International Journal of Biotechnology and Biomedical Sciences
p-ISSN 2454-4582, e-ISSN 2454-7808, Volume 4, Issue 2; July-December, 2018 pp. 94-99
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http://www.krishisanskriti.org/Publication.html

Biological Technologies for Wastewater Treatment in Rural India

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Abstract—*Rural India faces a lack of appropriate systems to treat wastewater. Under the status quo, the health of locals and the state of the local environment is harmed due to an increasing amount of wastewater being accumulated both in the soil and on the surface close to housing areas.*

Cheap and easy to maintain technologies are required to meet the problems of a lack of funding and a lack of professionals in rural areas. Biological technologies have immense potential in solving these problems due to their sustainability and low costs.

This study evaluates two innovative biotechnologies that are in use as systems of wastewater treatment. The first is Vermifiltration, a technology that relies on worms as the main sources of treatment. The second is Constructed Wetlands which relies on aquatic plants as the main sources of treatment. The evaluation is based on the advantages that the technology brings to the local community, the cost, the limitations and the suitability to Indian climate.

1. INTRODUCTION

The conventional method to treat domestic sewage is through Sewage Treatment Plants. These systems are capital and energy intensive. They require large pieces of land preferably within city limits. Due to these two reasons, Sewage Treatment Plants are not used to treat wastewater originating from rural areas. Villages that do not fall under the jurisdiction of large cities cannot afford to build their own Sewage Treatment Plants. Moreover, even if some rural villages did get the necessary funding to construct an STP, maintenance would be hard due to a lack of trained individuals. In a study of the number of villages in the rural area of the district of Ludhiana, it was found that a mere 2 out of 10 villages were connected to the main sewage system, the rest disposed of their waste in stabilisation ponds, injection into the ground or by direct disposal into a nearby water body.

The main methods of disposing of wastewater in rural areas involve basic stabilisation ponds through which wastewater slowly percolates into the ground and unused wells to empty wastewater into aquifers. Although these methods very cheap and relatively easy to construct, they can cause contamination of groundwater that is later used for other purposes such as drinking and irrigation. The gases emitted from these ponds along with the odour of the wastewater has been found to irritate the nasal passages and lungs of local citizens. These ponds may also become sources of diseases due to contact with insect or animal vectors that may breed in them or use them as a drinking source. Since, these ponds are usually very close housing, the spread of diseases is a big problem with these systems.

Additionally, it has been shown that the performance of stabilisation ponds in controlling pathogens found in wastewater to prevent the birth of diseases and eutrophication of water bodies has been disappointing. In a study by Canter et al., (1982) the removal efficiencies of BOD, nitrogen and phosphorous have been reported to be 75-90%; 30-50% and 20-60%. Sometimes wastewater in rural areas is directly used for means of irrigation and although the fertiliser value of this water maybe advantageous, this method creates a risk of transmission of water-borne diseases (Krishnan and Smith, 1987).

India requires technologies that are cheap, easy to use and can be maintained with relative ease to meet the issues of funding and a lack of professionals in rural areas. Environmental biotechnology has a large scope of application in this field to solve these issues. Plants, microbes, and other organisms can be used to treat not only domestic wastewater but also industrial effluents to a certain extent. A number of technologies using these organisms have been developed and in some cases tested for their effectiveness as well. This paper seeks to analyse four such technologies and determine to what extent they would be suitable to India’s climatic, cultural and environmental factors.

2. VERMIFILTRATION

2.1 Introduction to technology

Vermifiltration is a technology which takes advantage of earthworms’ abilities to ingest, absorb and facilitate microbial biodegradation of organic waste, heavy metals and solids from wastewater. The structure of vermifilter is a large reactor made from a material able to eliminate the entry of unwanted organisms such as flies with a certain amount of ventilation to sustain the growth of worms and microorganisms. The vermifilter consists of an organic layer containing earthworms and an inorganic layer of gravel and sand with a drainage system at the bottom to either recirculate the water to the top of the system or to dispose of it [21].

2.2 Mechanism of reduction of pollutants

The Vermifilter contains earthworms which act as decomposers and promoters of the growth of decomposing bacteria. Singleton et al. (2004) showed that Earthworms have been shown to increase the growth of bacteria in the soil by excreting them from their guts along with nitrogen and phosphorous. These two nutrients are used by the microbes for intensive multiplication in their numbers. In addition to that, they also showed that the bacterial species in the digestive tract of an earthworm were associated with abilities to degrade several categories of organics including polychlorinated biphenyl, a class of toxic industrial effluents. The number of decomposing bacteria acting on organic material ingested by earthworms increases 1,000 fold after passing through the gut so effectively a population of 15,000 bacteria would nurture a population numbering in the millions and billions in the presence of earthworms [6].

The action of earthworms and bacteria are carried out at the same time in the vermifilter. These include complex biodegradation processes which adsorb and stabilise solids in wastewater. Bacteria biochemically decompose matter in the wastewater while earthworms selectively graze on harmful microbes and reducing competition to decomposing bacteria in the medium. Earthworms grind silt and sand particles to give a high surface area for the action of Bacteria and adsorption. They make concentrate organic material and make it more bioavailable for decomposition by bacteria in the soil by consuming it and excreting it. Furthermore, Earthworms bioaccumulate heavy metals, with some species having been found to bioaccumulate up to 7600 mg of lead (Pb)/gm of the dry weight of their tissues [17].

2.3 Studies showing the effectiveness of Vermifiltration

Sinha et al (2008), Brisbane, constructed a vermifilter reactor with multiple layers of sand, silt and gravel with a soil layer for earthworms and compared its performance to a control reactor devoid of earthworms. It is important to note that the control reactor contributes to filtration of wastewater by adsorption of impurities on surfaces. Their experiment showed better neutralisation of pH at around 7 compared to compared to a pH of around 6 in the control, over 90% removal of Total Suspended Solids (TSS) compared to 58% in the control, 98% reduction of turbidity compared to 97% in the control, 98% reduction in BOD_5 compared to 77% and 45% reduction in COD compared to 18% in the control

Table 1: Showing the most effective results Sinha et al's experiment.

Parameter	Untreated Sewage	Treated Sewage (With worms)	Treated Sewage (Without worms)
pH	5.76	7.35	6.05
TSS (mg/l)	438	22	184
Turbidity (NTU)	120	0.6	1.5
BOD5 (mg/l)	328	2.06	83.2
COD (mg/l)	293	132	245

Xing et al. (2005), Shanghai, constructed a vermifilter reactor consisting of granular material and earthworms. The average TSS of the untreated sewage used was 186.5 mg/l, the average BOD_5 was 297 mg/l and the average COD was 408.8 mg/l. Their experiment showed a 97-98% reduction in TSS, 91-98% reduction of BOD_5 and 81-86% reduction in COD.

Manyuchi et al. (2013), Harare, constructed a Vermifiltration based bio-filter bed consisting of aggregates of soil and gravel and garden soil and a control bio-filter bed without earthworms. The untreated sewage had an average pH of 6.45, an average BOD_5 of 300 mg/l, an average COD of 190 mg/l, and an average TSS of 300mg/l. Their experiment showed a neutralisation of pH at around 7.0 for the bed with worms compared to the control at a pH of 6.6, a reduction in BOD_5 of 98% compared to 75% in the control, a reduction of COD of 70% compared to 20% in the control and a reduction in TSS of 95% compared to a 60% in the control.

2.4 Significance of performance and advantages of Vermifiltration

Low Energy Requirements: Vermifilters can either be made to be vertical or horizontal. In a vertical structure the wastewater load would be added from the top and slowly flow through the layers of granulated matter until it reaches the bottom as treated wastewater. In a horizontal structure, the wastewater flows from one end to another with a slight incline using gravity to cause the movement of the water. Since both of these type of structures rely on gravity for the movement of the water, there is no energy required unless a recirculation system for water is required in which case a pump requiring energy would be installed.

Treated water is free of pathogens and heavy metals: Earthworms have been found to secrete a coelomic fluid which has anti-bacterial properties and inhibit the formation of rot causing microorganisms. They also foster the growth of bacteria and fungi that produce substances with antibiotic properties that can kill pathogenic organisms including E. coli, Salmonella, helminth ova and enteric viruses in wastewater [1, 13]. They have also been shown to bioaccumulate cadmium (Cd), mercury (Hg), lead (Pb), copper (Cu), manganese (Mn), calcium, iron (Fe) and zinc (Zn) along with endocrine disrupting chemicals (EDCs).

End product applications: Vermifiltration produces two substances that are useful in agriculture. Vermicompost, which is stabilised sludge resulting from the treatment process can be used as an additive to soil for crop growth. Vermicast, which is the earthworms' excreta is rich in nitrogen (N), phosphorous (P), and potassium (K). Earthworms further mineralise nitrogen in the soil to make it more bioavailable to plants as nitrates. The biomass of earthworms available from this treatment can be used as a probiotic food for cattle, poultry and fish farming. Hence there is recycling of inputs through this treatment.

Potential in treating industrial and agricultural effluents: A study by Sinha et al (2012) showed a high efficiency of earthworms in removing industrial effluents from petroleum contaminated water from the automobile industry. The study consisted of a reactor with earthworms and a control reactor without earthworms. The earthworm reactor showed a reduction of 99.91% compared to a reduction of 9.52% by the control of Hydrocarbons (C 10 to C 14), a reduction of 99.85% compared to a reduction of 21.42% by the control of Hydrocarbons (C 15 to C 28), a reduction of 99.74% compared to a reduction of 6.94% by the control of Hydrocarbons (C 29 to C 36). Earthworms have been shown to absorb herbicides and pesticides from wastewater [2]. They have also been shown to remove polycyclic aromatic hydrocarbons (PAHs) [10].

2.5 Limitations of Vermifiltration

It has been shown that prolonged exposure to freezing temperatures or temperatures above 35°*C and direct sunlight to are detrimental to the health of earthworms and can result in paralysis or death. They are known to survive in a pH of between 5.0 to 8.0. This may be a limiting factor because the pH of wastewater may part of the load intro vermifilter may be lower than 5 due to the presence of acidic effluents. [4].*

Earthworms also cannot sustain a high hydraulic load into the vermifilter as their body is made of soft muscular tissues and cannot resist the impact of a large amount of water. Furthermore, a high hydraulic load results in air pockets in the soil filling up with water in the bottom layers due to the percolation of the water. This causes earthworm activity in the bottom layers to reduce and causes an overall fall in the efficiency of the process. However, earthworms are also affected by dryness in the soil. Due to dryness in the top layer, earthworms move to deeper layers where they may meet saturated soil without any airspaces for them to reside. In the case where the deep layers are dry as well, they choose to go into hibernating condition called diapause.

Saline water cannot be treated through Vermifiltration because the salt ions disturb the osmotic balance between the body of the earthworm and its surroundings reducing survival, biomass, growth and reproduction rates [16]. However, Eiseniafetida, a species of earthworm has been shown to survive in soils half as saline as seawater with average seawater salinity is around 35 g/l [8].

2.6 External Factors and Suitability to India

A study by Rajendran et al (2014), compared the decomposition performance of 3 species of earthworms. They found that E. fetida had the best overall performance with an intermediate growth rate and decomposition rate and Eudriluseugenaie had the highest decomposition rate. These two species of earthworms are readily available in India. Moreover, the temperature of the bioreactor can be regulated with proper ventilation and a cement frame to foster the growth of earthworms while protecting them from the hot climate of India.

Furlong et al (2016), evaluated the user satisfaction and chemical parameters of an on-site Vermicompost sanitation system in rural India. They found that user satisfaction was 100% while after 12 months, the accumulation of faecal solids was very low with about 0-10% coverage, the faecal coliforms reduction was 99% and the COD reduction was 57%. As noted by the users, the lack of smell and low need of emptying of the compost were the two major reasons for high satisfaction. According to the researchers, the Vermicompost would have to be replaced only once every 5 years.

The fact that earthworms are resistant to toxic chemicals in wastewater is an advantage of this technology considering that wastewater produced in rural areas may consist of pesticides, effluent from crop processing machinery and local manufacturing enterprises such as paper mills. Furthermore, the return of Vermicompost and Vermicast that farmers would receive from investing in this technology would, along with low energy requirements and simple setup, prove to give strong incentives for the use of this technology in the rural areas of India.

3. CONSTRUCTED WETLANDS

3.1 Introduction to technology

Constructed Wetlands are man-made caricatures of natural wetlands and share their efficacy in water purification. They rely on the water purification properties of an ecosystem of plants, soil, and microorganisms. The structure of a Constructed Wetland are typically shallow, long, narrow trenches that hold slow moving water passing through water tolerant plants. The trenches' banks are covered with a barrier to prevent seepage into the soil that is not part of the structure. Constructed Wetlands are mainly either free water surface flow or subsurface flow systems, depending on the type of plant being used. Free water surface systems have water rising above the media on which plants grow while subsurface systems have water below the media on which plants grow.

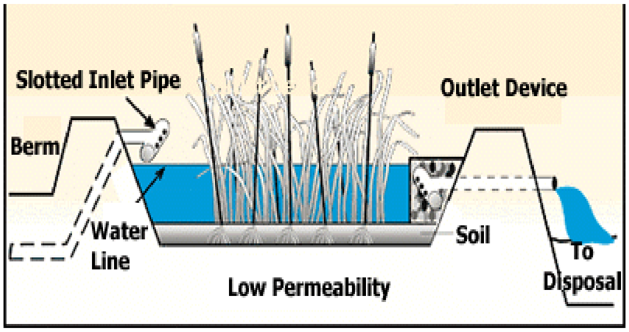

Image 1: Free water surface flow system

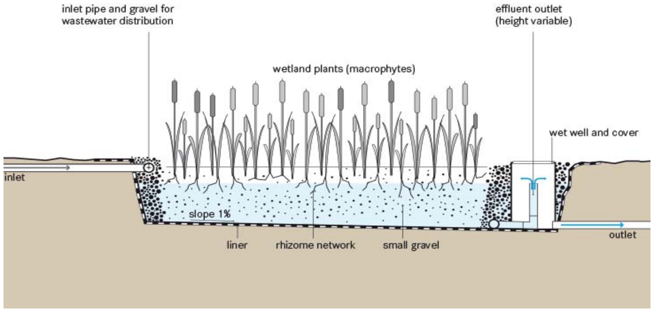

Image 2: Subsurface flow system

3.2 Mechanism of reduction of pollutants

Relatively large particles including suspended solids are physically filtered by submerged plants, stems and plant litter. The surfaces of the plant - roots, stems, leaves and litter - provide surface area for the growth of waste-consuming bacteria. These bacteria are the components of the wetlands that conduct the majority of purification of water. In free water surface flow systems, aerobic bacteria thrive near the surface of water and carry out their breaking down actions in the presence of oxygen. Oxygen is added into the system by the addition of wastewater that agitates the surface of the water. Both free water surface flow and subsurface flow systems hold colonies of anaerobic bacteria in the lower levels of water and in the soil. These bacteria perform their functions without the need for oxygen. Bacteria produce food sources such as methane, carbon dioxide and cellular material from their consumption of waste material. These food sources aid in the growth of plants in the wetland and contribute to the stabilisation of a cycle of growth and waste decomposition [19].

The waste reduction action of plants in wetlands is not completely understood yet but it is known that plants not only provide a habitat for the growth of bacteria, protozoans and worms in the wetlands, they also accumulate organic material, heavy metals and other nutrients through their tissues in water, their roots and rhizomes. They excrete oxygen from photosynthesis into the system which fosters the growth of aerobic bacteria and aids in more efficient breakdown of the load. In the case of Macrophytes being used as plants in Constructed Wetlands, they are able to secrete antibiotics that contribute to the killing of pathogens in the water. They also provide the system with an aesthetic look that would readily be accepted in the case of a sewage treatment system [3].

3.3 Studies showing the effectiveness of Constructed Wetlands

In a study by Sudarsan *et al.* (2015), a pilot scale subsurface flow system wetland was constructed and loaded with raw wastewater from a sewage treatment facility at SRM University, Kattankulathur. The primary plant used was *Phragmites australis.* The system showed a BOD_5 reduction rate of 75.99%, COD reduction rate of 76.16%, TDS reduction rate of 57.34%, Nitrate reduction rate of 62.08%, Potassium reduction rate of 58.03% and a Phosphorous reduction rate of 57.83%.

In a study by Meuleman *et al.* (1994), a functioning infiltration wetland, similar to subsurface flow systems, at Lauwersoog, The Netherlands, was analysed for pollutant parameters. The system showed a BOD_5 reduction rate of 95%, COD reduction rate of 81%, Nitrogen reduction rate of 35%, and a Phosphorous reduction rate of 26%.

In a study by Leuderitz *et al.* (2001), two reed bed CWs of different structures were compared in Germany. The first structure was vertical flow and the second was horizontal flow. The vertical flow system showed a BOD_5 reduction rate of 93.1%, COD reduction rate of 91.3%, Nitrogen reduction rate of 78%, and a Phosphorous reduction rate of 97.1%.

3.4 Significance of performance and advantages of Constructed Wetlands

Low energy requirements: In a study by analysing the energy requirements of wastewater treatment systems in India, CWs were found to have the lowest energy requirement with an average of 1.83 kWh compared with higher requirements in UASB, SBR and ASP technologies [7].

Ease of maintenance: Apart from the harvesting of the system's plants and the occasional need for elimination of vectors, CWs do not require heavy maintenance. Experience in India shows that one unskilled person is enough to operate a system with a capacity of up to 150 m^3 per day.

Low emissions to the environment: Compared to other large scale treatment systems like UASB, SBR, and ASP, CWs have the lowest emission to the air, mainly due to the process of sequestration of carbon by plants in the system.

Ability to be designed according to needs: From the studies above it can be inferred that different designs of CWs have different performances on the reduction of pollutants in wastewater. This is the reason behind the discrepancy in the reduction rates of Nitrogen and Phosphorous in the three studies. It has been suggested that CWs of different designs be used in conjugation with each other to ensure complete removal from wastewater. Where one design fails, another can fulfil the job. It is up to the designer to pinpoint the major pollutants in the wastewater that is to be treated and design a CW accordingly. Rural areas would not have a high incident of heavy metals for example unless they are near manufacturing units. They would also have a lower incident of inorganic chemicals used in the household due to a lack of their availability in the market. Hence, a CW in a typical rural setting in India would focus on structures that would be most efficient at removing a load low in organic chemicals but high in organic waste. This also makes the locals of a village more involved in the process of the construction of the system and make them more aware of maintenance procedures as well.

3.5 Limitations of Constructed Wetlands

Constructed wetlands require a large amount of land to be designed for maximum efficiency. In rural India, there is no lack of land but using land for a CW may incur the opportunity cost of farmland. The land should advisably be flat to reduce construction costs and if barriers are not installed, soil must be impermeable so as not to contaminate groundwater. Costs may be incurred in reducing unwanted insects and animals from spoiling the system. Harvesting of the plants in the CW maybe another cost, harvesting is essential as when pollutants such as heavy metals are bioaccumulated in plants and they die, the pollutants will return to the water.

In a tropical country like India, evapotranspiration is quite high and if the rate of evapotranspiration is higher than that of the loading of wastewater it may be detrimental to the growth of plants and microorganisms in a free water surface flow system. Another problem with the tropics is the growth of insect vectors such as mosquitoes. Uncontrolled growth of mosquitoes and subsequent malaria cases have been reported before [15]. Odour has also shown to be a problem in wetlands, specifically in anaerobic conditions.

Most of the limitations of Constructed Wetlands' limitations emerge from a high organic pollutant load in wastewater, thus it is suggested that CWs are used as successors to stabilisation ponds as sources of secondary treatment. In most cases, CWs are used at the stage of tertiary treatment but since this is not possible in rural India where STPs are not common, primary treatment by stabilisation ponds would reduce the organic load for more efficient polishing of the water by CWs and no problems such as odour [9].

3.6 External factors and suitability to India

In India, Constructed Wetlands have seen success in urban areas under the SWINGS (Safeguarding water resources in India with green and sustainable technologies) and systems have been implemented in Universities as a means to study the results of the systems on wastewater treatment. In rural areas however, CWs have seen less implementation.

In a study conducted at a Mother Dairy Plant in New Delhi, it was found that the size of gravel used in the CW affects its hydraulic retention time and efficiency of treatment. Small sized gravel was found to be clogged very quickly mainly by fats while large sized gravel reduced the porosity of the system and the ability of water to percolate through the wetland. Thus it was determined that medium sized gravel of about the size of a pea should be used.

In this same study it was found that Evapotranspiration, a phenomenon that would be common in systems in India, in fact aided in concentrating pollutants in the water and increased the efficiency of plants for uptake. However, the system being studied being made of stone slabs, suffered cracks and leakage of water due to evapotranspiration.

Overall, only a few studies have analysed the suitability of Constructed Wetlands in rural India. Seeing the success of CWs in urban areas however, it can be determined that CWs would prove to be beneficial in rural areas and would work efficiently considering the low amount of knowledge needed to maintain them. The only problem would lie in designing and constructing a wetland. When compared with other technologies such as Vermifiltration, the amount of variations in the structure and the knowledge required to determine the design best suited to local needs is proportionately high. A wrongly designed wetland could instead cause the multiplication of insect vectors while incurring an economic loss due to low quality treatment of the water.

4. CONCLUSION

Apart from Vermifiltration and Constructed Wetlands, there is a large number of biological technologies that are used as a part of a larger treatment system. Used alone, these technologies do not provide enough purification for the reuse of water for irrigation, gardening or domestic utilities. It could be suggested that a rural community be provided with a primary form of treatment such as UASB reactor through government funding with a secondary form of treatment as Stabilisation Ponds following that, however, in India, even large industrial cities such as Ludhiana do not have enough government funding to maintain UASB reactors that are part of treatment sites catering to the waste produced by the city. The problem again lies in a lack of both funding and professionals.

In some countries, the solution to this problem would be Concessions, Lease, BOOT Contract and Divesture schemes where a private organisation steps in to either partly or entirely control the running of a treatment site. The issue here is that these policies would not gain acceptance in India, considering how past case studies have shown that these policies have failed in terms of improving the welfare of local communities in India. This leaves rural areas in India with solutions that involve sustainable, cost effective technologies with a low consumption of power.

Vermifiltration and Constructed Wetlands are both well suited to Indian Climate and environmental conditions. They both have low energy requirements and ease of setting up, although Constructed Wetlands require extensive designing in some cases. These reasons make these two technologies good alternatives to the currently ineffective technologies of pond systems that may have a detrimental effect on local health due to their odours and gases produced such as methane.

REFERENCES

[1] Bajsa, O. et al. "Vermiculture As A Tool For Domestic Wastewater Management". *Water Science And Technology*, vol 48, no. 11-12, 2004, pp. 125-132. *IWA Publishing*, doi:10.2166/wst.2004.0821.

[2] Bolan, N. S., and S. Baskaran. "Characteristics Of Earthworm Casts Affecting Herbicide Sorption And Movement". *Biology And Fertility Of Soils*, vol 22, no. 4, 1996, pp. 367-372. *Springer Nature America, Inc*, doi:10.1007/bf00334585.

[3] Brix, Hans. "Functions Of Macrophytes In Constructed Wetlands". *Water Science And Technology*, vol 29, no. 4, 1994, pp. 71-78. *IWA Publishing*, doi:10.2166/wst.1994.0160.

[4] "Earthworms". *Penn State Extension*, 2018, https://extension.psu.edu/earthworms. Accessed 25 Sept 2018.

[5] Furlong, C. et al. "Technical And User Evaluation Of A Novel Worm-Based, On-Site Sanitation System In Rural India". *Waterlines*, vol 35, no. 2, 2016, pp. 148-162. *Practical Action Publishing*, doi:10.3362/1756-3488.2016.013.

[6] Edwards, Clive A., and K.E. Fletcher. "Interactions Between Earthworms And Microorganisms In Organic-Matter Breakdown". *Agriculture, Ecosystems & Environment*, vol 24, no. 1-3, 1988, pp. 235-247. *Elsevier BV*, doi:10.1016/0167-8809(88)90069-2.

[7] Kalbar, Pradip P. et al. "Assessment Of Wastewater Treatment Technologies: Life Cycle Approach". *Water And Environment Journal*, vol 27, no. 2, 2012, pp. 261-268. *Wiley*, doi:10.1111/wej.12006.

[8] Kerr M, Stewart AJ (2006) Tolerance test of Elseniafetida for sodium chloride. US Department of Energy Journal of Undergraduate Research

[9] Kivaisi, Amelia K. "The Potential For Constructed Wetlands For Wastewater Treatment And Reuse In Developing Countries: A Review". *Ecological Engineering*, vol 16, no. 4, 2001, pp. 545-560. *Elsevier BV*, doi:10.1016/s0925-8574(00)00113-0.

[10] Ireland MP (1983) Heavy metals uptake in earthworms; earthworm ecology. Chapman & Hall, London

[11] Manyuchi, M. M. "Vermifiltration Of Sewage Wastewater For Potential Use In Irrigation Purposes Using EiseniaFetida Earthworms". *World Academy Of Science, Engineering And Technology*, vol 78, 2013, pp. 538-542., Accessed 24 Sept 2018.

[12] Meuleman, A.F.M., 1994. Waterzuivering door moeras-systemen: onderzoeknaar de water- enstofbalansen van het rietinfiltratieveldLauwersoog. RIZA Nota 94.011, 1–134

[13] Pierre, V. "Anti-Bacterial Activity Of The Haemolytic System From The Earthworms". *Invertebrate Pathology*, vol 40, 1982, pp. 21-27., Accessed 24 Sept 2018.

[14] Rajendran, Modsarajah&Rajendram, Thivyatharsan. (2014). Performance of different species of earthworms on vermicomposting. International Journal of Research in Agriculture and Food Science. 2.

[15] Russel, R.C., 1999. Constructed wetlands and mosquitoes:Health hazards and management options- An Australian perspective. Ecol. Eng. 12, 107–124.

[16] Samal, Kundan et al. "Treatment Of Wastewater By Vermifiltration Integrated With Macrophyte Filter: A Review". *Journal Of Environmental Chemical Engineering*, vol 5, no. 3, 2017, pp. 2274-2289. *Elsevier BV*, doi:10.1016/j.jece.2017.04.026.

[17] Sinha, Rajiv K. et al. "Sewage Treatment By Vermifiltration With Synchronous Treatment Of Sludge By Earthworms: A Low-Cost Sustainable Technology Over Conventional Systems With Potential For Decentralization". *The Environmentalist*, vol 28, no. 4, 2008, pp. 409-420. *Springer Nature*, doi:10.1007/s10669-008-9162-8.

[18] Sinha, Rajiv K. et al. "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". *The Environmentalist*, vol 32, no. 4, 2012, pp. 445-452. *Springer Nature*, doi:10.1007/s10669-012-9409-2.

[19] "Surface Flow Systems Work Like Natural Wetlands". *Wateronline.Com*, 2018, https://www.wateronline.com/doc/surface-flow-systems-work-like-natural-wetlan-0001#5. Accessed 26 Sept 2018.

[20] Sudarsan, J. S. et al. "Domestic Wastewater Treatment Performance Using Constructed Wetland". *Sustainable Water Resources Management*, vol 1, no. 2, 2015, pp. 89-96. *Springer Nature*, doi:10.1007/s40899-015-0008-5.

[21] Taylor, M et al. "The Treatment Of Domestic Wastewater Using Small-Scale Vermicompost Filter Beds". *Ecological Engineering*, vol 21, no. 2-3, 2003, pp. 197-203. *Elsevier BV*, doi:10.1016/j.ecoleng.2003.12.003.

[22] Xing M, Yang J, Lu Z (2005) Microorganism-earthworm integrated biological treatment process—a sewage treatment option for rural settlements. ICID 21st European regional conference, 15–19 May 2005, Frankfurt; Viewed on 18 April 2006.