):16-32. doi: 10.1039/c7ew00195a.
66. Nakagiri A, Niwagaba CB, Nyenje PM, Kulabako RN, Tumuhairwe JB, Kansiime F. Are pit latrines in urban areas of sub-Saharan Africa performing? A review of usage, filling, insects and odour nuisances. BMC Public Health. 2016;16:120. doi: 10.1186/s12889-016-2772-z.
67. Crennan L. Sustainable Sanitation Manual and Construction Guidelines for A Waterless Composting Toilet. IWP-Pacific Technical Report (International Waters Project). No. 52. 2007. Available from: https://www.sprep.org/att/publication/000560_IWP_PTR52.pdf.
68. Portiolli GF, Rogers TW, Beckwith W, Tsai J, ole-MoiYoi P, Wilson N, et al. Development of trash exclusion for mechanized pit latrine emptying. Environ Sci Water Res Technol. 2021;7(10):1714-22. doi: 10.1039/d1ew00383f.
69. Wikipedia. Pit Latrine. Available from: https://en.wikipedia.org/wiki/Pit_latrine.
70. Bester JW, Austin LM. Design, construction, operation and maintenance of ventilated improved pit toilets in South Africa. No. 709. Water Research Commission; 1997. Available from: https://www.fsmtoolbox.com/assets/pdf/148_-_709-1-00.pdf.
71. Schmitt ML, Clatworthy D, Ogello T, Sommer M. Making the case for a female-friendly toilet. Water. 2018;10(9):1193. doi: 10.3390/w10091193.
72. Roma E, Philp K, Buckley C, Scott D, Xulu S. User perceptions of urine diversion dehydration toilets: experiences from a cross-sectional study in eThekwini municipality. 2013;39(2):305-12. doi: 10.10520/ejc134869.
73. Harroff LA, Liotta JL, Wangolo EE, Egan TJ, Bowman DD, Angenent LT. Field-scale co-fermentation of solid waste from urine-diverting dry toilets (UDDT-SW) and banana waste to produce undissociated carboxylic acids to inactivate ascaris eggs. Front Environ Sci. 2019;7:139. doi: 10.3389/fenvs.2019.00139.
74. Nienhuys S. Urine Diversion Toilet (UDT) Urine Diversion Dry (Dehydration) Toilet (UDDT): Ecological Sustainable Sanitation in Himalayan Conditions. Technical Working Paper. No. 13. 2012. Available from: https://www.researchgate.net/publication/232613892_Urine_Diversion_Toilet_UDT_Urine_Diversion_Dry_Dehydration_Toilet_UDDT_Technical_Working_Paper_-_number_13_Ecological_Sustainable_Sanitation_in_Himalayan_Conditions.
75. Rubio-Rincón FJ, Lopez-Vazquez CM, Ronteltap M, Brdjanovic D. Seawater for phosphorus recovery from urine. Desalination. 2014;348:49-56. doi: 10.1016/j.desal.2014.06.005.
76. Uddin SM, Ronteltap M, van Lier JB. Assessment of urine diverting dehydrating toilets as a flood-resilient and affordable sanitation technology in the context of Bangladesh. J Water Sanit Hyg Dev. 2013;3(2):87-95. doi: 10.2166/washdev.2013.113.
77. Tilley E, Günther I. The impact of conditional cash transfer on toilet use in eThekwini, South Africa. Sustainability. 2016;8(10):1070. doi: 10.3390/su8101070.
78. Brigidi P, Vitali B, Swennen E, Bazzocchi G, Matteuzzi D. Effects of probiotic administration upon the composition and enzymatic activity of human fecal microbiota in patients with irritable bowel syndrome or functional diarrhea. Res Microbiol. 2001;152(8):735-41. doi: 10.1016/

s0923-2508(01)01254-2.
79. Anand CK, Apul DS. Composting toilets as a sustainable alternative to urban sanitation – a review. Waste Manag. 2014;34(2):329-43. doi: 10.1016/j.wasman.2013.10.006.
80. De Gisi S, Petta L, Wendland C. History and technology of Terra Preta sanitation. Sustainability. 2014;6(3):1328-45. doi: 10.3390/su6031328.
81. Reader D, Huelgas A. Basic Overview of Composting Toilets (With or Without Urine Diversion). 2010. p. 1–19. Available from: http://www.gtz.de/en/dokumente/gtz2010-en-technology-review-composting-toilets.pdf.
82. Hill GB, Baldwin SA, Vinnerås B. Evaluation of Solvita compost stability and maturity tests for assessment of quality of end-products from mixed latrine style compost toilets. Waste Manag. 2013;33(7):1602-6. doi: 10.1016/j.wasman.2013.03.021.
83. López Zavala MÁ, Funamizu N, Takakuwa T. Characterization of feces for describing the aerobic biodegradation of feces. Doboku Gakkai Ronbunshu. 2002;2002(720):99-105. doi: 10.2208/jscej.2002.720_99.
84. Hotta S, Funamizu N. Nitrogen recovery from feces and urine in urine diverting composting toilet system. Dry Toilet Seminar, Tampere, Finland [Internet]. 2006. p. 16-9. Available from: http://www2.gtz.de/Dokumente/oe44/ecosan/en-nitrogen-recovery-from-feces-and-urine-2006.pdf.
85. Wang X, Chen J, Li Z, Cheng S, Mang HP, Zheng L, et al. Nutrient recovery technologies for management of blackwater: a review. Front Environ Sci. 2023;10:1080536. doi: 10.3389/fenvs.2022.1080536.
86. Nagy J, Zseni A. Human urine as an efficient fertilizer product in agriculture. Agron Res. 2017;15(2):490-500.
87. Compost toilets - St Ives Community Orchard CIC. 2017. Available from: https://www.stivesorchard.co.uk/compost-toilets/.
88. Zhu P, Pan X, Shen Y, Huang X, Yu F, Wu D, et al. Biodegradation and potential effect of ranitidine during aerobic composting of human feces. Chemosphere. 2022;296:134062. doi: 10.1016/j.chemosphere.2022.134062.
89. Tidåker P. Life Cycle Assessment of Grain Production Using Source-Separated Human Urine and Mineral Fertiliser. 2003. Available from: https://pub.epsilon.slu.se/3812/1/tidaker_p_090928.pdf.
90. Shih K. Incinerating Hong Kong Water Treatment Sludge: The Potential of Ash Reuse and Recycling. 2009; Available from: https://hub.hku.hk/handle/10722/63206.
91. Astari AJ, Somantri L, Bratanegara AS, Ihsan HM, Aliyan SA. Ecological criteria for sustainability in global, national, and local scales: a review of the literature and case study in the indonesian palm oil sector. IOP Conference Series: Earth and Environmental Science 2022;1089(1):012072. doi: 10.1088/1755-1315/1089/1/012072.
92. Jayathilake N, Drechsel P, Keraita B, Fernando S, Hanjra MA. Guidelines and Regulations for Fecal Sludge Management from On-Site Sanitation Facilities. International Water Management Institute (IWMI); 2019. p. 1-62.
93. Uddin SM, Ronteltap M, van Lier JB. Assessment of urine diverting dehydrating toilets as a flood-resilient and affordable sanitation technology in the context of Bangladesh. Journal of Water, Sanitation and Hygiene for Development. 2013; 3 (2): 87–95. doi: 10.2166/washdev.2013.113.
94. Riungu J, Ronteltap M, van Lier JB. Anaerobic stabilisation of urine diverting dehydrating toilet faeces (UDDT-F) in urban poor settlements: biochemical energy recovery. J Water Sanit Hyg Dev. 2019;9(2):289-99. doi: 10.2166/washdev.2019.099.
95. Liu B, Yang B, Zhang C, Wei X, Cao H, Zheng X. Human waste substitute strategies enhanced crop yield, crop quality, and soil fertility in vegetable cultivation soils in north China. Agronomy. 2021;11(11):2232. doi: 10.3390/agronomy11112232.
96. Castro-Herrera D, Prost K, Schäfer Y, Kim DG, Yimer F, Tadesse M, et al. Nutrient dynamics during composting of human excreta, cattle manure, and organic waste affected by biochar. J Environ Qual. 2022;51(1):19-32. doi: 10.1002/jeq2.20312.
97. Sharda Kc, Shinjo H, Harada H. People's perception on ecological sanitation and health risks associated in Central Nepal. Sanit Value Chain. 2020;4(3):3-19. doi: 10.34416/svc.00023.
98. Adjama I, Derkyi NS, Uba F, Akolgo GA, Opuko R. Anaerobic co-digestion of human feces with rice straw for biogas production: a case study in Sunyani. Model Simul Eng. 2022;2022(1):2608045. doi: 10.1155/2022/2608045.
99. Triastuti J, Sintawardani N, Irie M. Characteristics of composted bio-toilet residue and its potential use as a soil conditioner. Indones J Agric Sci. 2009;10(2):73-9.
100. Schoeber M, Rahmann G, Freyer B. Small-scale biogas facilities to enhance nutrient flows in rural Africa—relevance, acceptance, and implementation challenges in Ethiopia. Org Agric. 2021;11(2):231-44. doi: 10.1007/s13165-020-00329-9.
101. Mackie Jensen PK, Phuc PD, Knudsen LG, Dalsgaard A, Konradsen F. Hygiene versus fertiliser: The use of human excreta in agriculture – a Vietnamese example. Int J Hyg Environ Health. 2008;211(3-4):432-9. doi: 10.1016/j.ijheh.2007.08.011.
102. Riungu J, Ronteltap M, van Lier JB. Build-up and impact of volatile fatty acids on *E. coli* and *A. lumbricoides* during co-digestion of urine diverting dehydrating toilet (UDDT-F) faeces. J Environ Manage. 2018;215:22-31. doi: 10.1016/j.jenvman.2018.02.076.
103. Penn R, Ward BJ, Strande L, Maurer M. Review of synthetic human faeces and faecal sludge for sanitation and wastewater research. Water Res. 2018;132:222-40. doi: 10.1016/j.watres.2017.12.063.
104. Rattan S, Parande AK, Nagaraju VD, Ghiwari GK. A comprehensive review on utilization of wastewater from coffee processing. Environ Sci Pollut Res. 2015;22(9):6461-72. doi: 10.1007/s11356-015-4079-5.
105. Kaur H, Sohpal VK, Kumar S. Designing of small-scale fixed dome biogas digester for paddy straw. Int J Renew Energy Res. 2017;7(1):422-31.
106. Ahmad S, Razzaq S, Rehan MA, Hashmi MA, Ali S, Amjad MS, et al. Experimental investigation of novel fixed dome type biogas plant using gas recovery chamber in rural areas of Pakistan. Int J Renew Energy Res. 2019;9(3):1537-47. doi: 10.20508/ijrer.v9i3.9306.g7742.
107. Mojares JG. Implementing biogas technology project in Malvar, Batangas, Philippines. Asia Pac J Multidiscip Res. 2015;3(4):158-64.
108. Noorollahi Y, Kheirrouz M, Farabi Asl H, Yousefi H, Hajinezhad A. Biogas production potential from livestock manure in Iran. Renew Sustain Energy Rev. 2015;50:748-54. doi: 10.1016/j.rser.2015.04.190.