Chapter 1
Applicability of Vermifiltration for Wastewater Treatment and Recycling

Bhavini, Kavita Kanaujia, Amber Trivedi, and Subrata Hait

Abstract With the rapid population growth and wastewater generation due to anthropogenic activities, availability of freshwater is decreasing annually. Untreated wastewater discharged from the municipal and industrial sectors reaches to the local surface water bodies and degrades water quality. Conventional wastewater treatment systems possessing high carbon footprint require mechanistic operations and need to be made affordable with ease of operation. To overcome the impediments associated with the conventional treatment systems, vermifiltration technique employing earthworms in a filter bed has emerged as an alternative for wastewater treatment and recycling. Further, the potential of macrophyte has also been explored by integrating with the vermifiltration system for wastewater treatment. This chapter presents the applicability of vermifiltration technique with various filter design configurations and mechanisms involved for the treatment and recycling of both sewage and industrial effluents. Further, the influence of different operational parameters like hydraulic retention time (HRT), organic loading rate (OLR), hydraulic loading rate (HLR), filter media bed design, earthworm density and flow mode on organic, nutrient and pathogen removals from domestic and industrial wastewater is discussed concisely. Moreover, future perspectives have been provided towards the improvement of the efficacy of the vermifiltration system for wastewater treatment and recycling.

Keywords Vermifiltration · Earthworms · Macrophytes · Integrated system · Wastewater treatment and recycling

Bhavini · K. Kanaujia · A. Trivedi · S. Hait (✉)
Department of Civil and Environmental Engineering, Indian Institute of Technology Patna, Patna, Bihar, India
e-mail: shait@iitp.ac.in

S. A. Bhat et al. (eds.), *Earthworm Assisted Remediation of Effluents and Wastes*,
https://doi.org/10.1007/978-981-15-4522-1_1

1.1 Introduction

Increase in global population, urbanization and industrialization has resulted in environmental pollution and degradation including diminished water quality (Verma et al. 2012). Disposal of untreated sewage and industrial effluents into the surface water bodies leads to water pollution (Goel 2006). Wastewater carrying organics like biochemical oxygen demand (BOD), chemical oxygen demand (COD) and nutrients like nitrogen and phosphorus results in the problems like depletion of dissolved oxygen (DO) and eutrophication (Metcalf et al. 1991; Zheng et al. 2013). In addition, exposure to the water contaminated by the release of pathogens from sewage into the surface water leads to water-borne diseases (Reddy and Smith 1987). Thus, deterioration of river ecology along with the loss of freshwater sources creates an unhealthy environment for humans (Wang et al. 2012). Furthermore, the per capita available water is becoming less with an increase in the population pertaining to the limitation of freshwater sources (Pimentel et al. 2004). Therefore, it becomes necessary to reuse wastewater generated from households and other places after giving a certain level of treatment. Owing to the water scarcity and water pollution due to anthropogenic activities, there is an urgent need to treat and reuse the treated effluent in industrial, agricultural and non-potable purposes.

For wastewater treatment, anaerobic and aerobic processes are being used worldwide (Speece 1983). In the anaerobic process, microbes convert organic matters into methane and carbon dioxide, whereas in the aerobic process, aerobic microbes convert organic matters into biomass and carbon dioxide (Metcalf et al. 1991). The anaerobic process is effective for high COD wastewater, requires less energy, and produces less sludge in comparison to aerobic process. However, it has been documented that the aerobic process is comparatively better than the anaerobic process in terms of acclimatizing the variation in pH, temperature and organic loading rates (OLR) (Degremont 1991). Further, the aerobic process requires less time to restart and can work between a range of temperature from 25 to 35 °C as compared to the optimum temperature for the anaerobic process is 30 °C (Singh et al. 2019b). However, both conventional wastewater treatment techniques required high capital cost, recurring expenditures, skilled manpower, more time to restart after complete shutdown and mechanized and energy-intensive operations (Noumsi et al. 2005). In addition, the sludge generated from conventional processes requires further treatment before getting disposed into the environment. Other than the biological treatment process, physical and chemical processes are also being used in some part of the world (Adin and Asano 1998). However, physical and chemical processes are not efficient organic and nutrient removal from wastewater (Ra et al. 2000). Thus, in the present scenario, an economical and sustainable process is required to treat wastewater with less capital and operation and maintenance cost and ease of operation process.

Integration of earthworms in wastewater filtration process has evolved as an eco-friendly and economical alternative to conventional wastewater process, collectively known as vermifiltration (Tomar and Suthar 2011). Wastewater passing through the initial layer, where the organic matter is converted into humus by earthworm, is followed by the filtration through filter media which supports micro-organism's growth and subsequently secondary treatment occurs. Recent studies have shown that the vermifiltration technique can emerge as a suitable and sustainable alternative for wastewater treatment and recycling. Thus, the chapter presents an overview of the vermifiltration technique with various filter design configurations, applicability and performance evaluation of the technique for the treatment and recycling of sewage and industrial effluents, explaining the mechanisms involved. Additionally, the performance of an integrated macrophyte-vermifiltration system for wastewater treatment and recycling has also been presented. Further, the effects of different filter design and operational parameters on the system performance have been summarized. Moreover, future research perspectives have been provided towards the improvement of the efficacy of the system for wastewater treatment and recycling.

1.2 Overview of Vermifiltration Technique

Vermifiltration system comprises an earthworm active zone along with filter media bed which supports microbial community for domestic and industrial wastewater treatment. The species of earthworms employed in vermifiltration include *Eisenia fetida*, *Lumbricus rubellus*, *Eudrilus eugeniae* and *Eisenia andrei* with filter bed consisting of soil, compost and cow dung which are available for pollutant degradation in earthworm active zone (Singh et al. 2019b; Xing et al. 2011). In filter media design, different materials like sand, gravel, cobblestone and quartz sand are commonly used (Singh et al. 2019b). In vermifiltration system, wastewater is firstly passed through earthworm active zone followed by filter media bed. Depending on the wastewater flow direction, vermifiltration system, in general, can be of two types: horizontal flow system (HFS) and vertical flow system (VFS). In HFS, wastewater flows horizontally through the bed while in VFS wastewater is fed vertically through the bed as shown in Figs. 1.1 and 1.2, respectively. A hybrid system combining both horizontal and vertical flow systems in the sequence is used for the treatment of wastewater. The flow of wastewater in the hybrid system is either from a horizontal

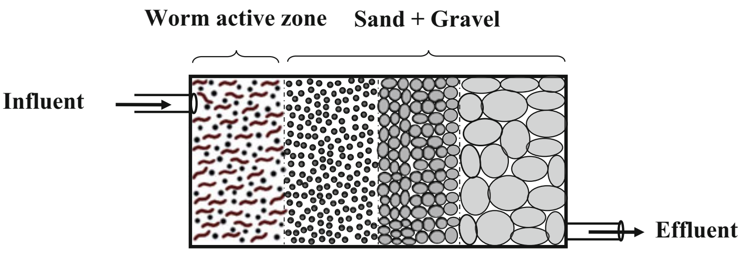

Fig. 1.1 Schematic of a typical horizontal flow vermifiltration system

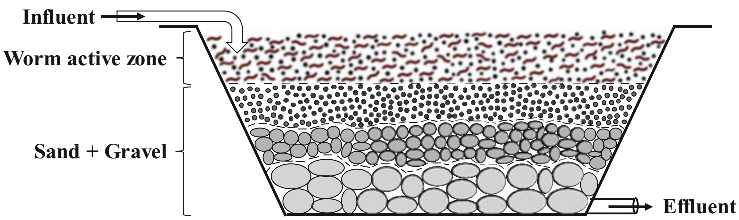

Fig. 1.2 Schematic of a typical vertical flow vermifiltration system

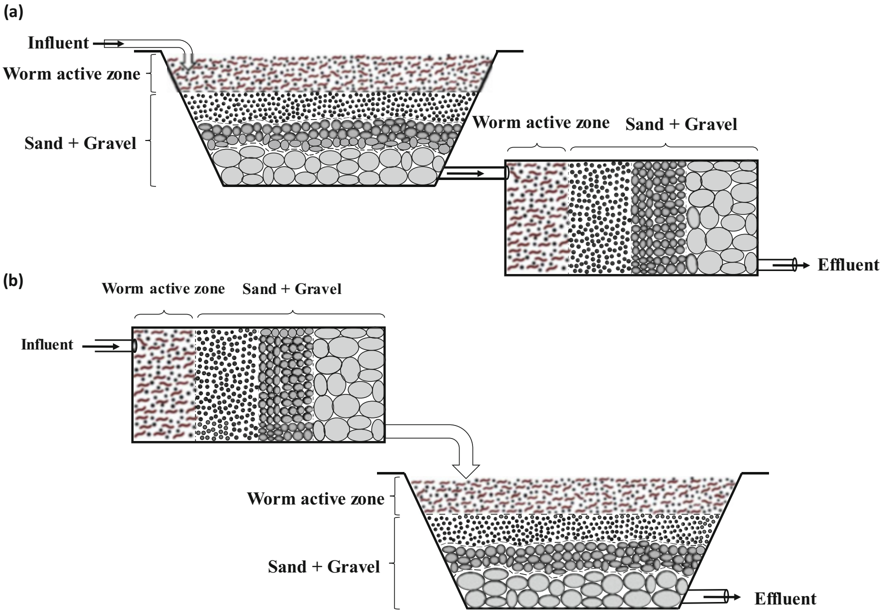

Fig. 1.3 Schematic of hybrid vermifiltration systems based on the wastewater flow direction: (**a**) VFS followed by HFS and (**b**) HFS followed by VFS

system followed by a vertical one or vice-versa as schematically presented in Fig. 1.3a, b, respectively.

Nowadays, researchers are focusing on the integrated macrophyte-vermifiltration system to improve the wastewater treatment efficiency. In macrophyte-assisted vermifiltration system, the concept of wetlands using different plant species like *Canna indica*, *Phragmites australis*, *Typha angustifolia*, *Saccharum spontaneum*, *Cyperus rotundus*, etc. is integrated with vermifiltration system for wastewater treatment (Chen et al. 2016; Nuengjamnong et al. 2011; Samal et al. 2017a; Tomar and Suthar 2011; Wang et al. 2010b). Removal from wastewater takes place when macrophyte uptakes significant amount of nutrients for their growth. A macrophyte-assisted vermifiltration system has been schematically shown in Fig. 1.4. The root or rhizospheric zone of plants helps to provide a favourable

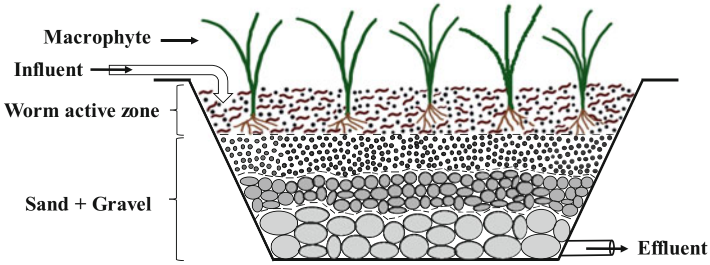

Fig. 1.4 Schematic of a macrophyte-assisted vermifiltration system

environment for the growth of the diverse microbial community to degrade organic contaminants (Bezbaruah and Zhang 2005). Further, researchers have found that macrophyte transfers oxygen from the atmosphere to the rhizosphere which is further consumed by the microbial community (Bezbaruah and Zhang 2005; Brix 1994). Increased oxygen is responsible for maintaining aerobic condition for the microbes as well as for earthworms which is useful to accelerate the degradation of organic contaminants.

1.3 Performance Evaluation of Vermifiltration System

1.3.1 Applicability of Vermifiltration for Sewage Treatment

It has been reported that the vermifiltration technique is an efficient and eco-friendly process to treat wastewater originating from households (Kumar et al. 2016; Li et al. 2009). Vermifiltration technique has been applied to domestic wastewater treatment and has shown a significant reduction of COD and NH_3^+-N (Sinha et al. 2008; Wang et al. 2010a; Xing et al. 2011). Applicability of vermifiltration technique with associated process parameters for wastewater treatment is summarized in Table 1.1. Earthworms consume retained suspended particles in the filter during ingestion and significantly reduce BOD by more than 90% and COD in the range of 80–90% and a significant reduction in nutrients concentration (Li et al. 2009; Wang et al. 2011). According to Kumar et al. (2016), application of vermifiltration employing earthworm species *Eisenia fetida* and *Eudrilus eugeniae* to treat wastewater generated from domestic activities has shown the reduction of about 88% and 70% BOD, 78% and 67% TSS and 75% and 66% TDS, respectively, whereas a laboratory-scale study has revealed the removal of contaminants like BOD_5, COD and TSS from domestic wastewater in the range of 55–66%, 47–65% and 57–78%, respectively (Xing et al. 2010). The earthworm species *Eisenia fetida* is one of the most common species employed to treat domestic wastewater (Gunadi et al. 2002; Hughes et al. 2009; Sinha et al. 2008). In another study on domestic wastewater treatment, employing *Eisenia fetida* as an earthworm species has shown removal of

Table 1.1 Application of vermifiltration technique with associated process parameters for the treatment of sewage and industrial effluents

Wastewater	Flow direction	Earthworm species	Earthworm density	Macrophyte (if any)	Dimensions (L × W × H) (cm)	Filter bed: Bedding material (top to bottom) and thickness (in cm)	HRT (h)	OLR (kg COD/ m^3/d)	HLR (m^3/ m^2/d)	Duration (d)	Organic removal (%)	Nutrient removal (%)	Pathogen removal (%)	References
Synthetic wastewater spiked with sewage	Vertical	*Eisenia fetida*	10,000 earthworms/m^3	–	30 × 25 × 60	Gravel and vermicompost (30); sand (10); and coarse gravel (15)	6	–	1.3	70	COD: 74; BOD: 85	–	TC; FC; FS; *E. coli*: 99	Arora et al. (2014)
Pharmaceutical wastewater	Vertical	*Eudrilus eugeniae*		–	–	Sand; vermicast and fine soil	24–96	0.8–3.2	–	–	BOD: 86–97; COD: 84–97	–	–	Dhadse et al. (2010)
Human faeces	Vertical	*Eisenia fetida*	4 kg/m^2	–	37 × 27 × 25.5	Coir; woodchip; mixture of coir and woodchip; mixture of coir; woodchip and vermicompost	–	–	–	360	COD: 87–89	TP: 56–59	*E. coli*: 99	Furlong et al. (2014)
Sewage	Vertical	*Eisenia fetida*	5000–6000 earthworms/m^3	–	100 × 100 × 150	Fine gravel (20); worm active zone (20); sand and compost (50); fine gravel (40); coarse gravel (20)	–	–	2	45	COD: 80	Nitrate: 60	–	Ghasemi et al. (2019)
Gelatine industry wastewater	–	*Lumbricus rubellus*	–	–	900 × 700 × 100	Sawdust; cow dung; *Leucaena leucocephala* foliage; bovine urine	–	–	–	180	COD: 90; BOD: 89	–	–	Ghatnekar et al. (2010)
Sewage	Vertical	*Eisenia fetida*,	10,000 earthworms/m^3	–	25 × 20 × 30	Vermicompost (5)	–	–	2.5	90	BOD: 88; TOC: 85	NH_3-N: 86	FC: 99	Kumar et al. (2016)
		Eudrilus eugeniae				River bed material (20)					BOD: 70; TOC: 62	NH_3-N: 74	FC: 90	
Sewage	Vertical	*Eisenia andrei*	3000 earthworms/m^2	–	400 × 250 × 200	Chaff; fine wood flour and turf (30); coarse wood flour and chaff (40); coarse quartz sand (10) and fine quartz sand (20)	–	–	1	365	BOD_5: 89, COD: 84	TN: 35; TP: 24	–	Li et al. (2009)

Sewage	Vertical	*Eisenia fetida*	0.008 g/m^3	–	–	Ceramsite	–	–	4.2	510	BOD_5: 78, COD: 68	$NH_4{}^+$-N: 92	–	Liu et al. (2013)
Sewage	Vertical	*Eisenia fetida*	5000–10000 earthworm/m^2	–	–	Soil (15); fine gravel and sand (10.25); gravel (40)	2	–	–	–	BOD_5: 98, COD: 70	–	–	Manyuchi et al. (2013)
Cheese whey wastewater		*Eisenia fetida*	–	–	–	Coarse compost (30); fine compost (100); stone (15)	7	0.3–3	–	460	BOD: 76; COD: 82	TN: 60; TP: 77	–	Merlin and Cottin (2009)
Synthetic dairy wastewater	Vertical	*Eisenia fetida*	10,000 earth-worms/m^3	*Canna indica*	–	Vermicompost and soil (20); sand (20); fine gravel (20); coarse gravel (20)	–	–	0.65	70	BOD: 81; COD: 76	TN: 24–42	–	Samal et al. (2017b)
Dairy wastewater	Vertical	*Eisenia fetida*	10,000 earth-worms/m^3	*Canna indica* (R_1), *Saccharum spontaneum* (R_2), *Typha augustifolia* (R_3)	H: 90; Dia.: 19.8	Soil and vermicompost (30); sand (10); soil (15); coarse gravel (15)	11	–	0.6	90	BOD_5 (R_1): 88, BOD_5 (R_2): 80, BOD_5 (R_3): 84 COD (R_1): 83, COD (R_2): 76, COD (R_3): 79	TN (R_1): 62; TN (R_2): 53; TN (R_3): 56; TP (R_1): 60; TP (R_2): 55; TP (R_3): 58	–	Samal et al. (2018b)
					60 × 18 × 30	Garden soil and vermicompost; lat-erite soil	10	–	–					
Hospital wastewater	Vertical	*Eisenia fetida*	10,000 earth-worms/m^3	–	40 × 40 × 120	Soil and earthworm bed (30); sand (30); detritus (30); cob-blestone (20)	–	–	1	122	COD: 90; BOD_5: 82–90	–	–	Shokouhi et al. (2020)
Synthetic wastewater	Horizontal	*Eisenia fetida*	10,000 earth-worms/m^3	–	80 × 20 × 20	Garden soil and compost (64); dolochar (16)	26.66	3.38 kg. COD/m^3.d	1.8	60	COD: 96	TN: 22; $NH_4{}^+$-N: 86; TP: 43; $PO_4{}^{3-}$-P: 61	–	Singh et al. (2019a)
Dairy wastewater	Vertical	*Eisenia fetida*	16,000 earth-worms/m^3	–	–	Soil (10); sand and gravel (20); gravel (50)	6–10	–	–	–	BOD_5: 99; COD: 80–90	–	–	Sinha et al. (2007)
Sewage	Vertical	*Eisenia fetida*	20,000 earth-worms/m^3	–	–	Soil (10); sand and gravel (20), gravel (50)	1–2	–	–	–	BOD_5: 98; COD: 45	–	–	Sinha et al. (2008)

(continued)

Table 1.1 (continued)

Wastewater	Flow direction	Earthworm species	Earthworm density	Macrophyte (if any)	Dimensions (L × W × H) (cm)	Filter bed: Bedding material (top to bottom) and thickness (in cm)	HRT (h)	OLR (kg COD/m^3/d)	HLR (m^3/m^2/d)	Duration (d)	Organic removal (%)	Nutrient removal (%)	Pathogen removal (%)	References
Petroleum industry wastewater	Vertical	*Eisenia fetida*	–	–	–	Soil (10); sand and gravel (20); gravel (50)	1–2	–	–	–	C10–C14: 99; C15–C28: 99; C26–C36: 99	–	–	Sinha et al. (2012)
Sewage	Vertical	*Perionyx sansibaricus*	0.022–0.0245 g/m^3	*Cyperus rotundus*	80 L	Soil with small stones and pebbles (25.4); leaves (5.08); sawdust (5.08); small stones and gravels (5.08); large stones (12.7)	1	–	–	–	COD: 90	NO_3^-N: 93; PO_4^{3-}:98	–	Tomar and Suthar (2011)
					59.69 × 45.72 × 38.1	Small pebbles and sand (15.24); large pebbles (25.4)								
Sewage	Vertical	*Eisenia foetida*	1000 earthworms/m^3	*Phragmites australis*		Peat (40); sand (60); gravel (30)	6	0.192	1	420	COD: 90	$NH_4{}^+$- N: 92; phosphorus: 91	–	Wang et al. (2010b)
Synthetic wastewater	Vertical	*Eisenia fetida*	0, 0.0045, 0.0085, 0.0125, 0.0165 g/m^3	–	30 × 30 × 75	Cobblestone (5); detritus (15); silver sand (15); earthworm packing bed (artificial soil and earthworm) (35)	1	–	0.2	60	COD: 68–77	NH_3-N: 72–78; TN: 63–66; TP: 80–82	–	Wang et al. (2013)
Sewage	Vertical	*Eisenia foetida*	21,000 earthworms/m^2	–	–	Ceramsite and quartz sand (20); quartz sand (10)	18.3; 9.2; 7.3; 6.6	–	2.4, 4.8, 6, 6.7	120	BOD_5: 55–66; COD: 47–65	TN: 8–15; NH_4-N: 21-62	–	Xing et al. (2010)
Domestic wastewater sludge	Vertical	*Eisenia foetida*	32 g/L	–	Dia.: 30 and H: 60	Ceramic pellets (50)	–	–	3	200	TCOD: 49–54		–	Zhao et al. (2010)
Synthetic wastewater	Vertical	*Eisenia fetida*	–	*Acorus calamus*	100 × 80 × 80 (main frame)	Slag (25); gravel (20)	–	–	–	365	COD: 87	TN: 86; TP: 83	–	Zhao et al. (2014)
					80 × 70 × 80 (vermifilters)	Artificial soil (peat soil and wood chips) (30); mixed sand (5); ceramsite (15); gravel (5)								

78% BOD_5, 68% COD and 90% TSS (Liu et al. 2013). A study has been conducted by Zhao et al. (2014) to treat synthetic wastewater through macrophyte-assisted vermifiltration using different combinations of vertical sub-surface flow constructed wetlands platned with macrophyte *Acorus calamus* and earthworm *Eisenia fetida*. Results of the study revealed the removal of up to 87% COD, 86% total nitrogen (TN) and 83% total phosphorus (TP).

Nitrogen removal from wastewater is mainly responsible for the nitrifiers and denitrifiers microbes present in the earthworm's intestinal guts (Ihssen et al. 2003). Earthworms are able to aerate the system through its borrowing action which enhances the nitrification process and creates a favourable microenvironment for the growth of aerobic nitrobacteria (Samal et al. 2017a). Wang et al. (2010b) have combined macrophyte *Phragmites australis* and earthworm species *Eisenia fetida* to treat domestic sewage with an OLR of approximately 192 $g/m^2/d$ and hydraulic loading rate (HLR) of 1 $m^3/m^2/d$, and the results showed an average reduction of about 90% COD, 93% SS and 92% NH_4^+-N. Wang et al. (2013) reported 63–66% removal efficiency of TN and 72–78% removal of NH_3^-N from synthetic domestic wastewater. Liu et al. (2013) also reported about 92% NH_4^+-N removal from domestic wastewater. Further, the removal of phosphorus depends upon the sorption capacity, surface area and size of vermifilter bed material along with chemical reaction like ligand exchange reaction, complexation and precipitation (Samal et al. 2017a). Vermifiltration system combined with macrophytes *Perionyx sansibaricus* and *Cyperus rotundus* reported the reduction of wastewater pollutants like COD, total suspended solids (TSS), total dissolved solids (TDS) and NO_3^- by more than 85% (Tomar and Suthar 2011). Wang et al. (2013) reported 80–82% removal of TP using bedding material which consists of cobblestone, detritus, silver sand and earthworm bed while removal of 87% of TP using cobblestone, soil and sawdust. Furlong et al. (2014) obtained a removal efficiency of TP in the range of 56–59% in human faeces.

The most crucial parameter in the sewage treatment from the human health point of view is pathogen removal. In this context, a comprehensive review of available literature by Swati and Hait (2018) underscores that earthworms are capable of pathogen reduction from various wastes. Arora et al. (2014) reported around 99% removal of *Escherichia coli* (*E. coli*), total coliform (TC), faecal coliform (FC) and faecal streptococci (FS) from synthetic wastewater spiked with sewage in a vermifiltration system. Further, Kumar et al. (2016) have treated domestic wastewater with vermifiltration and achieved a reduction of FC by 99%. An experimental run of 365 days of vermifiltration showed the reduction of COD by more than 87 and 99% thermotolerant coliforms using domestic wastewater (Furlong et al. 2014).

1.3.2 Applicability of Vermifiltration for Industrial Effluents

Initially limited to the treatment of the domestic wastewater, the vermifiltration technique has gradually evolved to be studied for the treatment of the industrial effluents. However, very few studies (Table 1.1) are being carried out on the vermifiltration of industrial wastewater because of the sensitive nature of earthworms towards parameters like pH, heavy metals, pesticides and salinity. Regardless of this, vermifiltration applied to industrial effluent from the food and beverage sector has shown encouraging pollutant removal efficiency and can pave way for application for many other industrial effluents that have low or no toxicity (Singh et al. 2019a). Additionally, vermifiltration system has been applied to other industrial effluents, such as petroleum industry and pharmaceutical industry (Dhadse et al. 2010; Sinha et al. 2012). Sinha et al. (2007) have successfully applied vermiltration system to treat effluent from dairy industries which mainly consist of organics like proteins, carbohydrates and fats. According to the study, earthworm species *Eisenia fetida* has resulted in the removal of about 99% BOD_5 and COD in the range of 80–90%. It also leads to the removal of TDS and TSS in the range of 90–92% and 90–95%, respectively. Another study conducted by Sinha et al. (2012) on petroleum industry wastewater has shown 99% removal of C10–C14, C15–C28 and C26–C36. Further, cheese whey waste has been treated by using vermifiltration and achieved about 76% BOD, 82% COD and 77% TSS removal efficiency (Merlin and Cottin 2009). Ghatnekar et al. (2010) reported the removal of COD and BOD by 89 and 90%, respectively, from gelatine industry wastewater employing earthworm species *Lumbricus rubellus*. Dhadse et al. (2010) studied application of vermifiltration on herbal pharmaceutical effluents using earthworm *Eudrilus eugeniae* at different organic loading rates (OLR) of 0.8, 1.6, 2.4 and 3.2 kg COD/m^3/d with 3.2 kg COD/m^3/d as the optimum with COD and BOD removal efficiencies in the range of 85–94% and 90–96%, respectively. Macrophyte-assisted vermifiltration was applied to treat synthetic dairy wastewater by employing macrophyte species *Canna indica* and reported removal of BOD, COD, TSS, TDS and TN by 81%, 76%, 85%, 23% and 43%, respectively (Samal et al. 2017b).

1.4 Mechanisms of Vermifiltration Technique

Vermifiltration technique works in combination of earthworms and microbes. Evolving from the basic system, macrophyte-assisted vermifiltration has emerged as an eco-friendly alternative for wastewater treatment and recycling. In order to unravel the treatment mechanisms, the roles of various layers and components of a typical macrophyte-assisted vermifiltration system have been schematically presented in Fig. 1.5. The solids retained on the filter bed are consumed by the earthworms and converted into the humus (Sinha et al. 2008; Singh et al. 2017). A microbial layer formed on the filter bed also contributes to the degradation of the contaminants retained on the filter bed. Generally, vermifiltration system consists of components, i.e. earthworms and filter bed. Filter bed supports the earthworm growth by providing food source by sorption mechanism from the wastewater, and a microbial layer is formed because of low porosity (Liu et al. 2013; Singh et al. 2017; Wang et al. 2010a, b). Further, the earthworm active zone is also known as aerobic zone while

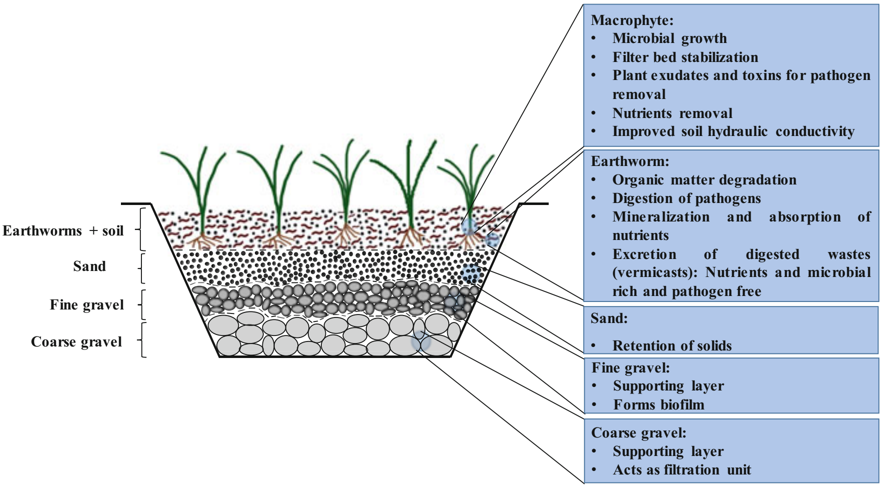

Fig. 1.5 Schematic representation of the role of different layers and components in macrophyte-assisted vermifiltration system

filter bed is called anoxic zone in vermifiltration (Samal et al. 2018a). Oxygen level is increased in filter bed by the borrowing action of earthworms. Further, the increase in the surface area of soil particles with an increase in vermibed porosity to retain more organic pollutants and suspended solids facilitates further decomposition by earthworms (Jiang et al. 2016; Sinha et al. 2008; Singh et al. 2018). Earthworms process wastes by actions like ingestion, grinding, digestion and excretion, and these actions have several physical, chemical and biological effects on the internal ecosystem of earthworm active zone (Singh et al. 2017). The ingestion and grinding actions by earthworm result in conversion of feed waste material into small particles (2–4 microns) followed by the digestion due to symbiotic action of microbes and enzymes in intestine (Kumar et al. 2015; Sinha et al. 2010; Singh et al. 2017; Wang et al. 2011). Numerous enzymes like protease, lipase, amylase, cellulase and chitinase are secreted in the gizzard and intestine of the earthworms which lead to biochemical conversion of the cellulosic and the proteinaceous materials present in the wastewater (Sinha et al. 2010). Since earthworm gut hosts diverse microbial communities, ingested food materials are excreted as vermicast into the soil with nutrients. Microbes present in the biofilm for their population growth further degrade nutrients retained on it, and the nutrients present in the vermicast (Sinha et al. 2008). Earthworms secrete mucus (slimy fluid) from their body which is composed of various metabolites to keep their body surface humid, which also helps in absorbing oxygen (Singh et al. 2017). Earthworms are able to convert large organic matter into complex amorphous solids which contains phenolic compounds and this process is called 'humification'. These humic substances present in vermibed help in metal adsorption and contain those organic compounds which have complex molecular structure as aromatic rings, carbonyl groups, phenolic and alcoholic hydroxyl. This molecular structure binds with different metal ions and thereby helps in metal removal (Singh et al. 2017).

In addition, significant pathogen reduction by the vermifiltration technique has been reported (Samal et al. 2017a). Earthworms have the capacity to cull the pathogens present in the ingested materials (Sinha et al. 2010). The pathogen reduction in vermifiltration is caused mainly because of the enzymatic and microbial activities (Alberts et al. 2002; Hartenstein 1978; Monroy et al. 2008, 2009; Swati and Hait 2018). In addition, inhibition in humates in the guts of earthworms is responsible for the pathogen removal (Brown and Mitchell 1981; Hartenstein 1978).

1.5 Future Perspectives

The potential of vermifiltration to treat domestic as well as industrial wastewater is well documented. An insight of vermifiltration based on the experimental results, design configurations and treatment mechanism has been provided. Vermifiltration integrated with macrophyte is an emerging technique for the wastewater treatment. Most of the studies have demonstrated vertical vermifilter at laboratory-scale level only for synthetic wastewater treatment. For this purpose, vermifiltration studies with real sewage and industrial effluents will be useful to assess the organic, nutrient and pathogen removal efficiency. However, research is warranted to explore the different vermifiltration system design configuration for wastewater treatment. Various process parameters such as earthworm stocking density, flow rate, hydraulic retention time (HRT), OLR and filter bed configuration need to be optimized for scaling-up the process. In addition, most of the studies have employed epigeic earthworm species *Eisenia fetida* only. In this context, it is pertinent to explore the various other earthworm species as pure and mixed cultures as diverse earthworm species co-exist in nature. Studies are required to be conducted to explore the effect of symbiotic relationships or mixed earthworm species on the removal of contaminants from wastewater.

1.6 Conclusions

The applicability of vermifiltration technique for the treatment of both sewage and industrial effluents along with the treatment mechanisms involved has been extensively discussed. Additionally, the potential of macrophytes has also been discussed in an integrated vermifiltration system for wastewater treatment. Further, the influence of different filter design and operational parameters on the system performance has been presented. The combined effect of earthworm active zone and filter media in the vermifiltration system has been reported for the effective removal of pollutants from the wastewater. Maximum organic and nutrient removal efficiencies of 99% BOD, 96% COD, 86% nitrogen and 83% phosphorus have been reported in the vermifiltration of wastewater. Pathogen removal of 90–99% for FC and 99% for TC, faecal streptococci and *E. coli* by the vermifiltration technique has also been reported. Further, the nutrient removal in an integrated macrophyte-vermifiltration system is mainly because of uptake by macrophytes for their growth. Removal of pollutant is highly selective on the components of vermifilter like filter media composition, earthworm species and macrophyte employed in the process. Moreover, it is necessary to assess vermifiltration system for wastewater treatment employing mixed cultures as diverse earthworm species co-exist in nature. The effect of various process parameters like HLR, OLR and earthworm density during vermifiltration is not quite clear. Extensive research is warranted to optimize different process parameters along with an optimized vermifilter design for efficient wastewater treatment and recycling.

References

Adin A, Asano T (1998) The role of physical-chemical treatment in wastewater reclamation and reuse. Water Sci Technol 37(10):79–90

Alberts B, Johnson A, Lewis J (2002) Molecular biology of the cell, 4th edn. Garland Sci, New York

Arora S, Rajpal A, Kumar T, Bhargava R, Kazmi AA (2014) Pathogen removal during wastewater treatment by vermifiltration. Environ Technol 35(19):2493–2499

Bezbaruah AN, Zhang TC (2005) Quantification of oxygen release by bulrush (*Scirpus validus*) roots in a constructed treatment wetland. Biotechnol Bioeng 89(3):308–318

Brix H (1994) Functions of macrophytes in constructed wetlands. Water Sci Technol 29(4):71–78

Brown BA, Mitchell MJ (1981) Role of the earthworm, *Eisenia foetida*, in affecting survival of *Salmonella enteritidis* ser. *typhimurium*. Pedobiologia 22:434–438

Chen Z, Hu S, Hu C, Huang L, Liu H, Vymazal J (2016) Preliminary investigation on the effect of earthworm and vegetation for sludge treatment in sludge treatment reed beds system. Environ Sci Pollut Res 23(12):11957–11963

Degremont G (1991) Water technical handbook. Lavoisier Publishing, Paris

Dhadse S, Satyanarayan S, Chaudhari PR, Wate SR (2010) Vermifilters: a tool for aerobic biological treatment of herbal pharmaceutical wastewater. Water Sci Technol 61(9):2375–2380

Furlong C, Templeton MR, Gibson WT (2014) Processing of human faeces by wet vermifiltration for improved on-site sanitation. J Water Sanit Hyg De 4(2):231–239

Ghasemi S, Mirzaie M, Hasan-Zadeh A, Ashrafnejad M, Hashemian SJ, Shahnemati SR (2019) Design, operation, performance evaluation and mathematical optimization of a vermifiltration pilot plan for domestic wastewater treatment. J Environ Chem Eng 103587

Ghatnekar SD, Kavian MF, Sharma SM, Ghatnekar SS, Ghatnekar GS, Ghatnekar AV (2010) Application of vermi-filter-based effluent treatment plant (pilot scale) for biomanagement of liquid effluents from the gelatine industry. Dynam Soil Dynam Plant 4(1):83–88

Goel PK (2006) Water pollution: causes, effects and control. New Age International

Gunadi B, Blount C, Edwards CA (2002) The growth and fecundity of *Eisenia fetida* (Savigny) in cattle solids pre-composted for different periods. Pedobiologia 46(1):15–23

Hartenstein R (1978) Utilization of soil organisms in sludge management. In: Conference proceedings. US department of commerce, national technical information services, PB286932. Springfield, Virginia, p 171

Hughes RJ, Nair J, Ho G (2009) The risk of sodium toxicity from bed accumulation to key species in the vermifiltration wastewater treatment process. Bioresour Technol 100(16):3815–3819

Ihssen J, Horn MA, Matthies C, Gößner A, Schramm A, Drake HL (2003) N_2O-producing microorganisms in the gut of the earthworm *Aporrectodea caliginosa* are indicative of ingested soil bacteria. Appl Environ Microbiol 69(3):1655–1661

Jiang L, Liu Y, Hu X, Zeng G, Wang H, Zhou L, Liu S (2016) The use of microbial-earthworm ecofilters for wastewater treatment with special attention to influencing factors in performance: a review. Bioresour Technol 200:999–1007

Kumar T, Bhargava R, Prasad KH, Pruthi V (2015) Evaluation of vermifiltration process using natural ingredients for effective wastewater treatment. Ecol Eng 75:370–377

Kumar T, Rajpal A, Arora S, Bhargava R, Hari Prasad KS, Kazmi AA (2016) A comparative study on vermifiltration using epigeic earthworm *Eisenia fetida* and *Eudrilus eugeniae*. Desalin Water Treat 57(14):6347–6354

Li YS, Xiao YQ, Qiu JP, Dai YQ, Robin P (2009) Continuous village sewage treatment by vermifiltration and activated sludge process. Water Sci Technol 60(11):3001–3010

Liu J, Lu Z, Zhang J, Xing M, Yang J (2013) Phylogenetic characterization of microbial communities in a full-scale vermifilter treating rural domestic sewage. Ecol Eng 61:100–109

Manyuchi L, Kadzungura L, Boka S (2013) Vermifiltration of sewage wastewater for potential use in irrigation purposes using *Eisenia fetida* earthworms. World Acad Sci Eng Technol 78:538–542

Merlin G, Cottin N (2009) Performance of a compost biofilter containing earthworms to treat cheese whey. Environ Technol 30(10):995–1002

Metcalf L, Eddy HP, Tchobanoglous G (1991) Wastewater engineering: treatment, disposal, and reuse, 3rd edn. McGraw-Hill, New York

Monroy F, Aira M, Domínguez J (2008) Changes in density of nematodes, protozoa and total coliforms after transit through the gut of four epigeic earthworms (Oligochaeta). Appl Soil Ecol 39(2):127–132

Monroy F, Aira M, Domínguez J (2009) Reduction of total coliform numbers during vermicomposting is caused by short-term direct effects of earthworms on microorganisms and depends on the dose of application of pig slurry. Sci Total Environ 407(20):5411–5416

Noumsi IM, Akoa A, Eteme RA, Nya J, Ngniado P, Fonkou T, Brissaud F (2005) Mosquito development and biological control in a macrophyte-based wastewater treatment plant. Water Sci Technol 51(12):201–204

Nuengjamnong C, Chiarawatchai N, Polprasert C, Otterpohl R (2011) Treating swine wastewater by integrating earthworms into constructed wetlands. J Environ Sci Health A 46(7):800–804

Pimentel D, Berger B, Filiberto D, Newton M, Wolfe B, Karabinakis E, Clark S, Poon E, Abbett E, Nandagopal S (2004) Water resources: agricultural and environmental issues. Bioscience 54 (10):909–918

Ra CS, Lo KV, Shin JS, Oh JS, Hong BJ (2000) Biological nutrient removal with an internal organic carbon source in piggery wastewater treatment. Water Res 34(3):965–973

Reddy, K. R., & Smith, W. H. (1987). Aquatic plants for water treatment and resource recovery. In: Conference on research and applications of aquatic plants for water treatment and resource recovery, Magnolia Publishing Inc, Orlando, Fla. (USA), 1986

Samal K, Dash RR, Bhunia P (2017a) Treatment of wastewater by vermifiltration integrated with macrophyte filter: a review. J Environ Chem Eng 5(3):2274–2289

Samal K, Dash RR, Bhunia P (2017b) Performance assessment of a *Canna indica* assisted vermifilter for synthetic dairy wastewater treatment. Process Saf Environ Prot 111:363–374

Samal K, Dash RR, Bhunia P (2018a) Effect of hydraulic loading rate and pollutants degradation kinetics in two stage hybrid macrophyte assisted vermifiltration system. Biochem Eng J 132:47–59

Samal K, Dash RR, Bhunia P (2018b) A comparative study of macrophytes influence on performance of hybrid vermifilter for dairy wastewater treatment. J Environ Chem Eng 6 (4):4714–4726

Shokouhi R, Ghobadi N, Godini K, Hadi M, Atashzaban Z (2020) Antibiotic detection in a hospital wastewater and comparison of their removal rate by activated sludge and earthworm-based vermifilteration: environmental risk assessment. Process Saf Environ Prot 134:169–177

Singh R, Bhunia P, Dash RR (2017) A mechanistic review on vermifiltration of wastewater: design, operation and performance. J Environ Manag 197:656–672

Singh R, Bhunia P, Dash RR (2018) Understanding intricacies of clogging and its alleviation by introducing earthworms in soil biofilters. Sci Total Environ 633:145–156

Singh R, Bhunia P, Dash RR (2019a) Optimization of organics removal and understanding the impact of HRT on vermifiltration of brewery wastewater. Sci Total Environ 651:1283–1293

Singh R, Samal K, Dash RR, Bhunia P (2019b) Vermifiltration as a sustainable natural treatment technology for the treatment and reuse of wastewater: a review. J Environ Manag 247:140–151

Sinha RK, Bharambe G, Bapat P (2007) Removal of high BOD and COD loadings of primary liquid waste products from dairy industry by vermifiltration technology using earthworms. Indian J Environ Prot 27(6):486–501

Sinha RK, Bharambe G, Chaudhari U (2008) Sewage treatment by vermifiltration with synchronous treatment of sludge by earthworms: a low-cost sustainable technology over conventional systems with potential for decentralization. Environmentalist 28(4):409–420

Sinha RK, Agarwal S, Chauhan K, Chandran V, Soni BK (2010) Vermiculture technology: reviving the dreams of sir Charles Darwin for scientific use of earthworms in sustainable development programs. Technol Invest 1(03):155–172

Sinha RK, Chandran V, Soni BK, Patel U, Ghosh A (2012) Earthworms: nature's chemical managers and detoxifying agents in the environment: an innovative study on treatment of toxic wastewaters from the petroleum industry by vermifiltration technology. Environmentalist 32(4):445–452

Speece RE (1983) Anaerobic biotechnology for industrial wastewater treatment. Environ Sci Technol 17(9):416A–427A

Swati A, Hait S (2018) A comprehensive review of the fate of pathogens during vermicomposting of organic wastes. J Environ Qual 47(1):16–29

Tomar P, Suthar S (2011) Urban wastewater treatment using vermi-biofiltration system. Desalination 282:95–103

Verma AK, Dash RR, Bhunia P (2012) A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. J Environ Manag 93(1):154–168

Wang S, Yang J, Lou SJ (2010a) Wastewater treatment performance of a vermifilter enhancement by a converter slag–coal cinder filter. Ecol Eng 36(4):489–494

Wang DB, Zhang ZY, Li XM, Zheng W, Yang Q, Ding Y, Zeng GM (2010b) A full-scale treatment of freeway toll-gate domestic sewage using ecology filter integrated constructed rapid infiltration. Ecol Eng 36(6):827–831

Wang L, Guo F, Zheng Z, Luo X, Zhang J (2011) Enhancement of rural domestic sewage treatment performance, and assessment of microbial community diversity and structure using tower vermifiltration. Bioresour Technol 102(20):9462–9470

Wang J, Liu XD, Lu J (2012) Urban river pollution control and remediation. Procedia Environ Sci 13:1856–1862

Wang LM, Luo XZ, Zhang YM, Lian JJ, Gao YX, Zheng Z (2013) Effect of earthworm loads on organic matter and nutrient removal efficiencies in synthetic domestic wastewater, and on bacterial community structure and diversity in vermifiltration. Water Sci Technol 68(1):43–49

Xing M, Li X, Yang J (2010) Treatment performance of small-scale vermifilter for domestic wastewater and its relationship to earthworm growth, reproduction and enzymatic activity. Afr J Biotechnol 9(44):7513–7520

Xing M, Wang Y, Liu J, Yu F (2011) A comparative study of synchronous treatment of sewage and sludge by two vermifiltrations using an epigeic earthworm *Eisenia fetida*. J Hazard Mater 185 (2–3):881–888

Zhao L, Wang Y, Yang J, Xing M, Li X, Yi D, Deng D (2010) Earthworm–microorganism interactions: a strategy to stabilize domestic wastewater sludge. Water Res 44(8):2572–2582

Zhao Y, Zhang Y, Ge Z, Hu C, Zhang H (2014) Effects of influent C/N ratios on wastewater nutrient removal and simultaneous greenhouse gas emission from the combinations of vertical subsurface flow constructed wetlands and earthworm eco-filters for treating synthetic wastewater. Environ Sci Processes Impacts 16(3):567–575

Zheng C, Zhao L, Zhou X, Fu Z, Li A (2013) Treatment technologies for organic wastewater. Water Treat:249–286