Discover Water

Review

Vermifiltration: an opportunity to improve wastewater treatment—a sustainable and natural approach

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Abstract
Urbanization and industrialization in this modern time actually cause less availability of daily based water. In searching of a preferable solution to overcome this critical problem, waste water treatment seems to be considered as a much valuable option for reusing water. For this, sewage water treatment plants (STPs) are widely used. But this solution is actually ironical, as STP treatment causes hazardous damage to the environment in treating waste water. This system needs lots of harmful chemicals, high energy, and high build-up to operate the process. But a newly considered technology has come to counteract all these problems of STPs and the method is 'Vermifiltration'. In this technique, earthworms are used to treat waste water. Earthworm's body acts as biofilter and it can reduce higher percentage of BOD, COD, TSS from the waste water compared to the STPs. Earthworms eat up the sewage, making them treated, neutralized, and non-harmful and finally excrete them with several useful microorganisms. The symbiotic activity between earthworms and microorganisms works to filter the waste water. This method is completely odour less and harmless. No sludge is formed. With having all these characteristics, vermifiltration becomes much better option for the environment. In this review, the method of vermifiltration, its limiting factors, utilization and future developments are properly discussed.

Highlights

- The present review reports the mechanistic pathway of vermifiltration method.
- An eco-friendly and reusable vermifiltration method is applicable for the treatment of wastewater.
- Various parameters such as hydraulic loading rate, salinity rate, clogging, and sunlight have a positive impact on the efficacy of sustainable vermifiltration system.
- Active zone of this system can remediate organics (COD, BOD), nitrate from nitrogen, total phosphorus, total nitrogen, dissolved phosphorus from several kinds of wasteeffluents.
- The integrated vermifilter technique reduces the consumption of land and promotes reutilization of wastewater for cultivation purpose.

Keywords Sewage water treatment plants · Vermifiltration · Organics remediation · Nitrogen remediation · Total suspended solids · Pathogen removal · Earthworms

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1 Introduction

The increasing consumption of water and depletion of natural resources resulting from population growth and urbanization have become pressing issues that require proper resolution. The majority of the time, both urban and rural areas struggle with the issue of everyday access to clean water [1]. One of the main causes of it is poor wastewater management [2]. More than 80% of the world's wastewater flows back into the environment without being treated or reused, according to the United Nations; in some least-developed countries, the figure tops 95 percent [3]. Water use and subsequent discharge of spent water contain dangerous pollutants that will worsen the ecosystems on land and in water. The primary constituent of sewage is known as organic loadings, or such as total suspended solids (TSS), total dissolved solids (TDS), hazardous compounds, and biological and chemical oxygen demands (BOD and COD). The amount of dissolved oxygen (DO) in water is crucial to its quality. Reducing the organic load in the water is essential when sewage is released into rivers and seas. If not, aerobic bacteria in the aquatic ecosystem will use the DO to break down the organic materials. These lead to a significant decrease in DO, which has an impact on the ecosystem's normal state. Waste water from standard STPs can be handled more effectively, but the result of this treatment is a massive amount of sludge that contains harmful bacteria. In addition, it consumes more energy, costs more to maintain, and builds up and uses chemicals to carry out the cleaning process. As a result, traditional STPs fall short of the stringent disposal and discharge regulations that have been in place for the past few years [4]. There are numerous ways to align the points for improved waste water treatment outcomes. The physical and chemical approaches are among many that can be applied to accomplish the goal. Physically speaking, the process is simple and affordable, but because the pollutants cannot be entirely removed, it really has less success. However, these procedures are extremely costly. All previous techniques of treating waste water were replaced with biological treatment, which not only outperforms the others in terms of efficiency but also lessens their negative environmental effects. There are two types of biological remediation processes for waste water treatment: anaerobic systems and aerobic systems. Since 1970, these aerobic and anaerobic techniques have been used. Three steps—hydrolysis, acidogenesis, and methanogenesis—follow an organic material's biological conversion into methane and carbon dioxide throughout the anaerobic process. Aerobic mechanisms remediate biological waste by turning organic wastes into carbon dioxide and biomass. Less energy is used and less sludge is produced by anaerobic processes [5]. For high COD, this is far more successful. However, even so, it cannot be considered a reliable wastewater treatment technology because even little deviations from ideal circumstances can disrupt stabilization of the method [5]. In addition, it may take the system two to three months to possibly recover [5].

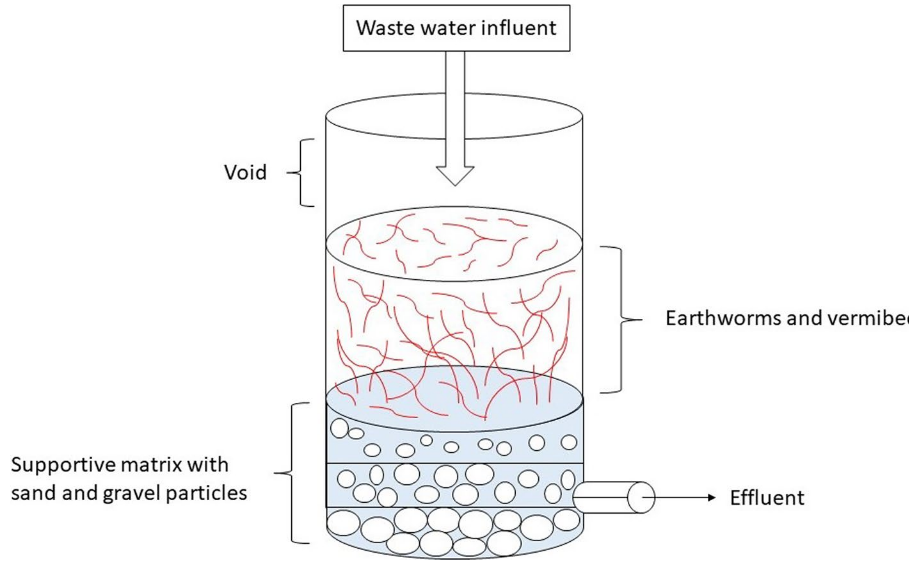
Aerobic systems have the advantage of being more vigorous than anaerobic systems [6]. Recovery time is shorter in the aerobic system than in the anaerobic system [6]. 25 to 35 °C is the ideal temperature range for this system [6]. However, in this instance, the rate of sludge generation surpasses that of the anaerobic process [6]. However, this procedure is typically not taken into consideration for high strength wastewater treatment due to its high sludge formation and increased aeration needs [6].

This can bring about a new era in waste water treatment and virtually eliminate all flaws. That is the vermifiltration method. In essence, they use their body walls to absorb organic debris, sediments, and heavy metals, which filters water [6]. The procedure does not produce any sludge that would need to be disposed of in a landfill at an additional cost. Furthermore, this procedure has no smell. This will also prevent anaerobic microbes from growing and releasing mercaptans and hydrogen sulfide. Many developing countries cannot afford the STPs' construction and maintenance costs. According to this perspective, they need more affordable choices for treating sewage water. This Vermifilter treatment system fulfills a lot of requirements. Its straightforward design, availability of basic equipment, reduced sludge generation, increased treatment capabilities, and relatively lower capital and operational expenses all contribute to its simplicity. Consequently, vermifitration technology presents a more promising avenue for addressing the issue of inadequate waste water treatment in developing nations [7].

2 Design requirements for vermifilter construction

A general structure of a vermifilter is depicted in Fig. 1. The construction and functioning of the vermifilter are crucial and must be done carefully. The hydraulic loading rate (HLR), or the rate at which wastewater interacts with the unit area of vermibed for a specific amount of time, is primarily responsible for the high removal effectiveness of a

Fig. 1 Design of a vermifilter



vermifilter. The length of time wastewater is in touch with the filter medium that earthworms reside in, known as the hydraulic retention time (HRT), needs to be carefully designed for optimal efficacy [6]. Only after enough time has passed for interaction to produce a competent microbial population can grow within the vermifilter. The filter medium layer's porosity, volume, and size all affect these two parameters. As a result, 3.5 to 8 h of HRT and 1.5 to 2.5 $m^3m^{-2}d^{-1}$ of HLR may be determined based on the vermifilter measurement.

Additional requirement parameters include age at maturity, earthworm health, and stocking density [8]. Stocking density is the number of worms that are dispersing throughout the bed. An optimal concentration of earthworms must continually be maintained in order to encourage and enhance microbial activities [8]. The survival of earthworms and the effectiveness of wastewater treatment can be affected by environmental parameters such as pH, temperature, ammonia and sodium, as illustrated in Table 1. Various sand kinds, such as quartz or river sand, as well as gravel and glass beads are used to construct the filter section of the vermifilter [8]. The characteristics of the microbial communities that make up the complex vermi-ecosystems and the efficacy of therapy are influenced by the parameters of this layer of filter medium. Two further consequences of filter bed medium are hydraulic conductivity and wastewater retention [8].

3 Mechanism of vermifiltration

Earthworms are crucial to the vermifilter's operation because they increase aeration and hydraulic conductivity. Granulation is the method used by earthworms to break down organic particles [9, 10]. This granulation serves to boost the adsorption capacity by expanding the area of the filter bed. The process of vermifiltration involves the breakdown of sludge, wastewater, microorganisms, and biological degradation [16]. There are three easy steps to describe the vermifilter process. The vermicomposting process is used in the first step to create humus [8]. The next stage is to filter. The number of microorganisms is increased by filter medium. The burrowing is done by worms. By doing this, the surface area of the filter medium is increased, increasing the rate at which organic and inorganic pollutants are absorbed from the waste effluent. Complex bioprocesses that occur in the active layer assist in stabilizing an absorbed particle. As illustrated in Fig. 2, particles that have fully dissolved in the wastewater treatment process continue to descend. Adsorption of these particles occurs in the media matrix, whereupon they are further broken down by the symbiotic action of earthworms [17].

When the ejected casting interacts with the bedding during this process, the surface area of the vermibedding expands, increasing the sorption capacity of the bedding [18]. With the aid of calcium produced by its crop, the earthworm's alimentary canal can neutralize compounds. This helps to balance the pH, allowing the chemicals that were before unusable for further degradation to now be used by the body [19]. By generating antibiotics, earthworm mucus aids in the disease's resistance and creates an environment that is conducive to the growth of gut flora. Mucus inhibits an anaerobic environment while promoting an aerobic one, per one study [20].

Table 1 Distribution of different earthworm species and their temperature tolerance level in different regions

SL. No.	Earthworms species	Types	Adult worm's weight (g)	Temperature tolerance (°C)	Moisture tolerance (%)	Active season	Distribution	Refs
1	*Eisenia fetida*	Epigenic	0.3–0.7	15–30	20–40	Throughout the year	Temperate areas of India, North America, Europe	[7]
2	*Dichogaster bolaui*	Endogenic	0.04–0.07	20–28	20–30	July–October	Tropical countries	[11]
3	*Eudrilus Eugeniae*	Epigenic	1.5–2.5	18–35	20–40	Throughout the year	Tropical Africa and South America	[12]
4	*Dicogaster affinis*	Anecic	0.04–0.07	20–28	20–30	July–October	Tropical countries	[13]
5	*Lumbricus rubellus*	Epigenic	0.8–1.5	1.5–18	20–40	October- January	North America, European countries	[14]
6	*Perionyx sansibaricus*	Epigenic	0.8–1.2	8–30	30–50	Throughout the year	Tropical countries	[15]

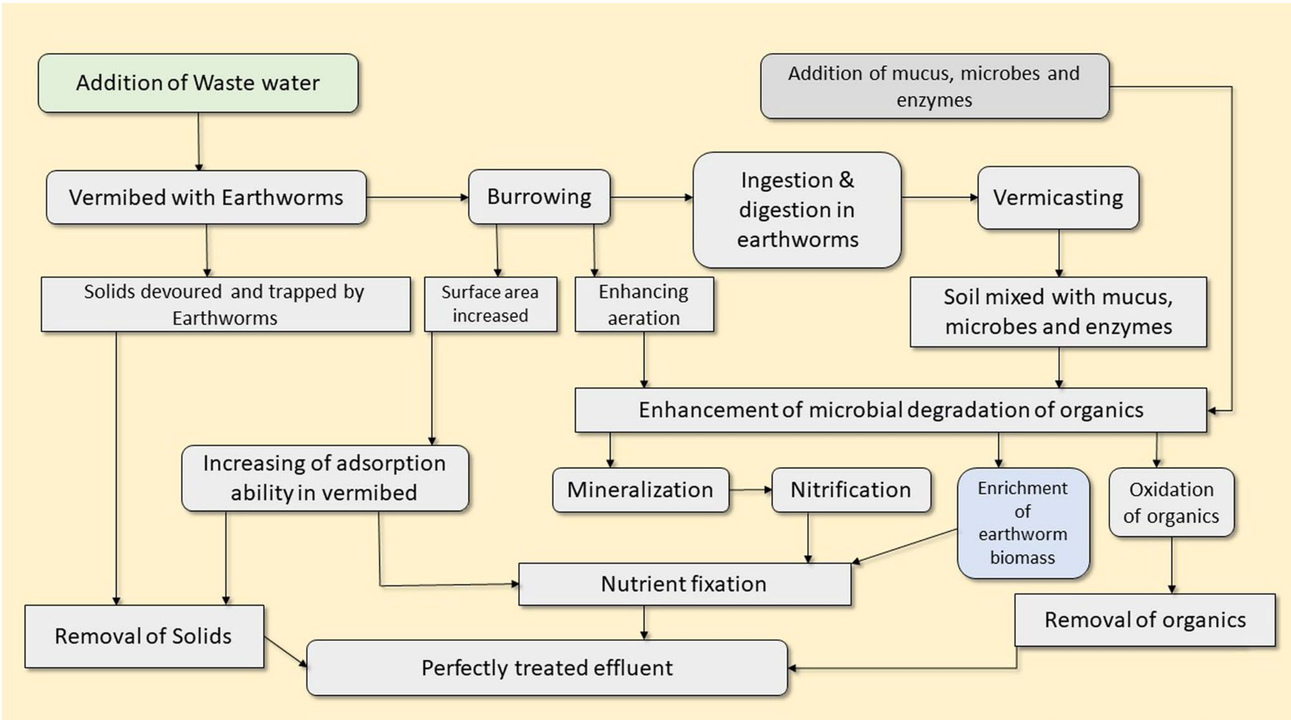


Fig. 2 Mechanism of a vermifilter

4 Specific role of earthworms for pollutants remediation

Since they are poikilothermic by nature, the temperature outside has a big impact on their body temperature. The ideal temperature range for epigenic earthworm species' activity, growth, and reproduction is between 25 and 27 °C as depicted in Table 1. According to a number of studies, the earthworms *Eisenia fetida, Perionyx sansibaricus, Lumbricus rubellus, Eudrilus eugeniae*, and *Eisenia hortensis* are capable of treating wastewater at greater moisture levels [20]. The relation between microorganisms and earthworms is very interesting as earthworms harbour different kinds of microorganisms in their gut region. They normally contain 14% lipids, 14% carbs, 3% ash, and 65% protein (70–80% high quality "lysine rich protein" on a dry weight basis) [20]. Proper aeration of soil is important factor on which earthworms survive because they breathe through their skin [6] 0.29 °C is the optimum temperature and 60–75% is optimum moisture content required for their survival [21]. Earthworms can tolerate dehydration too caused by extensive water loss [21]. Mechanism of the interaction and the role of microbes in earthworm's nutrition is still unclear needs more study and research [10, 22–28]. According to certain research, bacteria are eliminated as they enter the earthworm's digestive system. Although the connection between microorganisms and earthworms is crucial for maintaining the soil's fertility and structure, no observation has been made to support the idea that microbes are a part of the diet of earthworms [29]. Organic pollutants break down in the gut thanks to microbes. Examples of biological and physical modification include the addition of sugar and other chemicals, assimilation, homogenization, modification of the microfauna population, digestion, mucus production, and ammonia and urea excretion [30]. Because earthworms are bisexual creatures, their sexuality is thought to make them extremely unique and intriguing. According to certain research, earthworm populations can double at a minimum of every 60–70 days. Depending on the ideal circumstances, which include moisture content, temperature, and feeding supplies. Earthworms also possess the ability to develop continuously throughout the duration of their lives [6]. Many species of microbes are present in the earthworm cast in a large amount. Earthworms do not contain eyes or ears, but they still have some cells which are sensitive to light. This type of cells helps them to difference between light and darkness. Their bodies are also sensitive to vibrations. Sodium chloride concentration also determines proper growth of earthworms as their entire body surface is sensitive to the addition of sodium chloride. Their adaptation in this solution is slow. Touches also stimulate their activity and here adaptation is rapid. Earthworm's prostomial region seems to be very sensitive to these stimuli and also to sucrose, glycerol and quinine [6].

In addition to organic pollutants such as nitrogenous compounds, phosphorus compounds, carbon compounds, organic acids, COD, and BOD, earthworms are important in the breakdown of complex molecules that have phenolic, aromatic, alcoholic, hydroxyl, and carbonyl groups that bind with different metal ions [31]. In their guts, earthworms create mucus and digestive enzymes that aid in the vermi bed's ability to absorb organic waste [26]. Air permeability is also preserved by the mechanism to facilitate the decomposition of organic molecules. The excretory contents provide as a full food source for microorganisms. When the operation involving the earthworm's intestines is complete, the cast is placed. The texture of the cast ages over time, revealing the aging process [30, 32].

5 Factors affecting the vermifiltration process

5.1 HRT and HLR

Hydraulic retention time (HRT) is the amount of time it takes for wastewater to pass through the earthworm-inhabited soil profile (vermifilter bed). HRT can be increased by increasing the volume of soil factors. The number of adult worms that are alive and functioning per unit area in the vermifilter (VF) bed can also affect HRT [9]. Therefore, HRT is directly proportional to the volume of soil profile and inversely proportional to the rate at which wastewater flows through the vermifilter bed. This means that HRT is inversely related to the rate at which wastewater flows through the vermifilter bed [8, 18].

Hydraulic Loading Rate (HLR) is the amount of wastewater that is applied to each unit area of soil within each time frame. The quantity of mature, live, and healthy earthworms that are present in vermibed areas is the primary determinant that determines how well HLR functions. Reduced HRT in soil is adversely correlated with hydraulic loading rates [8]. A study showed that an increase in HLRhad a negative impact on the rates of ammonium and TN elimination. For the treatment of domestic wastewater, HLRs capacities were used in a study by and as seen in Table 2, it demonstrated that less pollution was eliminated for those with higher HLRs than for those with lower HLRs. This can be the result of the excessive moisture levels or saturated bedding [47].

5.2 C/N ratio

A low supply of C and N interferes with the vermifiltration process. This deficiency may cause inappropriate microorganism development [48]. The quantity of carbon in the influent is also abundant, which promotes bacterial metabolism. The ratio of chemical oxygen demand (COD) to nitrogen has an effect on earthworm population, and it can reduce earthworm population [50]. As shown in Table 2, the synergistic action of earthworms and microorganisms at lower ratios of COD and nitrogen improves denitrification performance of a filter [49].

5.3 Vermibed formation

The environment of the vermibed also regulates critical elements involved in the development of microbial biofilms. Vermicosis in vermi ecosystems and treatment activities sustain this microbial activity and their structure [41]. Since there is very little phosphorus removed by other mechanisms in the vermifilter, inadequate phosphate removal can result in pollutant loss in the aquatic ecosystem. More surface area is available for processing and biofilm formation thanks to the porous matrix. As a result, ceramic granules and expanded clay are frequently utilized [43]. Incorporating organic materials into the soil, such as peat, plant leaves, and small stones, can help to preserve its porosity and to improve filtering in situations when solid buildups obstruct the flow of water. Because earthworms are highly sensitive to elevated levels of dangerous metals, therefore, none of these should be included in the bedding material. Because of their superior thermal insulation properties, ceramic pellets can tolerate abrupt temperature changes. A further study shows that the riverbed is one of the best suitable bedding habitats when compared to coal, glass balls, and mud balls [10, 41]. Furthermore, the choice of filter material is crucial for preserving worm vitality and averting damage [41]. The dispersion of contaminants in the wastewater is also impacted by the wormhole's height. Additionally, it has been noted that as nest depth increases, earthworm activity diminishes [43]. According to reports, the greatest amount of artificial sewage contaminants were found 40 cm below the surface of the filter bed [11]. According to a research study, changes in filter height have an impact on earthworm growth and reproduction, bacterial flora variety, COD, and TP removal rate

Table 2 Different types of earthworm species used as a vermifilter for enhanced mitigation of harmful nutrients and other hazardous organic compounds from several kinds of waste effluents

SL. No.	Earthworm varieties	Earthworm density or abundance (EWD)	Waste effluent type	Bioremediation of COD	Bioremediation of BOD	Bioremediation of nitrogen and phosphorus	Bioremediation of nutrients	HLR ($m^3m^{-2}d^{-1}$)	Macrophyte-facilitated vermifilter (plant species)	Hydraulic retention time (HRT)	Refs
1	*Eisenia fetida*	4000–6000 worms/m^3	Real-domestic	97.5%	96.8%	TN = 87% ON = 100%	NH^{4+}-N = 98.2% TKN = 99%	3	–	24 h	[33]
2	*Eisenia fetida*	45 kg	Dairy	96.5%	94.6%	TN = 71.4%	NH^{4+}-N = 96.4% NO^3-N = 21.5%	2.5	–	11 h	[34]
3	*Eisenia fetida*	3000–6000 worms/m^3	Domestic	95%	98.7%	TN = 76.5% TP = 87.6%	TDS = 98.7% TSS = 78.4%	< 2.5	–	(2–8) h	[35]
4	*Eisenia fetida*	1 kg	Textile dye	(85–89) %	(76–80) %	–	TDS = (71–76) % TSS = (73–77) %	–	–	(8–10) h	[36]
5	*Eisenia fetida*	9661.33(earthworms/m^3**)**	Brewery	96.24%	–	TN = 21.57% TP = 43.3%	–	1.84	–	26.66 h	[18]
6	*Eisenia fetida*	10 kg	Distillery	89.4%	91.1%	TKN = 94.9% TP = 96.87%	TDS = 91.9% TSS = 92.4%	–	–	40 h	[37]
7	*Eisenia fetida*	2000–6000 worms/ m^3	Sewage	99.6%	95.7%	TN = 96.8% TP = 97.8%	–	1.56	–	28 h	[19]
8	*Eisenia fetida*	–	Dairy	73% 62.6% 43.9%	56.8% 78.9% 90%	TP = 61.1% 49.3% 38.3% TN = 37.8% 28% 18.8%	$NH4^+$-N = 68.3% 55.2% 31.6%	0.3 0.6 0.9	*Canna indica*	6–8 h	[31]
9	*Eisenia fetida*	20 g/L	Domestic	86.7%	98.5%	TN = 99.1%	NH^{4+} = 99.1% TSS = 96.6%	0.89	–	6 h	[16]
10	*Eisenia fetida*	–	Dairy	75.8%	87.4%	TN = 42.6%	NH^{4+}- N = 73.2%	0.65	*Canna indica*	9 h	[38]
11	*Eisenia fetida*	–	Domestic	–	88%	–	TSS = 78% TDS = 75%	2.5	–	45.6 h	[39]
12	*Eudrilus eugeniae*	–	Domestic		70%		TSS = 67% TDS = 66%	2.5		45.6 h	[39]
13	*Eisenia fetida*	–	Synthetic domestic	70–88%	85–90%	TP = 84–95% TN = 84–93%	NH^{4+}- N = 80–92%	–	*Iris japonica*	24–28 h	[40]
14	*Eisenia fetida*	56 g/L	Domestic	72.3%	81.2%	TN = 87.6% TP = 90.8%	NO^3-N = 31.2 mg/L PO^{4-} = 18.1 mg/L	2.5	–	43.2 h	[41]
15	*Eisenia fetida*	9 kg	Sewage	87.9%	98.5%	TN = 97.6% TP = 90.5%	–	3.6	–	5 h	[42]
16	*Eisenia fetida*	3000–6000 worms/ m^3	Domestic	94.2%	96.3%	TN = 58.2%	NH^{4+}- N = 93.3%	0.36	*Lolium perennel*	28–32 h	[43]
17	*Eisenia fetida*	500 g/L	Sewage	70%	98%	–	TDS = 95% TSS = 98%	2.5	–	40 h	[44]

Table 2 (continued)

SL. No.	Earthworm varieties	Earthworm density or abundance (EWD)	Waste effluent type	Bioremediation of COD	Bioremediation of BOD	Bioremediation of nitrogen and phosphorus	Bioremediation of nutrients	HLR ($m^3m^{-2}d^{-1}$)	Macrophyte-facilitated vermifilter (plant species)	Hydraulic retention time (HRT)	Refs
18	*Pheretima peguana*	36 kg	Swine	> 90%	96%	TN = > 90%	–	0.08	*Typha angustifolia*	48 h	[45]
19	*Perionyx sansibaricus*	10 kg	Urban	90%	86.5%	TN = 76.6%	PO_4^{3-} = 98.3%	–	*Cyprus rotundus*	7–10 h	[46]
20	*Eisenia fetida*	30.3 kg	Domestic	(47.3–64.7)%	(54.78–66.36)%	TN = (7.63–14.90)%	NH^4-N = (21.01–62.31)% TSS = (57.18–77.90)%	4.8	–	8 h	[47]

[43]. It was suggested to take into account a height of 60 cm of vermibed in order to enhance the removal of nutrients from sewage and because earthworms develop so strongly [43, 50].

5.4 Selection of earthworm species

Eisenia fetida, *Perionyx sansibaricus*, *Lumbicus rubellus*, *Eudrilus eugeniae*, *Eisenia hortensis*, *Dichogaster affinis*, and *Dichogaster bolaui* are the most often utilized species in the vermifiltration process (Table 1). *Eisenia fetida* is an epigenic earthworm species that thrives in partially decomposed trash and needs high humidity and dark circumstances [17]. Due to their ability to manage larger amounts of organic matter in extremely damp settings and their capacity to devour more soil than any other earthworm species—which in turn generates more stratification with NPK content—these species are highly beneficial [15]. The vermifilter's treatment capacity is contingent upon the earthworm population. The efficiency of the treatment increases with the number of worms applied to the bed [12]. Two separate units of vermifiltration (VF1 and VF2) that are based on epigenic earthworms (*Eisenia fetida* and *Eudrilus eugeniae*) to treat household wastewater was investigated. Overall, VF1's effluent showed that *E. fetida* could remediate wastewater through the vermifiltration process because it was heavy in nitrate and phosphate [41].

5.5 Feeder type

Three categories are typically offered in the wastewater feeding process. They are intermittent, batch, and continuous [51]. When the microorganisms' activity of vermifiltration increases over an extended period of time, the DO level falls in the continuous mode of feeding. As a result, the reduction efficiency for nutrients and organics is decreasing, and aeration is necessary to get a higher efficiency [50]. Low occupied land area can result in high efficiency when mechanical aeration is used [52]. By partially regaining the porosity, intermittent feeding helps to revive the filter by providing a habitat for bacteria that initiate the nitrification and denitrification processes [53]. Additionally, short HRT results in a reduced system waste disposal rate.

5.6 Other factors

Setting such as pH and ammonia and sodium concentrations can affect the growth and reproduction of earthworms employed in vermifilters [7]. According to reports, the majority of earthworm species can thrive in a pH range of 5 to 9 [30]. Worms in their juvenile stage exhibit greater sensitivity to changes in pH compared to their mature stages. Additionally, it has been shown that earthworm activity and the buffering effect of vermin compost help to keep the total pH in the vicinity of neutral. There have been no reports of any harmful effects related to the ammonia concentrations on earthworms. Furthermore, variations in sodium ions may cause osmotic dysregulation, which can be harmful to earthworms. Additionally, it is noted that the presence of chloride amplifies the harmful consequences.

6 Comparative study of conventional treatment method and vermifiltration method

6.1 Sustainable energy

Vermifiltration doesn't need any energy source other than pump for the translocation of wastewater to the vermifiltration unit.

6.2 Elimination of TSS and TDS

Organic substances in the wastewater are digested and decomposed which leads to end products which can be used efficiently in agriculture as well as horticulture. Earthworm saliva called grume softens the sludge present in wastewater, and neutralized by the oesophagus of the earthworm in the intestine with the aid of enzymes. Finally, the process of excreta is referred to as vermicomposting, which has the potential to be a potent fertilizer and soil enhancer [13].

6.3 Pathogens and microorganism eradication

Research revealed that infections are lowered below the threshold value in the vermifilter due to the symbiotic relationship between earthworms and microorganisms as well as the antibacterial activity of microflora connected to earthworms [8, 53]. The primary mechanisms by which pathogens (such as *Salmonella* sp., *Escherichia coli*, faecal *Coliform*, total *Coliform*, faecal *Streptococcus*, and intestinal enzymes released from worms' intestinal walls) are removed through vermifiltration include mucus secreted by roundworms and intestinal enzymes [53]. According to studies,earthworms can also acquire natural bacteria and fungi in their stomachs that create antibiotics that kill pathogens in addition to consuming pathogens found in sewage [39, 41, 54]. Additional elements that could be connected to the pathogen removal is the attachment of bacteria to the filter, which holds the germs in place while filtering occurs [41, 53]. It is possible to remove dangerous pathogenic bacteria, such as Salmonella spp. and E. coli, as well as other microorganisms, such as certain viruses, from sewage sludge considerably more effectively when *E. fetida* species is employed in vermifiltration [55],as illustrated in Fig. 3.

6.4 Removal of heavy metals and other toxic chemicals

Among the important traits of earthworms, there is bioaccumulation. Numerous studies have indicated that earthworms have the ability to accumulate higher concentrations of heavy metals, including those that cause disruption to the human intestine and those like cadmium (Cd), mercury (Hg), chromium (Cr), uranium (U), and lead (Pb) [2, 34]. These metals may or may not be biologically available. Earthworms are effective in bioaccumulating in both situations and have no effect on the organism's physiology [56]. Numerous investigations have documented the presence of significantly more zinc in the effluent than in the geo-microbial filters, which are actually in charge of the bioconversion of the unstable to the stable fraction of metals [57]. This conversion causes it to be fixed in the tissues of the earthworm and the bed. As pH rises, the concentration of heavy metals in the vermibed effluent decreases because of the production of hydroxide ions and the subsequent adsorption of these ions by the bed materials [58]. As shown in Table 3, it has been observed through multiple research that the highly polluted compost can be used for the cultivation of sunflower and mustard because these plants are capable of and tolerate phytoremediation [62].

6.5 Improvement in BOD and COD

Research has shown that the vermifiltration method—which uses earthworms—removes more organic waste from sewage supplies than does a standard filter system [63]. Lower BOD is associated with greater organic matter breakdown and oxidation, which may be caused by earthworm discharge and interactions with aerobic bacteria [63]. Earthworms have a unique ability to dissolve insoluble organic materials, which helps microbial degradation even further [63]. In the end, all of these steps increase the removal of organic matter's efficiency [18]. The elimination effectiveness of COD is lower, according to a small number of experiments [18]. The procedure is further expedited by the biodegradable portion of the input breaking down due to the earthworms and bacteria' symbiotic connection. Higher temperatures were observed to increase the clearance of organic materials [20]. Seasonal temperature fluctuations might also alter this process. Because earthworm microbiological and enzymatic activity releases atmospheric carbon dioxide, higher consumption of organic carbon leads to lower quantities of total organic carbon (TOC) in vermifiltration [46, 47]. Numerous studies demonstrate that earthworms may lower the average COD of sewage by 80–90%, whereas in the absence of earthworms (with only the geological and microbiological systems in the control series), it is more than 15–25%, as Tables 1, 2, and 3 illustrate.

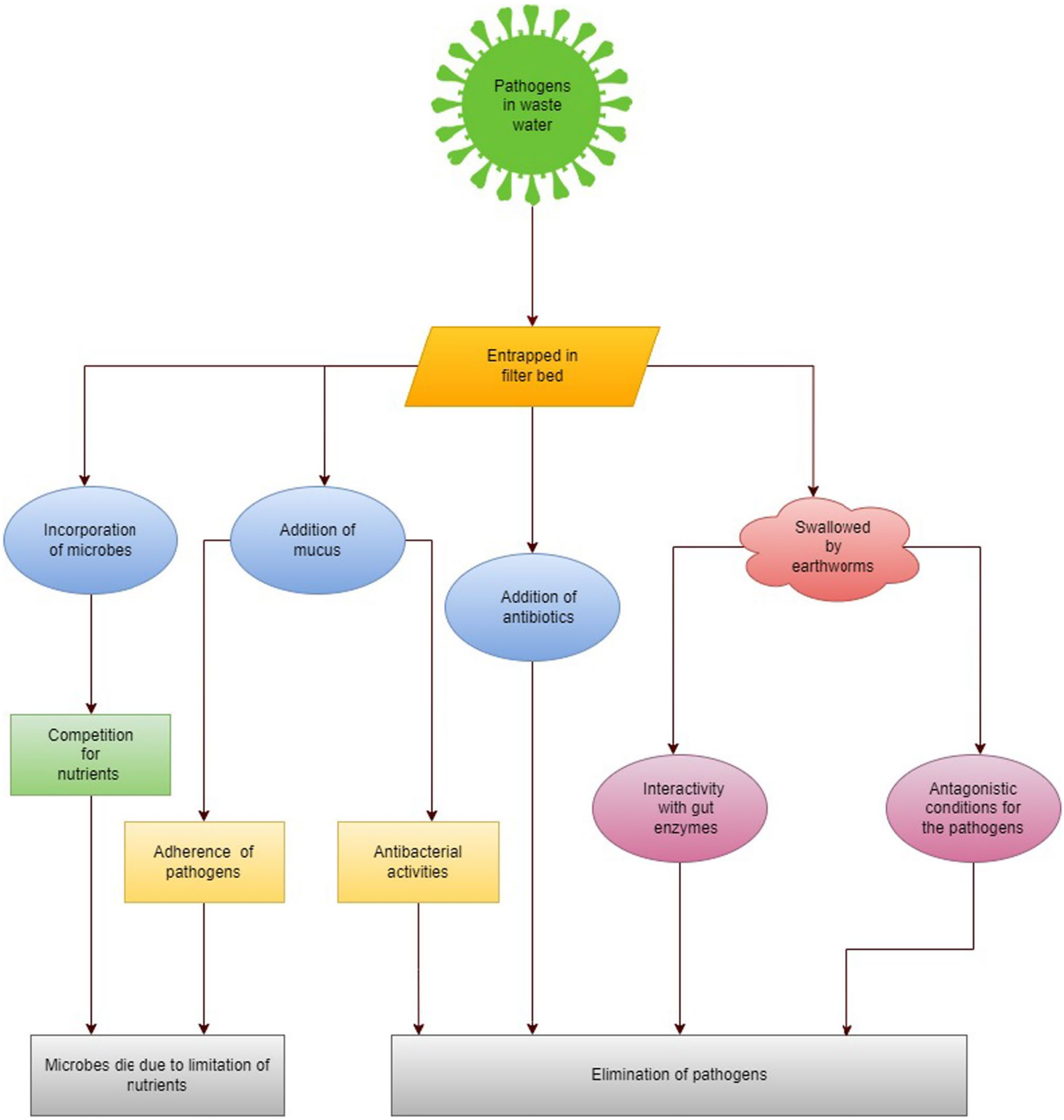


Fig. 3 Mechanism of pathogen removal

6.6 Other unique features of vermifiltration

6.6.1 No foul smell

In vermifiltration, earthworms are responsible for the absorbance of rot and decaying smell which are produced due to production of hydrogen sulphide and mercaptans. These chemicals are released due to the anaerobic microbes when their action is inhibited in the process of burrowing [46].

Table 3 Bioremediation of numerous kinds of emerging pollutants from different wastewater systems by vermifiltration technique

SL. No.	Earthworm species	Wastewater type	Pollutant	Pollutant type	Initial pollutant concentration	pH	Incubation period	Final pollutant concentration	Removal %	Refs
1	*Eisenia fetida*	Industrial	Cu (II) Zn (II)	Heavy metal(s)	2.0 mg/L 8.0 mg/L	8.16	45 days	–	96.8%	[34]
2	*Eisenia fetida*	Clinical laboratory	Antibiotic resistant bacteria Antibiotic resistant genes	Antibiotic residues	-	8.16	24 h	–	(85–99.5)%	[54]
3	*Eisenia fetida*	Industrial	Cu (II) Pb (II)	Heavy metal(s)	1600 mg/L	7.16	48 h	150 mg/L	64.5% 97.5%	[59]
4	*Eisenia fetida*	Hospital	Ciprofloxacin Ofloxacin Sulfamethoxazole	Antibiotic residue(s)	7505.08–14731.88 ng/L	8.16	24 h	265.8 ng/L	99.7%	[60]
5	*Eisenia fetida*	Dye effluent	Methylene blue	Dye	–	8.16	60 days	–	98%	[19]
6	*Eisenia fetida*	Industrial	Phenol	Dye	50 ppm	8.0	48 h	30 ppm	87.8%	[56]
7	*Eisenia fetida*	Industrial	Phenol	Dye	100 ppm	8.16	72 h	20 ppm	98.5%	[61]

6.6.2 Production of vermicompost

Worm excrement, which is used to make vermicast, has long been utilized as a nutrient-rich plant nourishment. Vital nutrients including potassium, phosphorus, and nitrogen are abundant in vermicast (NPK). 1.16% nitrogen, 1.22% phosphorus, and 1.34% potassium have been found in this worm excrement [46]. Additionally, earthworms release proteins, polysaccharides, and other nitrogenous substances into the sewage, which is then further mineralized to produce nitrogen (N), which is then accessible to plants as nutrients (mostly in the form of nitrates) [46]. As a result, this vermicast is highly valued in agricultural settings.

6.6.3 Biomass production

For earthworms to multiply quickly, they need a steady supply of food (such as organic materials and bacteria) as well as favorable moisture conditions. In the wastewater, everything that is needed is sufficiently present. In the process of vermifiltration, a massive population, or biomass, of earthworms develops over time. A sizable aggregate of earthworm biomass may be produced at some point during the vermifiltration process [47]. Probiotics and a few key amino acids, such as methionine and lysine, are abundant in this biomass [64]. As a result, it is frequently utilized as feed for fish, poultry, and cattle farms [64]. Given that it provides fish with a more nutrient-dense live meal, this becomes highly popular in the fishing industry.

7 Limitations

This system of treatment for wastewater and sludge can only be operated in underground flow and under filter setting; it cannot be operated in setting which is submerged or floating because earthworm survival is affected in such conditions. In only two positions, it can be worked in straight standing position and horizontally. Earthworm's bodies are formed of fragile muscles, they won't be able to survive under conditions of high hydraulic loading rate and direct rain [19, 36]. Additionally, the vermifilter's soil receives moisture and air gaps. There is a decrease in burrowing activity because it develops in the soil and rapidly loads with water [36]. Placement of the system is limited to the close door as earthworm cannot tolerate high temperature which can be caused because of the sun heat or other environmental factors [36]. Salinity disrupts earthworm's internal osmotic balance which makes it impossible for earthworms to flourish [15]. The subsequent treatment could be problematic which results in the decrease of absorption of organic wastes, heavy metals, and other contaminants. Growth of earthworm biomass, and reproduction could be so rapid that it damages the stability of the vermifiltration procedure. Lack of food and room cause the earthworms' condition to worsen [6]. Every system for its optimum work, it need to be clean and sanitized. Cleaning the whole system is big task. There has been very less study for the most efficient method of doing this so that earthworms are not harmed. Running time is short. Choking is caused by the buildup of solids, the development of microbial colonies, and the development of sludge on the surface. In the casting and feeding of filters during vermifiltration treatment system runs for a little period of time due to frequent choking [46, 47, 64].

8 Future perspectives and conclusion

When earthworms are introduced to treat the waste effluent, it shows maximum positive results as this method is auto regulated. Vermifiltration technology requires low cost and maintenance, less energy and thus it could become a greater option to replace STPs, making the environment healthier. In this technique energy is only require for pumping of wastewater. Vermifiltration doesn't need any professional labour as it doesn't require any high profile devices. Pumps are only need to pull up waste influent into filter [6]. Chance of air pollution can also be prevented through this process, as sludge is not formed here, therefore landfill incineration doesn't occur. Economically the technique is very impressive because the by-product and the rest wastes can be reutilized here. For example, vermicasts are used in agriculture and horticulture industry due to its high nutritive value. Investment in vermifiltration is also low as in one time earthworms must be bought from any vermiculture industry and in turn earthworms multiply rapidly in a very short time, making a heavy population in the vermibed media. From this study, it is now clearly understood that the vermifiltration technique may be a powerful alternative of the traditional waste water treatment by the STPs. This method is being more authentic and beneficial as earthworms acts as the major worker in vermifiltration. Earthworms have high impact in controlling environmental risks. In conventional STPs higher energy, huge amount of chemicals, high maintenance are required. These also require landfill incineration as heavy amount of sludge is generated here. Whereas, no sludge is formed in vermifiltration method, rather this process consumes less energy. The approach has also been used to solve the landfilling problem. All of the investigations show that, in an ideal setting, the BOD, COD, TSS, and TDS were reduced by roughly 97%, 90%, 90%, and 80%, respectively. These outcomes are far superior than those of the conventional sewage water treatment method. Moreover, the vermicast and treated effluent have significant nutritional effects since they include potassium (K), phosphorus (P), and nitrogen (N). As a result, the agricultural sector makes extensive use of both the effluent and the byproducts. The method's low maintenance costs and minimal negative environmental effects make it both cost-effective and environmentally beneficial. As a result, it is reasonable to state that the vermifiltration method of treating sewage water is safe and environmentally friendly.

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Declarations

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