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Application of Phytotechnology in Domestic Wastewater for Micropollutant Removal: A Review

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Abstract:

Many organic micropollutants present in wastewater, such as pharmaceuticals and hydrophilic pesticides, are poorly removed in conventional wastewater treatment plants (WWTP). The main challenge for scientific community consists in the improvement of the phytotechnology systems. Advanced treatments are very important and will be soon mandatory in Malaysia to reduce these substances that is present in aquatic environment. In developed countries, this problem is startingly resolved to some extent by using phytotechnology involving reed bed systems of native tolerant plants. Much research was done in the last years to clean up the environment from those compounds, but the most operations for getting optimum results are difficult and costly. There are still limitations in phytotechnology system as some of natural plants have low capacity to remove contaminants from wastewater. Hence, it is clear that we need to improve the performance of the naturally occurring plant species. Nowadays, phytotechnology process is an effective and affordable solution used to remove micropollutants from domestic wastewater. This phytotechnology is the cost effective and environmental friendly. This article aims to compile some information about phytotechnology performance to polish micropollutants from domestic wastewater, effects and their treatments, and also, to demonstrate that the installation of an additional phytotechnology process at a WWTP can

significantly reduce the discharge of micropollutants into the watercourses using native plants. Some recommended plants which are commonly used in phytotechnology and their capability to clean up the micropollutants contaminant are also reviewed.

Keywords: Micropollutants, Pharmaceuticals Contaminants, Domestic Wastewater, Phytotechnology.

تطبيق التقنية النباتية في معالجة مياه الصرف الصحي المنزلية لإزالة الملوثات الدقيقة: دراسة مراجعة

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الملخص:

توجد العديد من الملوثات العضوية الدقيقة في مياه الصرف الصحي، مثل المستحضرات الصيدلانية والمبيدات الحشرية المحبة للماء، والتي لا تتم إزالتها بشكل كافٍ في محطات معالجة مياه الصرف التقليدية. ويتمثل التحدي الرئيسي أمام المجتمع العلمي في تحسين أنظمة التقنية النباتية (Phytotechnology). إن المعالجات المتقدمة تُعد ذات أهمية كبيرة، ومن المتوقع أن تصبح إلزامية قريباً في ماليزيا لتقليل من هذه المواد الموجودة في البيئة المائية. في الدول المتقدمة، بدأ حل هذه المشكلة جزئياً باستخدام التقنية النباتية التي تعتمد على أنظمة تعدد الطبقات المزروعة بالنباتات محلية تتحمل الظروف البيئية (Reed Bed Systems). وقد أُجريت أبحاث عديدة في السنوات الأخيرة لتنظيف البيئة من هذه المركبات، غير أن العمليات اللازمة لتحقيق أفضل النتائج غالباً ما تكون صعبة ومكلفة. كما لا تزال هناك بعض القيود في نظام التقنية النباتية، إذ إن بعض النباتات الطبيعية لديها قدرة منخفضة على إزالة الملوثات من مياه الصرف. ومن الواضح أننا بحاجة إلى تحسين أداء لأنواع من النباتات الطبيعية. في الوقت الحاضر، تُعتبر عملية

التقنية النباتية حلاً فعالاً وبتكلفة معقولة لإزالة الملوثات الدقيقة من مياه الصرف الصحي المنزلية. وتمتاز هذه التقنية بانخفاض تكلفتها وصداقتها للبيئة. يهدف هذا البحث إلى جمع المعلومات الدقيقة حول أداء التقنية النباتية في إزالة الملوثات الدقيقة من مياه الصرف الصحي المنزلية، وبيان تأثيراتها وطرق معالجتها، بالإضافة إلى أن تركيب وحدة إضافية من التقنية النباتية في محطة معالجة مياه الصرف الصحي يمكن أن يسهم بشكل كبير في تقليل تصريف الملوثات الدقيقة إلى المجاري المائية باستخدام النباتات المحلية. كما تمت مراجعة بعض النباتات الموصى بها والشائعة الاستخدام في هذه التقنية وقدرتها على إزالة الملوثات الدقيقة من البيئة.

الكلمات المفتاحية: الملوثات الدقيقة، ملوثات الأدوية، مياه الصرف الصحي المنزلية، التكنولوجيا النباتية.

1. Introduction

The environmental destiny of micropollutants such as personal care products (PPCPs) and excess pharmaceuticals has become an area of great attention during the last decade, mostly in aquatic ecosystems (Conkle et al. 2008). Generally, PPCPs are designed to be biologically active at very low concentrations, and the impacts of exposure to these compounds, particularly under chronic exposures, are not totally understood (Comeau et al., 2008; Fent et al., 2006). Micropollutants like PPCPs are not perfectly aimed for removal by wastewater treatment systems (Fent et al., 2006), so all of these compounds are found out in surface waters globally (Carlson et al., 2013; Matamoros et al., 2012).

Pharmaceuticals and personal care products (PPCPs) constitute a various group of chemical compounds that have recently been recognized as particulate contaminants to the aquatic environment, especially for urban areas (Daughton and Ternes, 1999). Pharmaceuticals contaminants such as analgesics or antibiotics have frequently been found in surface waters at low concentration reaching $\mu\text{g L}^{-1}$ (Ashton et al., 2004; Bendz et al., 2005; Calamari et al., 2003; Glassmeyer et al., 2005; Gross et al., 2006; Kolpin et al., 2002, 2004; Moldovan, 2006; Roberts and Thomas, 2006; Vanderford et al., 2003; Vieno et al., 2005, 2006). In contrast, illicit drugs and personal care products have hardly been studied in environmental matrices and limited proofs of their presence in the environment (Boleda et al., 2007; Hummel et al., 2006; Zuccato et al., 2008). PPCPs comprise all prescription and cover the counter

drugs, diagnostic agents, and other consumer chemical compounds, such as polycyclic musk compounds frequently used as fragrances in perfumes and other household products, which, until recently, have not been of major concern with regards to their environmental impacts. When these compounds are freely discharged into the environment, they may cause some impact on aquatic and terrestrial organisms.

Due to the large amount of PPCPs consumed in developed societies, significant concentrations of these compounds can be found in wastewaters (Ternes, 1998; Kanda et al., 2003; Kolpin et al., 2004; Cargoue et al., 2004). However, conventional sewage treatment plants (STPs) have been reported not to be an effective barrier to these substances because of their low concentrations and specific metabolic properties (Paxeus, 2004). Therefore, those compounds which resist the treatment processes commonly used in STPs or other transformations which can naturally occur in the environment, can end up in surface and ground waters, as well as in sediments and soils.

PPCPs, coming either from domestic sewage, hospital wastewaters or industrial discharges, reach sewage treatment plants (STPs). During sewage treatment, a distribution will take place between the dissolved fraction and the solids present (primary or secondary sludge). This partition is especially relevant for the most lipophilic compounds. Therefore, the release of non-degraded PPCPs into the environment will occur not only with the final effluent of the plant, but also within the discharge of the excess sludge. Sewage sludge is predominantly disposed of on agricultural lands, and it has been reported to contain pharmaceutical substances (Khan and Ongerth 2002; Kupper et al. 2004; Kinney et al. 2006).

Drugs and their metabolites can enter water supplies and the food chain, and therefore risk assessments are being carried out in order to evaluate their possible impact both on the ecosystem and human health (Balk and Ford 1999; Stuer-Lauridsen et al. 2000; Bound and Voulvoulis 2006). From the data available concerning toxicity of PPCPs (Henry et al. 2004; Schreurs et al. 2004; Flippin et al. 2007; Hong et al. 2007) acute effects on aquatic organisms are not expected, except for spills, while very little information is available about chronic exposures, in particular with respect to biological targets (Fent et al. 2006). Besides, it should be considered that these compounds are usually present in complex mixtures, which may produce synergistic effects.

Drugs, as an essential part of modern human and veterinary medicine, are excreted via faeces and urine slightly transformed into glucoronides and sulphates or even unchanged (Ternes 1998). Human pharmaceuticals and their metabolites reach in this way sewage. Veterinary drugs are excreted in the manure, which can be used as fertilizers and enter ground waters via leachates. Another pollution source for human drugs is throwing expired medicines into the toilets or into landfills together with other solid urban wastes. Therefore, it is expected that drugs and their metabolites can be found in rivers and streams all around the world where a significant consumption of drugs exists. Unfortunately, environmental risks assessments are not available for most of these products so far, but there is some evidence of adverse effects of these compounds. Purdom et al. (1994) made 'in vitro' studies showing that exposure of fishes to only 0.1 ng/L of ethinylestradiol may provoke feminization in some species of male wild fishes. Finally, some contribution of pharmaceutically active compounds (-PhACs) in the aquatic environment is expected to be caused by manufacturing plants, although it is expected that the existing strong regulations and the new 'cleaner' manufacturing practices will minimize this issue in the near future.

Many studies on constructed wetlands have also been attempted to control organics, nutrients, and heavy metals using vertical and/or horizontal flow types of wetlands (Molle et al., 2008; Brix and Arias, 2005; Vymazal, 2005). In Korea, some of micropollutants have been reported to exhibit very high concentrations in both wastewater effluent and drinking water sources, and these could be effectively removed by processes using either reverse osmosis or nanofiltration membranes (Kim et al., 2007). Pharmaceuticals and personal care products have also been investigated, with respect to their removals using constructed wetlands, to relatively lesser extents than other contaminants, such as organic carbon (in terms of biochemical and chemical oxygen demands) and nutrients (e.g., nitrogen). Micropollutants exhibit a wide range of removal behaviors; for example, naproxen can be removed with relatively high removal efficiencies (ranging 52–92%) by full-scale (with very long retention time of 1 month) and engineered subsurface horizontal flow (SSF) constructed wetlands. Both relatively high and low removal efficiencies for diclofenac have been exhibited with full-scale and engineered SSF wetlands, respectively (Matamoros et al., 2008).

In previous studies, removal of atrazine within wetlands was dependent upon retention time. Hey and Kadlec (1994) reported between 25 and 95% removal of atrazine in different wetland cells after 3 to 4 weeks of retention time. Similarly, Kao et al., (2001) observed up to 99% removal of atrazine within 15 days in anaerobic cells spiked with sucrose media, but less than 9% removal in control wetlands that were not inoculated with media or a nitrogen source. While removal of atrazine from wastewater can be quite variable and very dependent upon the specific substrates and characteristics of the wetland, these results suggest that the wetland conditions are conducive to remove of atrazine. Other studies have reported relatively effective removal of carbamazepine, with 51% removal of carbamazepine via treatment in a forested wetland for 27 days, and up to 80% removal of carbamazepine in Typha inhabited freshwater wetlands over the course of 6 days (Conkle et al., 2008; Reyes-Contreras et al., 2012). These results agree with those of the current study where lagoon discharge was treated in a Typha dominated wetland with a residence time of approximately 20 hours. While carbamazepine is relatively persistent, it may be removed to some extent by sorption to suspended particles and uptake by plants, including biotransformation by Typha spp. (Dordio et al., 2011; Tanoue et al., 2012).

Malaysia has to face the issue that many of these foreign compounds or xenobiotics will increasingly create environmental problems in all regions of the country. Due to steadily improving capabilities for environmental analysis, we are nowadays able to detect compounds in very low concentration ranges in water bodies and sediments. Industrial wastewater discharged into aquatic ecosystems either directly or because of inadequate treatment of process water can lower water quality of a region by increasing concentrations of pollutants such as organic matter, suspended particulates, micropollutants, nutrients or heavy metals, thereby causing adverse effects on human health and undesirable changes in the composition of aquatic biota.

Alternative treatment systems, such as wetlands, need to be characterized for their efficacy at removing nutrients, PPCPs contaminants in a rural, prairie context. A preliminary work on "constructed wetland" has been established at Bukit Puteri, UKM in Selangor state of Malaysia to quantify the concentrations of pharmaceuticals in domestic wastewater lagoon effluent, but the effectiveness of wetland treatment in this region is currently

unknown. This paper aims to compile some information about reed bed constructed wetlands performance to remove the micropollutants compounds, sources, effects and their treatment. It also reviews deeply about phytoremediation technology and to evaluate the effectiveness of treatment wetlands in removal of these contaminants. It was hypothesized that the use of a treatment wetland would enhance degradation and elimination of these target compounds, and therefore, could be an option to complement the current lagoon wastewater treatment system in communities that rely solely on lagoon treatment.

2. Emergence of micropollutants in the environment

Over the past few years, many persistent organic pollutants or trace xenobiotic, such as pharmaceutical, pesticides, and personal care products, have been found frequently in the wastewater effluents, surface waters, drinking waters, ocean water and sediments and soil around the world (Ikehata et al., 2008; Klavarioti et al., 2009). It has been extensively reported that the micropollutants are present in the water environment in Asia (Kim et al., 2009; Lin et al., 2010; Nakada et al., 2007; Zhou et al., 2010) Europe (Andreozzi et al., 2003; Ashton et al., 2004; Belfroide et al. 1999; Carballa et al., 2004; Lindberg et al., 2005; Ternes, 1998), and North and south America (Benotti et al., 2009; Boyd, 2003; Ternes et al., 1999). The concentration of these organic compounds usually varies from ng/L to µg/L.

2.1. Types of compounds

Figure 1 classifies the categories of micropollutants. Micropollutants can be from PPCPs, detergents, toiletries and pesticides. The most representative pharmaceutical compounds detected in urban wastewaters are antibiotics, lipid regulators, anti-inflammatories, antiepileptics, tranquilizers, anti-depressants and X-ray contrast media. Common reported hormones are the natural estrogens, estrone and 17b-estradiol, as well as the contraceptive 17a-ethinylestradiol. Among cosmetic ingredients, the polycyclic musk fragrances, galaxolide, tonalide and celestolide, are ubiquitous. Different abbreviations are used to quote all or part of these compounds, such as PPCPs or pharmaceutically active compounds (PhACs), respectively, and some of them can exert endocrine disrupting effects.

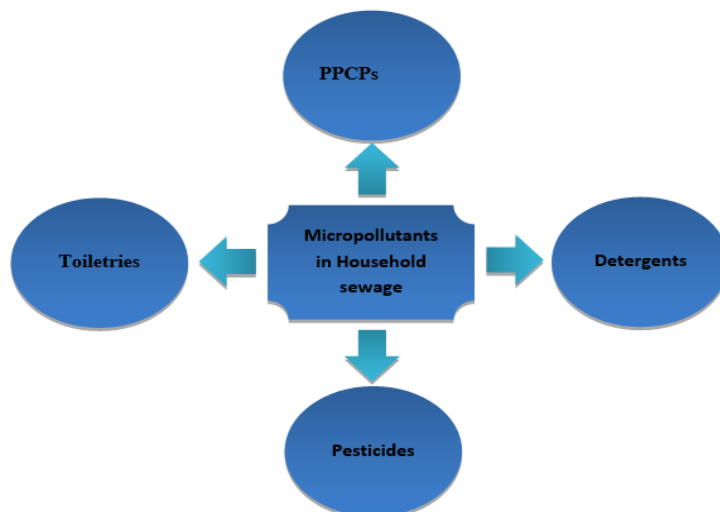


Figure 1. Micropollutants that charging from Household sewage.

2.2. Toxicity effect of micropollutants on organisms and environment

The release of micropollutants in to the environment may impose toxicity on any level of the biological hierarchy, namely cells, organs, organisms, population, ecosystems (Klavarioti et al., 2009). The possible adverse chronic effects of pesticides are not only carcinogenic and neurotoxic, but also effects on reproduction and cell development, particularly in the early stages of life (Burrows et al., 2002). Pharmaceuticals have a physiological effect on humans and animals at trace concentration. For many compounds and their metabolites, previous studies have tested, the occurrence of pharmaceuticals in Finnish sewage treatment plants and surface waters (Vieno, 2007) and the potential risks of pharmaceuticals in fertilizer use in agriculture (Winker, 2009). Pharmaceutical compounds are knowingly designed to affect biochemical and physiological functions of biological systems in humans. Nonetheless, they can also elicit biochemical and physiological changes in soil, plants and aquatic organisms. Most of the pharmaceuticals humans consumed are excreted via urine (partly via faeces) as unchanged parent compound or as metabolites (Jjemba, 2006; Jones et al., 2007; Kümmerer, 2009).

Pharmaceutical residues of medicines and hormonal compounds may be excreted through human urine and therefore, usage of urine is associated with risk of transfer of pharmaceutical residues to agricultural fields (Winker et al., 2010). Currently, there are no

specific threshold values available for micropollutants in fertilizers (Pronk et al., 2006), but still the introduction of potential hazardous substances into the environment should be avoided. One obstacle for fertilizer use of source separated urine is that there is not enough knowledge about the disadvantageous actions these compounds may elicit in crop plants.

3. Current treatment technology for micropollutants contamination

3.1. Conventional Technology

In addition to phytotechnology wetland process, other processes are also suitable in principle for removal of micropollutants. Among others include adsorption using granulated activated carbon, retention by selective membranes (nanofiltration, reverse osmosis) (Ikehata et al., 2006), substance oxidation with OH radicals (Advanced Oxidation Processes – AOP) (Ijpelaar et al., 2010), PAC and ozonation adsorption and the use of ferrate. These processes are not yet suitable for large scale use in municipal WWTP for various reasons such as lack of industrial scale experience, technical problems or poor economics.

3.2. Green Technology

Green technologies are natural, environmentally friendly, and less intrusive. Phytotechnologies create sustainable green space and can also provide visual screening, reduce noise, and require less intense human interaction to install and operate in the long term. Furthermore, phytotechnologies also create a barrier to odors, noise, and dust generated from other site activities as well. Therefore, the public perception of phytotechnologies can be quite favorable. However, a perception could be that phytotechnologies are merely beautification and not cleanup, particularly since phytotechnologies can take longer than other alternatives to meet objectives (ITRC 2009).

4. Phytotechnology as a potential remediation of micropollutants

Only in the last few years, the importance of wetland systems been elevated for their potential to effectively treat a variety of wastewaters. This elevation has led to numerous communities worldwide to either restore previous wetland areas or create constructed wetlands. This method has the advantage of lower costs and a high acceptance in the population, but the required space is

substantial. Therefore, this method is not applicable everywhere. Further investigations are required to investigate the mechanisms and a monitoring of the effluent concentration (Schröder et al, 2007). The removal efficiency of micropollutants (pharmaceuticals, fragrances, herbicides, veterinary drugs) were investigated depending on the season (sunlight for the photodegradation, temperature for microbial degradation) and the compound-structure, the removal rates were over 95% (ibuprofen, ketoprofen) and lower than 50% (clofibric acid, carbamenzene, flunixin, tertbutylazine) (Matamoros et al., 2008). This treatment ecosystem needs a lot of space and sunlight as well. However, this approach will be as an alternative to countries like Malaysia that has less an economic support and more sunlight.

4.1. Treatment Wetlands

4.1.1. Natural Wetlands

Natural wetlands ecosystems, which occur at the interface between land and water, have for many years been utilized for cleaning up polluted waters. As the benefit of natural wetlands remediation potential became known, engineers and scientists began directing more waste and sewage effluents to these areas.

4.1.2. Constructed wetlands

Constructed wetlands (CWs) are “engineered systems, designed and constructed to utilise the natural functions of wetland vegetation, soils and their microbial populations to treat contaminants in surface water, groundwater or waste streams” (ITRC, 2003). CWs can be used as part of decentralized wastewater treatment systems and are a robust and “low tech” technology with low operational requirements. They can be used for the treatment of various types of wastewaters, and play an important role in many ecological sanitation concepts. The number of CWs in use has very much increased in the past few years. The use of constructed wetlands in the United States, New Zealand and Australia is gaining rapid interest (Sim, 2003). Most of these systems cater for tertiary treatment from towns and cities. However, in European countries, these constructed wetland treatment systems are usually used to provide secondary treatment of domestic sewage for rural populations. These constructed wetland systems have been seen as an economically attractive, energy-efficient way of providing high standards of wastewater treatment. Table 1, presents the mean

pharmaceutical removal efficiencies (%) in the wetland treatment systems studied and comparisons with other conventional studies of WWTP.

In terms of concentrations, PPCPs were in the ng L^{-1} instead of mg L^{-1} for pesticides. Low PPCP concentrations are typical of a WWTP effluent (Ternes et al., 2004a) but high pesticide concentrations are expected due to the inadequate treatment of these compounds by WWTPs (Reemtsma and Jekel, 2006). In addition, the widely used PPCP compounds with high removal rates in WWTPs (i.e. ibuprofen, methyl dihydrojamonate) occur at low concentration levels in the WWTP effluent while the less used and more recalcitrant compounds are prevalent (i.e. ketoprofen, diclofenac and carbamazepine). Furthermore, the prevalence of aerobic conditions in the wetland promotes biochemical pathways, such as aerobic respiration, that are more efficient in removing most emerging pollutants than anaerobic pathways (Zwiener and Frimmel, 2003; Yu et al., 2006). In addition, when this tertiary treatment is compared with advanced oxidation treatments like ozonation (Zwiener and Frimmel, 2000) or membrane bioreactors (MBR) (Kimura et al., 2005), the PPCP removal efficiency is similar. Furthermore, it has the advantage of low operational and maintenance costs, no external energy requirement and landscape integration.

Until now, research on the behavior of organic micropollutants in wetlands has been limited. Based on previous research in other areas, the removal mechanisms of organic micropollutants in wetlands may be abiotic, such as by adsorption onto soils and phytoremediation, or even microbiological degradation under anoxic conditions (Chisaka and Kearney, 1970; Englehardt et al., 1973; Mohn and Tiedje, 1992; Schwarzenbach et al., 2003). This publication deals only with Reed Bed Constructed Wetlands (RBCWs) with a substrate of coarse sand for treatment of domestic wastewater in developing countries and countries in transition. RBCWs are reliable treatment systems with very high treatment efficiencies for the removal of organic matter and pathogens. Constructed wetlands can be considered as a secondary treatment step since suspended solids, larger particles including toilet paper and other rubbish as well as some organic matter need to be removed before wastewater can be treated in subsurface flow CWs. Pre-treatment is extremely important to avoid clogging of subsurface

flow CWs, which is an obstruction of the free pore spaces due to accumulation of solids.

Table 1. Mean Pharmaceutical Removal Efficiencies (%) in The Wetland Treatment Systems Studied and Comparisons with other Conventional Studies of WWTP.

Micropollutant compounds	SFCWs %	HFCWs %	VFCWs %	WWTP %
Ibuprofen	98 ^a ; 96 ± 2 ^d ; No. R ^k	71 ^b ; 17.7 ^k	98 ^a	92.6 ^c ; 99 ^e ; 92±8 ⁱ ; No. R ^d ; 5.6 ^f ; 40±15 ^l ; 90 ^c ; 60-70 ^d
Diclofenac	76±7 ^a ; 85±16 ^d ; 5.49 ^k	15 ^a ; 30.2 ^k	73±3 ^a	17 ^h ; 26±17 ⁱ ; 99 ^d ; 15.2 ^f ; 17 ^b
Ketoprofen	98±1 ^d ; 35.9 ^k	No. R ^k	No. R ^a	48-69 ^m ; 51-100 ⁱ ; 60±18 ^l ; 73.8 ^c ; 23.3 ^h ; 20.5 ^c
Carbamazepine	76±7 ^a ; 39±12 ^d ; No. R ^k	16 ^a ; No. R ^k	26±14 ^a	26 ^c ; 8 ^h ; 79 ^d ; 12.18 ^f ; 22.3 ^c ; 7 ^m ; 8 ^h ; No. R ^l
caffeine	98±1 ^a ; 25.17 ^k	97 ^a ; 79.5 ^l	99±1 ^a	94 ^r ; >99 ^h
Galaxolide	92±1 ^a ; 87±2 ^d	86 ^a	90±1 ^a	65±15 ^l ; 70-85 ^t ; 89 ^v
Tonalide	82±1 ^a ; 89±1 ^d	88 ^a	82±1 ^a	60±8 ^l ; 75-90 ^t ; 88 ^v
hydrocinnamic acid	98±2 ^a	No. R ^a	99±1 ^a	—
salicylic acid	98±1 ^a ; 31.6 ^k	96 ^a ; 31.9 ^k	98±1 ^a	88.2 ^h ; 70-85 ^t ; 89 ^e

Removal values observed from other studies for surface flow constructed wetlands (SFCWs), horizontal subsurface flow constructed wetlands (HFCW), vertical flow constructed wetlands (VFCWs), and conventional WWTP are shown for comparison.

4.2. Engineered design of constructed wetland

Constructed wetlands or reed beds are flexible systems which can be used for single households or for entire communities. Also, due to climate change, more and more regions are experiencing droughts or flooding. Hence, water recycling as well as resilient technologies are key aspects to adapt to these effects of climate change.

Experimental studies conducted by Matamoros et al. (2008) and Zwiener and Frimmel (2003) showed that aerobic conditions are in general more efficient in removing most emerging contaminants than anaerobic pathways. In addition, the photodegradation processes which take place in surface flow systems are able to eliminate certain PPCPs (like ketoprofene and diclofenac) from aquatic environments (Andreozzi et al., 2003; Bartels and von

Tumpling, 2008; Zhou et al., 2009). High hydraulic retention times promote biodegradation and photodegradation reactions involved in the removal of emerging contaminants.

In this study, a reed bed system (Figure 2) with tanks filled with coarse gravel substrate to a depth of 40cm, and the water level kept 10 cm below the surface of the substrate, and the total water depth will be 30cm. All the reed bed tanks will be planted with native plants of Malaysia "Scripus grossus" (figure 3) locally known as rumput menderong, and operated at different arrangements so as to allow the experiments to be carried out at different levels and process (batchwise and continues, subsurface and free flow) to compare the treatment performance and to evaluate the feasibility of using this technology to reduce of micropollutants from domestic wastewater. Also, a recirculation system is installed to enable diffusion of oxygen from the air to maintain aerobic conditions to enhance pollutants microorganisms' interaction.



Figure 2. Constructed wetland pilot-scale system in Bukit Putri (UKM)



Figure 3. Native plants of rumput menderong (*Scirpus grossus*)

The pilot-scale treatment wetland of reed bed system (Figure 4) consisting of four lines where each line has three identical beds that are made of fiberglass tanks, 100 cm W x 200 cm L x 100 cm D with PVC pipe. A tap located on the side of each tank for sampling test. Gravels of different sizes were used as the media in the system with an alternative arrangement of 10-15 mm, 3-5 mm (river sand) and 30-35 mm, respectively from the top (Jehawi, O.M. et al, 2014, 2015, 2019). The conventional method is to form multiple layers in the reed beds.

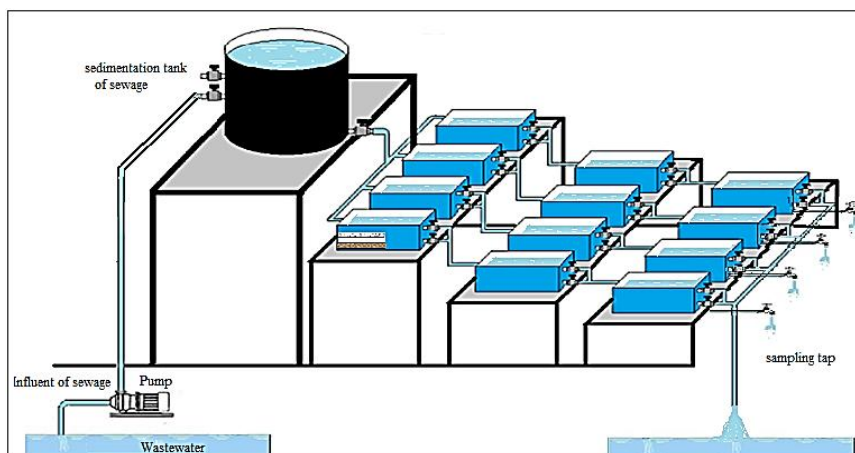


Figure 4. The schematic illustration of pilot-scale system in Bukit Puteri in Universiti Kebangsaan Malaysia (UKM)

Channeling the domestic wastewater generated by more than 110 households from Bukit Puteri in UKM, like toilets, bathrooms and kitchens into a sedimentation tank, a pump is installed to pump the

wastewater from the intermediate level of the sedimentation tank into the designated reed beds for treatment to avoid the presence of sludge.

4.3. Classification of reed bed constructed wetlands (RBCWs)

Constructed Reed Bed wetlands are classified according to the water flow regime (Figure 5) into either surface flow (SF) or subsurface flow (SSF) CWs, and according to the type of macrophyte plant as well as flow direction. Constructed wetlands used macrophyte plants which are aquatic plants that grow in or near water. However, the main benefits of horizontal and vertical subsurface flow systems are the existence of aerobic, anaerobic and anoxic conditions in proximity to the plant rhizomes which provide an opportunity to reduce concentrations of different drug compounds, as some pharmaceuticals are best reduced under aerobic conditions (ibuprofen), removal of others is favoured by anaerobic conditions (clofibric acid, diclofenac) (Lin and Reinhard, 2005) and halogenated pollutants are eliminated at a higher rate in anoxic conditions.

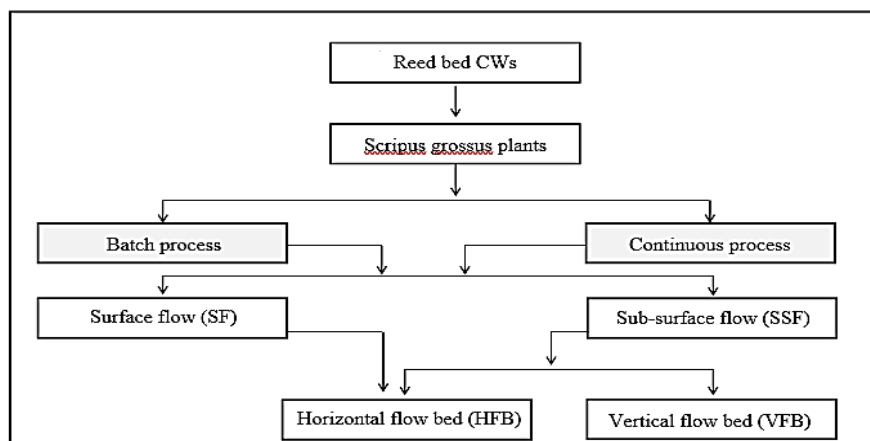


Figure 5. Classification of constructed wetlands (modified from Vymazal and Kroepfelová, 2008).

Subsurface flow CWs are designed to keep the water level totally below the surface of the filter bed. They can even be walked on and this arrangement can avoid the mosquito problems of FWS CWs. Different types of constructed wetlands may be combined with each other to form hybrid systems in order to exploit the specific advantages of the different systems. The coarse sand used in

subsurface flow CWs contributes to the treatment processes by providing a surface for microbial growth and by supporting adsorption and filtration processes. Gravel bed systems are widely used in Asia, North Africa, South Africa, Australia and New Zealand. The sand bed systems have their origin in Europe and are now used all over the world.

4.4. Types and wise use of constructed wetland treatment systems

Constructed wetland systems are classified into two general types: the Horizontal Flow System (HFS) and Vertical Flow System (VFS). HFS has two general types: Surface Flow (SF) and Sub-Surface Flow (SSF) systems.

4.4.1. Surface Flow (SF) - The use of SF systems is extensive in North America. These systems are used mainly for municipal wastewater treatment with large wastewater flows for nutrient polishing. The SF system tends to be rather large in size with only a few smaller systems in use. The majority of constructed wetland treatment systems are Surface-Flow or Free-Water surface (SF) systems (Figure 6). These types utilize influent waters that flow across a basin or a channel that supports a variety of vegetation, and water is visible at a relatively shallow depth above the surface of the substrate materials (Ismail, N.I. et al., 2019, 2020). Substrates are generally native soils and clay or impervious geotechnical materials that prevent seepage (Reed, et al., 1995). Inlet devices are installed to maximize sheet flow of wastewater through the wetland, to the outflow channel. Typically, bed depth is about 40 cm.

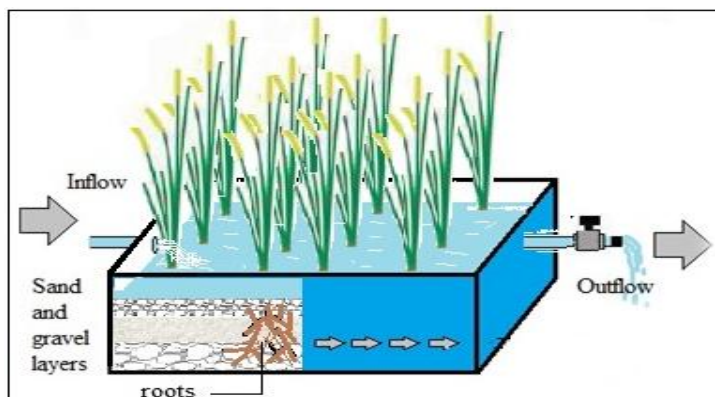


Figure 6. Typical configuration of a surface flow wetland system (Kadlec and Knight 1996)

4.4.2. Sub-surface Flow (SSF) system -The SSF system includes soil-based technology which is predominantly used in Northern Europe and the vegetated gravel beds are found in Asia, Europe, Australia, South Africa and almost all over the world.

In a vegetated Sub-surface Flow (SSF) system, (see Figure (6)) water flows from one end to the other end through permeable substrates which is made of mixture of soil and gravel or crusher rock. The substrate will support the growth of rooted emergent vegetation (Al-Sbani, N. H. et al, 2016). It is also called “Root-Zone Method” or “Rock-Reed-Filter” or “Emergent Vegetation Bed System”. The media depth is about 0.4 m deep and Media size for most gravel substrate ranged from 5 to 230 mm with 13 to 76 mm being typical. Wastewater flows by gravity horizontally through the root zone of the vegetation about 100-150 mm below the gravel surface. Many macro and micro-organisms inhabit the substrates (Sim, 2003). Free water is not available.

4.4.2.1. Horizontal flow beds (HFBs) - As the initial designs of subsurface flow CWs were for HFBs, these are still the most common type of subsurface flow CW. HFBs are an interesting option especially in locations without energy supply and low hydraulic gradient. In HFBs the wastewater flows slowly through the porous medium under the surface of the bed in a horizontal path until it reaches the outlet zone (see Figure 7). At the outlet the water level in the HFB is controlled with an adjustable standpipe. For continuous operation the submerged height of the bed should be less than one third of the total height of the filter bed to avoid anaerobic conditions in the bed. Oxygen supply plays an important role for the efficiency of the treatment process.

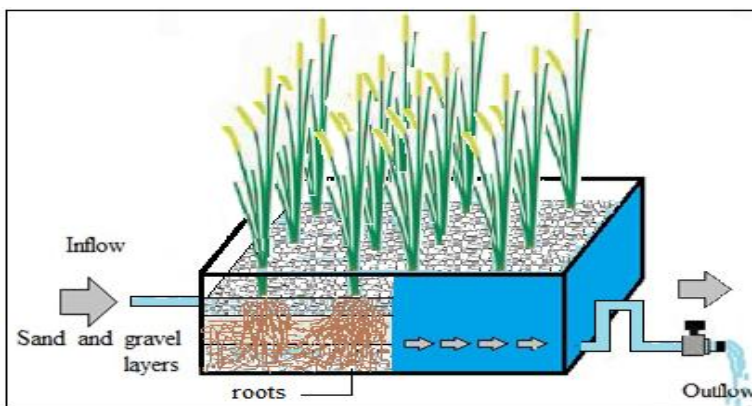


Figure 7. Schematic cross-section of HFBs (source: Morel et al, 2006).

4.4.2.2. Vertical flow beds (VFBs) - VFBs are more suitable than HFBs when there is a space constraint as they have higher treatment efficiency and therefore need less space.

In VFBs wastewater is intermittently pumped onto the surface and then drains vertically down through the filter layer towards a drainage system at the bottom (see Figure 8). The treatment process is characterized by intermittent short-term loading intervals and long resting periods during which the wastewater percolates through the unsaturated substrate, and the surface dries out. The intermittent batch loading enhances the oxygen transfer and leads to high aerobic degradation activities.

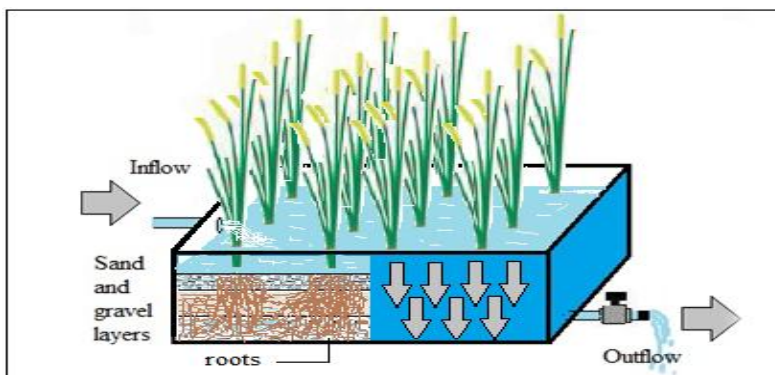


Figure 8. Schematic cross-section of a vertical flow system VFB (source: Morel and Diener, 2006)

4.5. Advantages and limitations of Phytotechnology

Figure 9 summarizes the advantages and limitations of phytotechnology. Among the advantages, it is environmental friendly with low emissions of odour, dust and other wastes making phytotechnology a safe treatment. It also provides aesthetics, supports wild life habitat and increase biodiversity (Al-Sbani, N. H. et al, 2015). Phytotechnology can be a potential resource recovery from the harvested plants for their energy, essential oils, compost and fiber for handcrafts. Apart from that, it is cost effective and takes advantage of natural processes, and thus lowers labor, equipment, and operational expenses. Runoff and soil erosion can be controlled through phytotechnology. In most cases, it can be used in conjunction with other remediation methods as a polishing unit in wastewater treatment and may be more beneficial than a stand-alone technology. With this technology, fewer health risks for workers since it is dealing with natural habitat and highly public

accepted (Baker et al., 1994; Salt et al., 1998; Garbisu and Alkorta, 2001).

Despite the advantages, phytotechnology requires a relatively large area if it were to be implemented with some requirement on plant maintenance for cutting and harvesting. Lengthy time required for remediation to occur since it depends on plant growth. Moreover, the remediation is based on contaminant contact with plant roots and clean-up occurs only surrounding the roots zone. Plants are selective since they need to be tolerant of contaminants. The technology is highly dependent on local climate conditions, planting space and seasonal nature of plants. There is possibility of transmittance of contaminants to surrounding creatures.

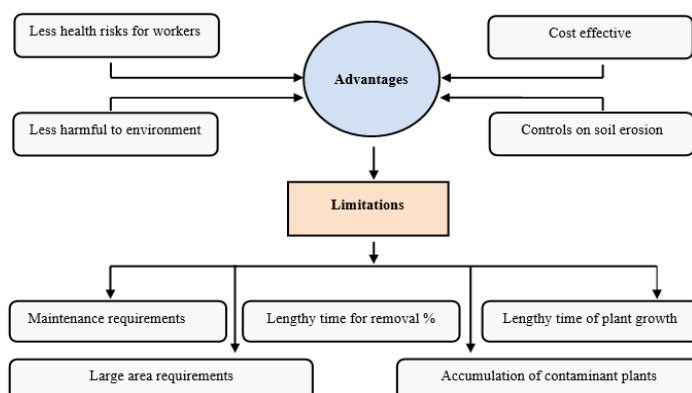


Figure 9. Advantages and limitation of phytotechnology

5. Plants of wetland

Wetland plants themselves are very unique in terms of their ability to survive both submerged and drought conditions. Wetland plants for phytoremediation have unique attributes allowing uptake and storage or degradation of targeted contaminants. The uptake of chemicals into plants through roots depends on the plant's uptake efficiency, the source concentration, and the transpiration rate.

The uptake efficiency factor, defined as the transpiration stream concentration factor (TSCF) by Dietz (2001), is the ratio of contaminant concentration in the transpiration stream to that in the soil water. The chemical uptake rate (mg day^{-1}) is calculated from the product of the uptake efficiency (TSCF - dimensionless) times the transpiration rate (L Day^{-1}) times the soil water concentration of the chemical (mg day^{-1}) (Dietz and Schnoor, 2001). The TSCF depends on physico-chemical properties, chemical speciation, and specific plant properties (Dietz and Schnoor, 2001). Transpiration

rate is a key variable in the selection of plants for phytoremediation applications. Transpiration rate is dependent on plant type, leaf area, nutrients, soil moisture, temperature, wind condition and relative humidity. Plants with high transpiration rate (rapid uptake) such as fast growing phreatophytes with large leaf area are often selected (Dietz and Schnoor, 2001).

The Common Reed (*Phragmites* spp.) and Cattail (*Typha* spp.) are good examples of emergent species used in constructed wetland treatment systems (Ismail, N.I. et al., 2015, 2017). Plant selection is quite similar for SF and SSF constructed wetlands. Emergent wetland plants grow best in both systems. These emergent plants play a vital role in the removal and retention of nutrients in a constructed wetland. There is a variety of marsh vegetation that is suitable for planting in a CWTS (Table 1). These marsh species could be divided into deep and shallow marshes.

Table 2. List of Emergent Wetland Plants Used in Constructed Wetland Treatment Systems (Lim et al., 1998)

Planting zones	Scientific name	Common name
Shallow marsh (0-0.3 m)	<i>Fimbristylis globulosa</i>	<i>Globular Fimbristylis</i>
	<i>Polygonum barbatum</i>	<i>Knot Grass</i>
	<i>Scleria sumatrana</i>	<i>Sumatran Scleria</i>
	<i>Eleocharis variegata</i>	<i>Spike Rush</i>
	<i>Erioucaulon longifolium</i>	<i>Asiatic Pipewort</i>
	<i>Rhynchospora corymbosa</i>	<i>Golden Beak Sedge</i>
Marsh and deep marsh (0.3-1.0 m)	<i>Eleocharis dulcis</i>	<i>Spike Rush</i>
	<i>Phragmites karka</i>	<i>Spike Rush</i>
	<i>Scirpus mucronatus</i>	<i>Bog Bulrush</i>
	<i>Scirpus grossus</i>	<i>Greater Club Rush</i>
	<i>Phylidrium lanuginosum</i>	<i>Fan Grass</i>
	<i>Lepironia articulata</i>	<i>Tube Sedge</i>
	<i>Typha angustifolia</i>	<i>Cattail</i>

6. Conclusions

The use of constructed wetlands to treat micropollutants from domestic wastewater is relatively new in Malaysia. However, the impressive results achieved thus so far by other researchers have prompted great expectations about the technology and what it can

achieve. This paper describes the current state of the wetland on additional technical processes for removal of micropollutants from domestic wastewater. Treatment wetlands offer a potential option for cost effective removal of micropollutants from domestic wastewater. Reed bed CWs can be used as a secondary treatment step, this system tends to be less resource intensive than conventional wastewater treatment plants and have been used successfully for treatment of municipal sewage in small communities. However, removal efficiency in wetlands is affected by a number of factors, including age of the wetland, seasonality, and presence or absence of plants.

In the expect results of this review article that clearly demonstrate of recent studies of wetland has a good capacity for removing a variety of emerging contaminants close to the ones obtained in high-cost tertiary treatments (conventional treatments). Therefore, the application of cost-effective technologies such as constructed wetlands should be considered as an efficient alternative summary, for reducing the amount of emerging contaminants discharged into aquatic ecosystems.

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