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Efficiency of *Megascolex konkanensis* in Treating Kitchen Wastewater

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ABSTRACT
Earthworms, generally known as environmental engineers, are versatile waste eaters, decomposers and can tolerate toxic chemicals in the environment. The present study aims to illustrate the potential of vermifilteration system using *Megascolex konkanensis* in treatment of kitchen wastewater. A small-scale vermifiltration unit was constructed having three layers, soil-sand-gravel along with *M. konkanensis* in it. The worms were given one month settling time in the soil bed to acclimatize with the new environment. Another unit without earthworms acted as an experimental control. The study was carried for 36 days and the observations on physico-chemical parameters were taken at an interval of 5 days. pH levels were brought to near neutral while Dissolved oxygen increased (14.7%) by the treatment system. Vermifiltration system significantly decreased the level of Turbidity (69.97%), Conductivity (42.54%), Total suspended solids (94.07%), Total dissolved solids (32.32%), Phosphate (60.90%), Sodium (22.72%), while the levels of Nitrate and Potassium increased. All parameters examined were within the permissible limits of WHO and BIS standards for recycled wastewater. Results thus suggest that vermifiltration system is ecofriendly, cost effective and very efficient in terms of contamination removal and wastewater purification.

Key words: Kitchen wastewater, *Megascolex konkanensis,* Vermifilter, Wastewater treatment

INTRODUCTION

Global water contamination is a serious issue as significant chemical presence is brought on by human activities such as farming, runoff from metropolitan areas, industrial output, and transportation. Aquatic ecosystems are directly exposed to discharge from a variety of production processes, including paint, metallic plating, food complexes, pharmaceutical industries and battery engineering. These processes all use heavy metal ions, dyes, and organic components (Pakdel and Peighambardoust 2018). In recent years, quality criteria for treating wastewater effluents have been raised, increasing the expenses of developing, running, and maintaining the treatment facilities, as well as power needs and technological advances (Hunter et al. 2019). Wastewater treatment and disposal solutions that are both environmentally friendly and cost effective have already acquired popularity in many areas, particularly in smaller settlements. Constructed wetlands, lagoons, stabilizing ponds, soil filters, groundwater recharge, drip irrigation and other similar systems are examples of such technologies. Simplicity of these systems, cost-effectiveness, efficiency, and dependability has given prospective applications for such environmentally beneficial technologies (Ambulkar and Nathanson 2023).

Natural wastewater treatment systems rely mostly on natural processes to accomplish their goals; while they may require pumps and piping for wastewater transportation, they do not require external energy sources for significant processing (Crites et al. 2014). Natural wastewater treatment techniques convert highly contaminated effluents to water with lower levels of suspended solids, total nitrogen, total phosphorus, biochemical oxygen demand (BOD_5) and Chemical oxygen demand (COD). They are also effective at avoiding hazardous organic compounds and heavy metals (Qian et al. 2007). Vermifiltration is one such organic treatment method that makes use of earthworms. Earthworms have long been understood to play important role in the management of waste, improvement of soil fertility, and promotion of plant development. However, they are currently employed in the restoration of polluted soil and treatment of wastewater (Gupta 2015).

The health, maturity, and population abundance of earthworm's impact treatment efficiency. Aerobic atmosphere and a moist substrate of the system promote the development of microorganisms as a biofilm. Microorganisms degrade organic materials in wastewater by biochemical decomposition. Earthworms regulate microbial biomass and activity by feeding on microorganisms directly or indirectly (Jiang et al. 2016). Earthworms ingest biofilm and organic matter, which is eventually processed into biologically inert castings (humus) (Liu et al. 2012). More the time wastewater remains inside the filter, better the removal of BOD_5 and COD occurs, but at the cost of hydraulic loading. Wastewater must have enough contact time with the biofilm to allow for pollutant adsorption, transformation, and reduction (Hughes et al. 2008). According to research, the presence of earthworms in wastewater resulted in considerable sludge stabilization by increasing the reduction of volatile suspended solids (Gupta 2015). The present study focuses on using vermifilteration process to recycle Kitchen wastewater and reuse it for agricultural purpose.

MATERIALS AND METHOD

The earthworm *Megascolex konkanensis* belonging to the family Megascolecidae, was collected from a locality in Chungam of Kottayam district, in Kerala (India). These earthworms were brought to the laboratory and transferred in to the stock crate. Prior to the beginning of the experiment, the worms were given one month settling time in the soil bed to acclimatize with the new environment. Rectangular plastic crates (50×35×40 cm) were used to construct the soil-sand-gravel layer experimental setup. Soil layer (topmost layer), Sand layer (middle layer) and Gravel layer (bottom layer) were of 10, 10 and 15 cm, respectively. Between the sand layer and gravel layer a mesh was kept in order to the prevent movement of earthworms into the bottom layer and also to enable proper filtration of water, which was collected from the bottom layer.

Kitchen wastewater was collected and the effluent was poured into a rectangular basin having a capacity of 7 liters. Water from this was allowed to flow downwards through a pipe which had perforations in it. These perforations allowed the water to distribute equally onto a plastic net, which prevented the entry of solid particulates into the system. The flow of the water through the pipe was kept under control to maintain a Hydraulic Retention Time (HRT) of 3 hours. The filtered water was collected in another crate, through a pipe fitted at the bottom. The study was carried out for 36 days and readings were taken at an interval of 5 days. As the earthworms played the critical role in wastewater purification, their number and population density were also kept under monitoring.

The physicochemical characteristics of untreated kitchen wastewater and water output from the treatment construct were examined using EUTECH 650 Multiparameter water analyser. The parameters analysed include pH, conductivity, Total dissolved solids (TDS), Dissolved Oxygen (DO). Nitrate and Phosphate contents were examined following standard APHA procedures using UV-VIS Spectrophotometer. Potassium and sodium content at each interval were measured using Flame photometer. The treatment system with earthworms and the control system devoid of earthworms were both kept under observation. Soil bed was examined on a regular basis to check its appearance, kitchen wastewater percolation, and for any bad odour production.

Statistical analysis

The data of all the physicochemical parameters were expressed as Mean ± Standard deviation. Along with that percentage reduction efficiency of the treatment systems were also expressed. Statistical significance of different treatments was evaluated by one-way analysis of variance (ANOVA) followed with Tukey's HSD post hoc at $P < 0.05$ level of significance by using SPSS software (20.0 version).

RESULTS AND DISCUSSION

The earthworms on the soil bed were healthy and active. Their number, weight and length increased as also reported in other studies (Sinha et al. 2007, Tomar et al. 2011). Mean pH value of the wastewater was 6.48 (Table 1), which is slightly acidic in nature. During the treatment process with each passing day, the pH changed to near neutral by the system containing *Megascolex konkanensis*, it was increased to 6.92 (Fig.1). Similarly, control unit was also able to increase the pH from 6.48 to 6.74. There was statistically significant difference among both the treatment units (one-way ANOVA; $F(2, 21) = 6.549$, $p = 0.006$). Azuar and Ibrahim (2012) observed similar trends when using vermifiltration technology to treat the palm oil mill effluent. This change could

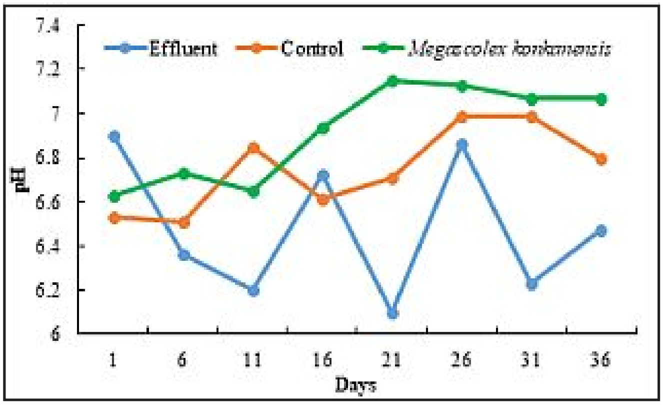

Figure 1. pH of the water

be caused by earthworm-mediated rapid mineralization of organic fractions of wastewater (Rajpal et al. 2012), indicating the innate capability of earthworms to act as buffering agents and neutralize pH of the wastewater (Arora et al. 2014).

Mean turbidity value of the wastewater was 35.37 NTU (Table 1), which decreased by 69.97 and 28.32% by the earthworm unit and the control unit, respectively. Turbidity of water by both the units had started decreasing from the 1st day itself, with each passing day earthworm unit was able to decrease turbidity consistently, while control unit had less reduction efficiency (Fig.2). There was statistically significant difference among both the treatment units (one-way ANOVA; $F (2, 21) = 17.157$, $p < 0.05$). Sinha et al. (2014), mentioned earthworms can remove more than 95% of the turbidity from wastewater. Turbidity decreases owing to adsorption of both macroscopic and microscopic suspended particles in the filters. Adsorption takes place in the soil, sand, and gravel. The earthworm unit was more efficient since they feed on organic substances, lowering organic waste and regulating turbidity correspondingly (Gwebu and Mpala 2022).

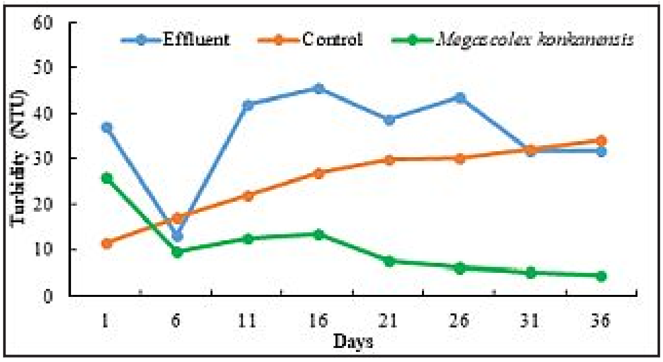

Figure 2. Turbidity (NTU) of the water

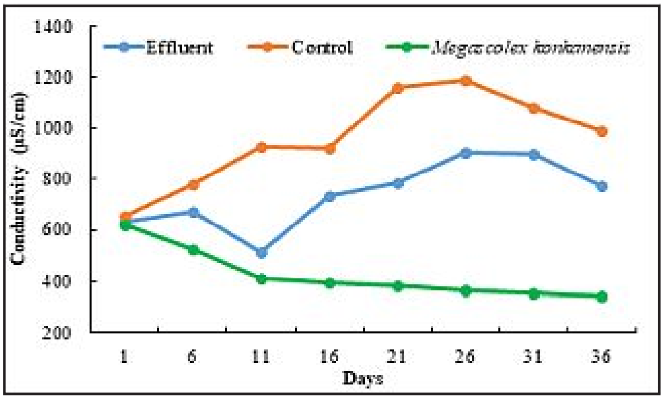

Figure 3. Conductivity (µS/cm) of the water

Conductivity of the water increases as the concentration of dissolved salts and other inorganic chemicals in the water increases. High conductivity is an indicator of high salinity which ultimately leads to less dissolved oxygen. The untreated wastewater had a conductivity of 738.81 µS/cm (Table 1). System with *M. konkanensis* reduced conductivity to 424.48 µS/cm (42.54%) while the control system showed an increase by 30.41% (963.55 µS/cm) (Fig. 3). One-way ANOVA showed significant difference among the treatment units (ANOVA; $F (2, 21) = 29.114$, $p < 0.05$). Singh et al. (2010) also discovered that the reduction in conductivity could be attributed to the formation of soluble metabolites during vermicomposting. It may be related to the ingestion of minerals by the earthworms. Conductivity of control unit increased due to accumulation of inorganic substances in the filter media over the time (Fig.3).

The level of TDS is based on the amount of minerals, metals, organic material and salts dissolved in the water. In this study the mean initial TDS value of the wastewater was 368.93 ppm (Table 1), which decreased by 32.32% in the earthworm treatment

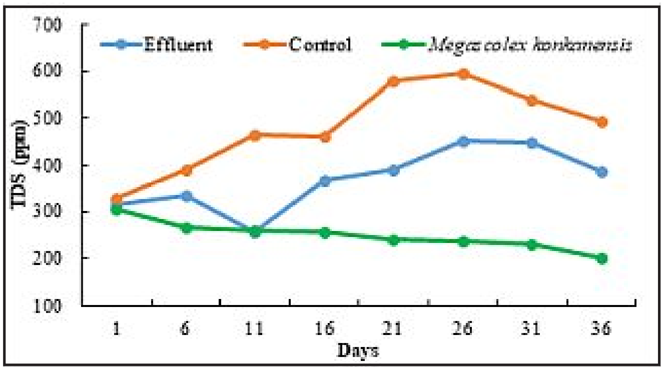

Figure 4. Total dissolved solids (TDS) of the water

Table 1. Physico-chemical parameters (mean± SD) initial and treated kitchen wastewater

Parameters	Effluent	Control unit	% Change	*M. konkanensis* containing unit	% Change
pH	6.48 ± 0.311	6.74 ±.0.190	+4.01	6.92±0.21	+ 6.79
Turbidity (NTU)	35.37 ± 10.31	25.35 ± 7.91	-28.32	10.62 ± 6.91	-69.97
Conductivity (μS/cm)	738.81 ± 132.62	963.55 ± 182.68	+30.41	424.48 ± 97.35	-42.54
TDS (ppm)	368.9 3± 66	481.75 ± 91.34	+30.58	249.68 ± 30.40	-32.32
TSS (mg/l)	257.5 ± 71.06	70 ± 11.95	-72.81	15.25 ± 22.34	-94.07
DO (mg/l)	2.71 ± .61	2.55 ± .24	-5.90	3.11 ± 0.49	+14.76
Nitrate (mg/l)	13.48 ± 5.83	37.52 ± 11.45	+178.33	52.37 ± 52.62	+288.50
Phosphate (mg/l)	.022 ± .0098	.012 ± .0011	-45.45	.0086 ± .0019	-60.90
Potassium (mg/l)	7.23 ± 1.38	16.35± 3.92	+126.14	13.62 ± 4.33	+88.38
Sodium (mg/l)	101.88 ± 21.62	131.47 ± 29.17	+29.04	78.73 ± 19.65	-22.72

(-)= Showing percentage reduction, (+)= Showing percentage increase

system (Fig.4) while the control system showed increased TDS levels by 30.58% (481.75 ppm). One-way ANOVA showed significant difference among the treatment units (ANOVA; $F(2, 21) = 23.722$, $p < 0.05$). The increase in control system was caused by the accumulation of trapped substances over time as sludge, which chokes the control system and ultimately stopping the function of working system (Sinha et al. 2010, Ghatnekar et al. 2010, Azuar et al. 2012). However, the system with earthworms was working properly. The decrease was due the ingestion of trapped organic and inorganic solid particles present in the kitchen wastewater by the earthworms. Earthworms may eliminate TDS from any liquid wastes by 90-92% using the general mechanism of ingestion and biodegradation of organic waste (Sinha et al. 2007). Similarly, Manyuchi et al. (2019) reported 80.2% reduction in TDS of swine wastewater treatment utilizing a three-stage vermifiltration technique involving *Eisenia fetida*.

The mean initial TSS value of the wastewater was 257.5 mg/l (Table 1), which decreased significantly by 94.07% (15.25 mg/l) and 72.81% (70 mg/l) by the *M. konkanensis* unit and the control unit, respectively. One-way ANOVA showed significant difference among the treatment units (ANOVA; $F(2, 21) = 68.050$, $p < 0.05$). TSS values started to decrease in both the units from the 1st day itself (Fig.5), due to adsorption by soil-sand-gravel layers which trap waste from the water. Earthworms serve as aerators, crushers, grinders, chemical degraders, and biological stimulators. They encourage the development of helpful decomposer bacteria and

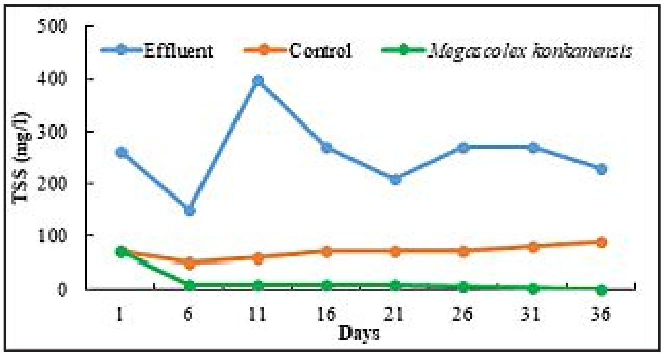

Figure 5. Total suspended solids (mg/l) of the water

fasten the breakdown of trapped particles (Gupta 2015). Nuengjamnong et al. (2011) treated swine wastewater by incorporating earthworms into constructed wetlands, achieving more than 90% TSS reduction. Sinha et al. (2008) reported more than 90% reduction in TSS in the vermifiltration of sewage from the Oxley wastewater Treatment Plant in Brisbane, Australia, as well as vermifiltration of brewery and dairy wastewater. Similarly, Soto and Toha (2008) reported 95% reduction of TSS in the vermifiltration of municipal wastewater in a pilot plant for treating wastewater from 1000 residents.

The initial mean Dissolved oxygen (DO) level was 2.71 mg/l, which reduced by the control system to 2.55 mg/l (5.90%), whereas the DO level increased by 14.7% by the earthworm containing treatment system (Table.1). DO levels gradually increased in the earthworm system and attained highest value on 26th day and then decreased from 31st day but had higher DO content in comparison to the control system (Fig.6). One-way ANOVA showed no

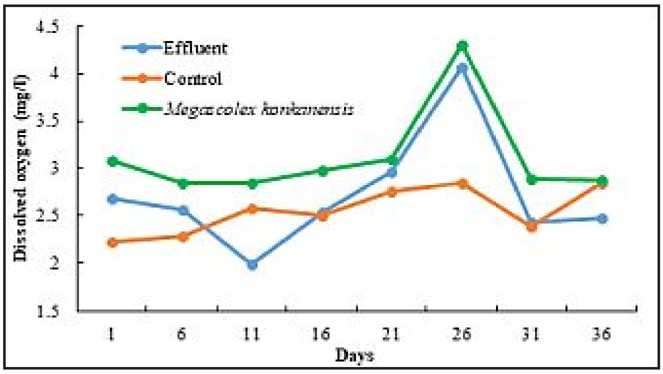

Figure 6. Dissolved oxygen (mg/l) content of the water

significant difference among the treatment units (ANOVA; F (2, 21) = 2.947, p = 0.074). The increase is mainly due to the burrowing activity of earthworms, creating aeration and facilitating microbial growth in the system, which ultimately leads to biodegradation of the wastes from the water. Manyuchi et al. (2019) reported rise in DO concentration by >345.5% in swine wastewater treatment utilizing the vermifiltration technique with *E. fetida*.

Kitchen wastewater is the primary source of nitrogen in greywater, ranging from 4 to 74 mg/l (Boyjoo et al. 2013). In the present study the initial mean nitrate values of the untreated wastewater was 13.48 mg/l which increased in both the control and the vermifilter to 37.52 (178.33%) and 52.37 mg/l (288.50%), respectively (Table 1). There was statistically no significant difference among the treatment units (one-way ANOVA; F (2, 21) = 3.149, p = 0.064). The nitrate content from the 1st day was higher in the earthworm and control treatment units in comparison to the effluent wastewater (Fig.7). The control unit had increased nitrate content because of biodegradation of organic matter by the microbes present in the filter media. Apart from this, earthworm containing unit help to convert organic matter into nitrogen compounds such as ammonium and nitrate. Worms boost soil nitrogen levels by adding their metabolic and excretory products (vermicast), body fluid, mucus, enzymes, and decaying tissues of dead worms (Suthar 2012). They also give nitrogen indirectly by fragmenting organic molecules and grazing soil microbes. Nitrates in untreated wastewater are anticipated to diminish throughout treatment because they are transformed from ammonia to nitrate and further degraded to nitrogen gas by the nitrification and denitrification processes. Adsorption causes a rise in the level of ammonia. Earthworms gut is likewise loaded with nitrifying and denitrifying bacteria (Gwebu and Mpala 2022). *Nitrosomonas* sp. remove ammonia by oxidizing it to nitrite (Ratnawati and Sugito 2021), while *Nitrobacter* sp. convert nitrite to nitrate (Nurhayati et al. 2019, Singh et al. 2019). Bacteria require oxygen to reduce ammonia; the higher the oxygen concentration, the greater the reduction of ammonia (Samal et al. 2018). Worm movement in the vermibed increases oxygen production and ammonia degradation (Samal et al. 2017). Wang et al. (2011) reported contradicting results when they investigated the performance of a vermifiltration system using the earthworm *E. fetida* for rural domestic wastewater treatment. The average removal of total nitrogen (as nitrates) was 60.2%.

Initial mean phosphate levels of wastewater was 0.022 mg/l (Table 1), which reduced to 0.012 mg/l (45.45%) and 0.0086 mg/l (60.90%) by the control and earthworm containing unit respectively (Fig.8). There was statistically significant difference among

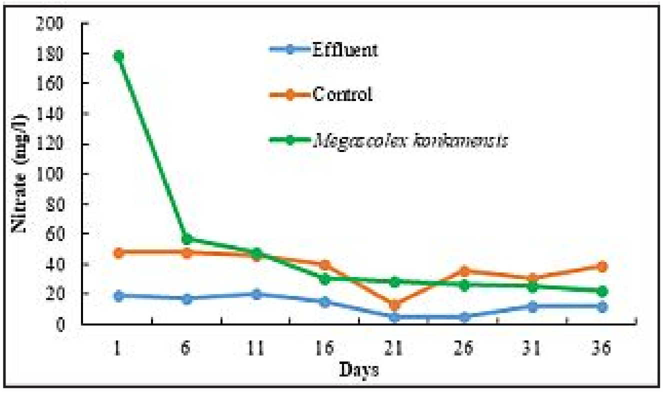

Figure 7. Nitrate (mg/l) content of the water

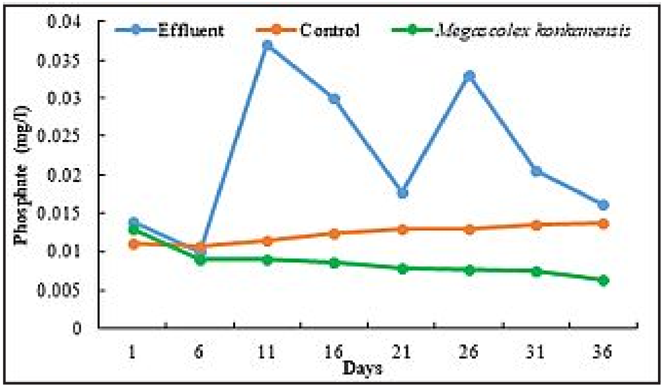

Figure 8. Phosphate (mg/l) content of the water

both the treatment units (one-way ANOVA; $F (2, 21) = 11.871$, $p < 0.05$). The control unit was able to decrease the phosphate content because, sand and gravel can effectively remove phosphate and other nutrients from wastewater (Achak 2023). Lee (1985) proposed that the transit of organic materials through a worm's gut converts phosphorous to forms that are more bioavailable to plants. This is accomplished in part through the action of worm gut enzyme phosphatases and in part through the release of phosphate-solubilizing bacteria in the worm cast. Soto and Toha (2008) observed that vermifiltration of municipal wastewater removed 70% of the phosphorus. Wang et al. (2011) reported 98.4% total phosphorus removal employing *E. fetida* in their vermifiltration system. Phosphate removal from wastewater prevents eutrophication. In the present study the phosphate levels in water at each interval were below the permissible limits prescribed by WHO (Anonymous 1993).

Potassium levels of the vermifilter treatment system increased by 88.38%. The initial mean potassium level of wastewater was 7.23 mg/l which increased to 13.62 mg/l by the earthworm containing unit, while the control unit increased it to 16.35mg/l (126.14% increase). There was statistically significant difference among the treatment units (one-way ANOVA; $F (2, 21) = 14.564$, $p < 0.05$). At the beginning of the experiment potassium levels were high in both the treatment system with earthworm and control in comparison to the effluent wastewater. Gradually over the time potassium levels started to decrease but still was higher compared to the effluent. The control unit was showing higher potassium levels when compared to the earthworm unit (Fig.9). This might be because the filter bed was already rich in potassium and accumulation of more nutrients during the treatment from the wastewater can further increase its levels. Earthworms mineralize minerals from sludge, producing more nutritious end products that are high in macro and micronutrients. Chemical tests of vermicasts revealed seven times more accessible potassium than the surrounding soil (Kaviraj and Sharma 2003). Elvira et al. (1998) also discovered an increase in the potassium content of sludge vermicompost. According to Basker et al. (1992), exchangeable potassium concentration increased dramatically in soil populated by earthworms as potassium was released from the non-exchangeable potassium pool as soil material travelled through the worm gut. The presence of microflora in earthworms' digestive systems is a critical aspect in the process of releasing and increasing potassium levels (Pramanik et al. 2007). They most likely produce microbial enzymes that convert insoluble potassium into soluble potassium (Kaviraj and Sharma 2003).

The high level of sodium containing compounds present in the utensil cleaning liquids and bars, increases the sodium content of kitchen wastewater. The initial mean Sodium value of kitchen wastewater was 101.8 mg/l (Table 1), which decreased by the vermifilter unit to 78.73 mg/l and increased by control unit to 131.47mg/l. One-way ANOVA showed significant difference among the treatment units (ANOVA; $F (2, 21) = 9.836$, $p < 0.05$). The earthworm unit exhibited a reduction efficiency of 22.72%, while control unit increased sodium content by 29.04%. The increase was due to the system getting saturated with sodium concentration during the wastewater treatment, whereas, the presence of earthworm biodegraded and reduced sodium content from the system. Domínguez et al. (2013) discovered that utilizing earthworms *E. andrei* to vermicompost

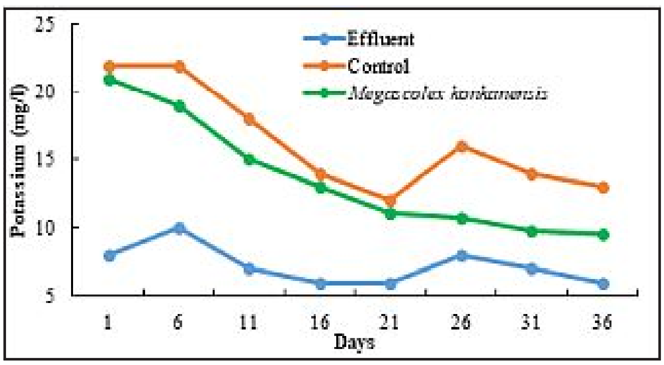

Figure 9. Potassium (mg/l) content of the water

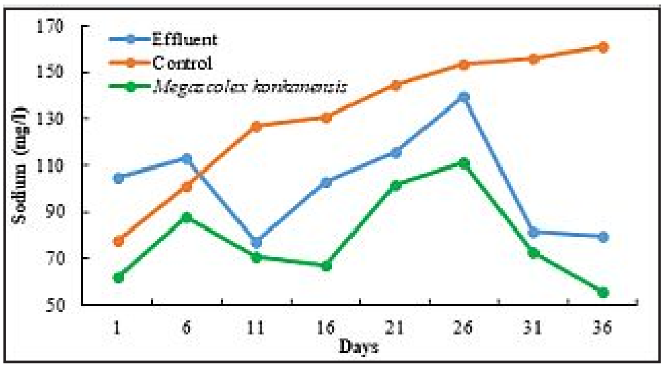

Figure 10. Sodium (mg/l) content of the water

cattle manure and sewage sludge resulted in a considerable decrease in sodium concentration over the time. Singh et al. (2017) used Milk Processing Industry Sludge (MPIS) for vermicomposting and reported a 53% decrease in total sodium concentration.

CONCLUSION

Earthworms have amazing physiology that allows them to tolerate and ingest certain level of chemicals, organic wastes and other contaminants present in wastewater. They digest and biodegrade all the suspended particles screened on the filter bed in their gut. Microbial processes and vermin-process simultaneously work in the vermifiltration system. Gut of earthworms has millions of microbes which are released into the system with vermicast. Aeration by the earthworms accelerates microbial activity, thereby stabilizing the soil and the filtration system to become more effective. In the present study, vermifiltration system caused significant decrease in level of Turbidity (69.97%), Conductivity (42.54%), TSS (94.07%), TDS (32.32%), phosphate (60.90%), sodium (22.72%). Nitrate and Potassium levels were increased by the system due the vermicasts produced by the earthworms. All the values were within the permissible limits; hence the treated wastewater was fit for landscaping and irrigation purpose. Vermifiltration is a low-cost aerobic natural treatment system, which has low mechanical and manual maintenance requirements. It is an eco-friendly technique which with some modifications can be used as an alternative to other conventional wastewater treatment techniques.

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REFERENCES

Achak, M., Boumya, W., Elamraoui, S., Asdiou, N., Taoufik, N., Barka, N., Aboulkas, A. and Lamy, E. 2023. Performance of olive mill wastewater treatment using hybrid system combining sand filtration and vertical flow constructed wetlands. Journal of water process engineering, 53, 103737. https://doi.org/10.1016/j.jwpe.2023.103737.

Ambulkar, A. and Nathanson, J.A. 2023. Wastewater Treatment. Encyclopaedia Britannica. https://www.britannica.com/technology/wastewater-treatment.

Anonymous. 2012. Indian Standard Drinking Water Specification. Bureau of Indian Standards, New Delhi.

Anonymous. 1993. Guidelines for Drinking Water Quality. World Health Organization Recommendations, 2nd edition, WHO, Geneva.

Arora, S., Rajpal, A., Bhargava, R., Pruthi, V., Bhatia, A. and Kazmi, A. A. 2014. Antibacterial and enzymatic activity of microbial community during wastewater treatment by pilot scale vermifiltration system. Bioresource Technology, 166 (1), 132-141. https://doi.org/10.1016/j.biortech.2014.05.041.

Azuar, S.A. and Ibrahim, M.H. 2012. Comparison of sand and oil palm fibre vermibeds in filtration of palm oil mill effluent (POME). Pp. 1414-1419. In: UMT 11th International Annual Symposium on Sustainability Science and Management, Terengganu, Malaysia.

Basker, A., Macgregor, A.N. and Kirkman, J.H. 1992. Influence of soil ingestion by earthworms on the availability of potassium in soil: An incubation experiment. Biology and Fertility of Soils, 14, 300–303. https://doi.org/10.1007/BF00395467.

Boyjoo, Y., Pareek, V.K. and Ang, M. 2013. A review of greywater characteristics and treatment processes. Water Science and Technology, 67(7), 1403-1424. https://doi.org/10.2166/wst.2013.675.

Crites, R.W., Middlebrooks, E.J. and Robert. K. B. 2014. Natural Wastewater Treatment Systems, 2nd ed., CRC press, Boca Raton. https://doi.org/10.1201/b16637.

Domínguez, J. and Gómez-Brandón, M. 2013.The influence of earthworms on nutrient dynamics during the process of vermicomposting. Waste Management and Research, 31(8), 859-868. https://doi.org/10.1177/0734242X13497079.

Elvira, C., Sampedro, L., Benitez, E. and Nogales, R. 1998. Vermicomposting of sludges from paper mill and dairy industries with *Eisena andrei*: A pilot-scale study. Bioresource Technology, 63(3), 205-211. https://doi.org/10.1016/S0960-8524(97)00145-4.

Ghatnekar, S.D., Kavian, M.F., Sharma, S.M., Ghatnekar, S.S., Ghatnekar, G.S. and Ghatnekar, A.V. 2010. Application of vermi-filter-based effluent treatment from biomangement of liquid effluents from the gelatine industry. Dynamic Soil, Dynamic Plant, 4(1), 83-88.

Gupta, H. 2015. A review on effectiveness of earthworms for treatment of wastewater. International Journal of Engineering Development and Research, 3(3), 1-4.

Gwebu, L. and Mpala, C. 2022. Application of vermifiltration for domestic sewage treatment. Wastewater Treatment. https://doi.org/10.5772/intechopen. 103920.

Hughes, R.J., Nair, J. and Ho, G. 2008. The toxicity of ammonia/ammonium to the vermifiltration wastewater treatment process. Water Science and Technology, 58, 1215-1220. https://doi.org/10.2166/wst.2008.478.

Hunter, R.G., Day, J.W., Wiegman, A.R. and Lane, R.R. 2019. Municipal wastewater treatment costs with an emphasis on assimilation wetlands in the Louisiana coastal zone. Ecological Engineering, 137, 21-25. https://dx.doi.org/10.1016/j.ecoleng.2018.09.020.

Jiang, L., Liu, Y., H, X., Zeng, G., Wang, H., Zhou, L., Tan, X., Huang, B., Liu, S. and Liu, S. 2016. The use of microbial-earthworm ecofilters for wastewater treatment with special attention to influencing factors in performance: A review. Bioresource Technology, 200, 999-1007. https://doi.org/10.1016/j.biortech.2015.11.011.

Kaviraj and Sharma, S. 2003. Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. Bioresource Technology, 90(2), 169-173. https://doi.org/10.1016/S0960-8524(03)00123-8.

Lee, K.E. 1985. Earthworms: Their Ecology and Relationships with Soils and Land Use. Sydney, Academic Press Inc.

Liu, J., Lu, Z., Yang, J., Xing, M., Yu, F. and Guo, M. 2012. Effect of earthworms on the performance and microbial communities of excess sludge treatment process in vermifilter. Bioresource Technology, 117, 214-21. https://doi.org/10.1016/j.biortech.2012.04.096.

Manyuchi, M.M., Mupoperi, N., Mbohwa, C. and Muzenda, E. 2019. Treatment of wastewater using vermifiltration technology. Pp. 215-230. In: Singh, R., Kolok, A. and Bartelt-Hunt, S. (Eds.) Water Conservation, Recycling and Reuse: Issues and Challenges. Springer, Singapore. https://doi.org/10.1007/978-981-13-3179-4_12

Nuengjamnong, C., Chiarawatchai, N., Polprasert, C. and Otterpohl, R. 2011.Treating swine wastewater by integrating earthworms into constructed wetlands. Journal of Environmental Science and Health Part A Toxic/Hazardous Substances & Environmental Engineering, 46(7), 800-804. https://doi.org/10.1080/10934529.2011.572002.

Nurhayati, I., Ratnawati, R. and Sugito. 2019. Effects of potassium and carbon addition on bacterial algae bioremediation of boezem water. Environmental Engineering Research, 24(3), 495-500. https://doi.org/10.4491/eer.2018.270.

Ratnawati, R. and Sugito. 2021. Active charcoal and zeolite to reduce COD and ammonia of domestic wastewater. Journal of Wetlands Environmental Management, 9 (2), 63–72. https://doi.org//10.20527/jwem.v9i2.281.

Pakdel, P.M. and Peighambardoust, S.J. 2018. Review on recent progress in chitosan-based hydrogels for wastewater treatment application. Carbohydrate Polymer, 201, 264-279. https://doi.org/10.1016/j.carbpol.2018.08.070.

Pramanik, P., Ghosh, G.K., Ghosal, P.K. and Banik, P. 2007. Changes in organic – C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresource Technology, 98(13), 2485-2494. https://doi.org/10.1016/j.biortech.2006.09.017.

Qian, Y., Wen, X. H. and Huang, X. 2007. Development and application of some renovated technologies for municipal wastewater treatment in China. Frontiers of Environmental Science and Engineering in China, 1, 1-12. https://doi.org/10.1007/s11783-007-0001-9.

Rajpal, A., Bhargava, R., Sasi, S.K. and Chopra, A.K. 2011.On site domestic organic waste treatment through vermitechnology using indigenous earthworm species. Waste Management and Research, 30, 266-275. https://doi.org/10.1177/0734242X11403798.

Samal, K., Dash, R.R. and Bhunia, P. 2017. Performance assessment of a *Canna indica* assisted vermifilter for synthetic dairy wastewater treatment. Process Safety and Environmental Protection, 111, 363-374. https://doi.org/10.1016/j.psep.2017.07.027.

Samal, K., Dash, R.R. and Bhunia, P. 2018. Effect of hydraulic loading rate and pollutants degradation kinetics in two stage hybrid macrophyte assisted vermifiltration system. Biochemical Engineering Journal, 132, 47-59. https://doi.org/10.1016/j.bej.2018.01.002.

Singh, J., Kaur, A., Vig, A.P. and Rup, P.J. 2010. Role of *Eisenia fetida* in rapid recycling of nutrients from bio sludge of beverage industry. Ecotoxicology and Environment Safety, 73 (3), 430-435. https://doi.org/10.1016/j.ecoenv.2009.08.019.

Singh, R., Samal, K., Dash, R.R. and Bhunia, P. 2019. Vermifiltration as a sustainable natural treatment technology for the treatment and reuse of wastewater: A review. Journal of Environmental Management, 247, 140-151. https://doi.org/10.1016/j.jenvman.2019.06.075.

Singh, S., Bhat, S.A., Singh, J., Kaur, R. and Vig, A.P. 2017. Earthworms converting milk processing industry sludge into biomanure. The Open Waste Management Journal, 10(1), 30-40. https://doi.org/10.2174/1876400201710010030.

Sinha, R.K., Agarwal, S., Chauhan, K., Chandran, V. and Soni, B.K. 2010. Vermiculture technology: Reviving the dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs. Technology and Investment, 1, 155-172. https://doi.org//10.4236/ti.2010.13019.

Sinha, R. K., Bharambe, G. and Bapat, P. 2007. Removal of high BOD and COD loadings of primary liquid waste products from dairy industry by vermifiltration technology using earthworms. Indian Journal of Environmental Protection, 27 (6), 486-501.

Sinha, R.K., Bharambe, G., Chowdhary, U. 2008. Sewage treatment by vermi-filtration with synchronous treatment of sludge by earthworms: A low-cost sustainable technology over conventional systems with potential for decentralization. The Environmentalist, 28(4), 409-420. https://doi.org//10.1007/s10669-008-9162-8.

Sinha, R.K., Patel, U., Soni, B.K. and Li, Z. 2014. Earthworms for safe and useful management of solid wastes and wastewaters, remediation of contaminated soils and restoration of soil fertility, promotion of organic farming and mitigation of global warming: A review. Journal of Environment and Waste Management, 1(1), 11-25.

Soto, M.A. and Toha, J. 2008. Ecological Wastewater Treatment. Advanced Wastewater Treatment, Recycling and Reuse. AWT 98, Milano.

Suthar, S. 2012. Vermistabilization of wastewater sludge from milk processing industry. Ecological Engineering, 47,115-119. https://dx.doi.org//10.1016/j.ecoleng.2012.06.005.

Tomar, P. and Suthar, S. 2011. Urban wastewater treatment using vermi-biofiltration system. Desalination, 282, 95-103. https://doi.org/10.1016/j.desal.2011.09.007.

Wang, L., Guo, F., Zheng, Z., Luo, X. and Zhang, J. 2011. Enhancement of rural domestic sewage treatment performance, and assessment of microbial community diversity and structure using tower vermifiltration. Bioresource Technology, 102(20), 9462-9470. https://doi.org/10.1016/j.biortech.2011.07.085

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