Phytotechnology, a Nature-Based Approach for Sustainable Water Sanitation and Conservation

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Abstract
Developing countries in Asia are threatened by environmental pollution due to the lack of waste treatment facilities. Most wastewater treatment technologies are known as being costly and not affordable by the municipalities and the small scale polluting industries. When land is available, phytotechnology is a promising and cost effective approach for domestic and industrial wastewater treatment. In addition, phytotechnology can be potentially used for rehabilitating degraded environment. This paper briefly discusses about the applications, ideas, and future perspectives of phytotechnology as an appropriate tools in promoting sustainable water sanitation and conservation in Asian countries.

Keywords: phytotechnology, application, advantages

Introduction
The tropical region in Asia is mostly occupied by low to middle income countries, with rapid industrial and urban development. As a consequence, environmental pollution has often occured due to insufficient control technology. For example, Indonesia should face severe environmental pollution, particularly in Java, Sumatera, Kalimantan, Sulawesi, Lombok, and Papua, where urban, industrial and mining wastes are not treated sufficiently. The nation wide Clean River Program (PROKASIH), which was implemented by the Environmental Impact Management Agency (BAPEDAL) during the 1990s (Trihadiningrum, Verheyen and De Pauw, 1997), did not show significant surface water quality improvement.

In addition to the above information, Malaysia has faced rapid urbanization and industrial developments since 1991. The inland water is polluted due to point sources and non-point sources of pollution. Point sources that have been identified include sewage treatment plants, manufacturing and agro-based industries and animal farms. Non-point sources are mainly diffused ones such as agricultural activities and surface runoffs. The storm water was also believed to contribute significant amount of nutrients, heavy metals, oil and grease to the surface water.

Tropical region is characterized by whole year solar energy resource, which can be transformed to biomass through efficient plant metabolism. This condition is beneficial for supporting plant based wastewater treatment technology, which is known as cost effective and publicly accepted. In the US such a technology is widely applied as an acceptable clean-up technology for polluted sites.

The term phytotechnology describes the application of science and engineering to examine environmental problems and provide solutions involving plants. This term promotes a broader understanding of the importance of plants and their beneficial role within both societal and natural systems. A central component of phytotechnological concept is the use of plants as *living technology* that provides services in solving environmental problems. The term phytoremediation is used to describe the plants processes in absorption, extraction, conversion and releasing for contaminants from one medium to another (Mangkoedihardjo, 2007).

Phytotechnology has been introduced and developed for the treatment of urban runoff, domestic and industrial wastewater, and remediation of polluted soil since the last three decades. Constructed wetlands and phytoremediation are examples of the most commonly applied technologies for removal of pollutants in water and soil. Phytotechnology is not only known as cost effective means for water quality improvement and stormwater control, but also provides aesthetics and wild life habitat (USEPA, 1993).

This paper briefly discusses about the applications, research experience in persistent pollutant removal, ideas, and future perspectives of phytotechnology as appropriate natural tools in promoting sustainable water sanitation and conservation.

Mechanisms, advantages and disadvantages of phytotechnology

In phytotechnology, the plants act as solar-powered pump-and treat systems as they take up water soluble contaminants through their roots, and transport them through various plant tissues, where they can be metabolized or volatilized (Doty *et al.*, 2007). Former researchers have identified various tolerant plants which are able to significantly reduce organic and inorganic pollutants in the waste water and in the polluted soils and surface waters. According to Kramer (2005) and Doty *et al. (*2007), there are several mechanisms of water and soil environment improvement using phytotechnology:

- Phytostabilization: a mechanism which is used more to providing a vegetation cover for heavily contaminated soils, thus preventing wind and water erosion. Plants suitable for phytostabilization develop an extensive root system, provide soil cover, possess tolerance to contaminants, and ideally immobillize the contaminants in the root system
- Phytoextraction: a mechanism, where pollutant tolerant plants concentrate and accumulate soil or water contaminants in their tissues. At the end of the growth period, the contaminant enriched plants are generally harvested and dumped; or dried and incinerated. Heat from the incineration is used for energy generation
- Phytovolatilisation: a mechanisms, where plants transport soluble pollutants to the above ground tissues and volatilize it to the atmosphere.
- Phytodegradation: a mechanism where plants, associated with aquatic or soil microorganisms, biodegrade organic pollutants

Phytotechnology is an accepted method for water and soil sanitation and conservation for it's various advantages, such as:

- It is an environmentally friendly technology**.** The lower air, odour, and dust emissions and other wastes makes phytotechnology a safe treatment
- It provides aesthetics and supports wild life habitat
- It is a potential for resource recovery from dun of ctithe harvested plants, for the proenergy, essential oils, compost, fiber for handcrafts.

- It is a cost effective technology. As a solar-driven system, phytotechnology takes advantage of natural processes, and thus lowers labor, equipment, and operational expenses. Table 1 shows the comparison of phytoremediation costs of polluted soils.
- It controls runoff and soil erosion.
- It can be used in conjunction with other remediation methods and may be more beneficial than a stand-alone technology.
- Other benefits of phytotechnology are: it controls fugitive dust emissions, reduces noise, causes fewer health risks for workers, and is accepted by public.

Table 1. Comparison of costs of different phytoremediation techniques for contaminated soil treatment (Kreuzig, 2005).

Remediation measure	**Costs (US$ / tonne)**	**Additional measures**
Thermal processes	75 - 425	Recultivation and monitoring
Excavation and disposal	100 - 500	transport, land filling, and monitoring
Chemical processes	100 - 500	recycling of used chemicals, monitoring
Phytoremediation	5 - 40	biogas production and disposal of biomass wastes, and monitoring

However, there are several limitations of this technology, which include:

- It requires a relatively large area
- The plants require maintenance, such as cutting and harvesting
- The remediation is based on contaminant contact with plant roots and the pollutant clean-up occurs in the roots zone.
- It needs a lengthy time for pollutant removal, and the time for plant growth can slow down the process.
- The technology is affected by phytotoxicity. The plants have particular tolerance levels to the contaminants.

Applications of phytotechnology

Phytotechnology has been applied for stormwater remediation in Putrajaya, Malaysia’s new Federal Government Administrative Centre. Central to this city is the 400 hectare man-made lake created by damming of Chua and Bisa rivers. The Putrajaya Wetland was constructed in 1997-1998. Construction and operation of the wetland is aimed to create a self-sustaining and balanced lake ecosystem and to ensure the lake’s water quality complies with standard set by Putrajaya Authority and suitable for body contact recreational activities. The wetlands are strategically located to act as buffer to the Putrajaya Lake which drains a catchment area of 50.9 km^2. Involving an area of 197 hectares and 12.3 million wetland plants, this wetland is one of the largest fully constructed freshwater wetlands in the tropics (Huat, 2002).

When land is available, application of phytotechnology is also considered to be appropriate for treating small scale pollutant sources. For example, domestic wastewater, where sewage treatment facility does not exist, can be treated using phytotechnology. This technology is also appropriate for treating industrial wastewater, which contains biodegradable organics, such as slaughter house, seafood, and tofu and sugar manufacturing industries (*e.g.* Sohsalam and Sirianuntapiboon, 2008; Sari, 1999).

The tropical Asian countries are famous for their traditional *batik* and waven cloth. Unfortunately, these products, in Indonesia in particular, are mostly manufactured in home scale industries, where wastewater treatment facility is not provided. As a consequence, coloured waste water with high COD and suspended solids levels is discharged directly into the environment with very limited treatment. The following discussion is focused on a successful wetland technology application for domestic wastewater treatment in Indonesia, and present research work on the use of plants for the treatment of waste water from a small scale yarn dyeing industry.

Wetland technology for domestic wastewater treatment

Domestic waste water from a community in Tlogo Mas Village, which is located in Malang town, East Java Province, Indonesia, was successfully treated using vertical flow subsurface system (SSF) constructed wetland, which was designed by Mr. Agus Gunarto. One hundred and ten houses have been connected to this wetland facility since 1990. The wetland facility consists of 3 primary reactors (or floating tanks) using water hyacinths (*Eicchornia crassipes*), and 3 secondary reactors (or subsurface tanks) using cattails (*Typha latifolia*) (Figure 1). The wetland facility has a depth of 1,5 m. Daily wastewater intake is 50 m^3, and detention time in each tank is 12 hours. Peak time occurs at 06.00 to 08.00 am, and at 04.00 to 07.00 pm.

This SSF wetland worked with a maximum BOD loading rate of 70 kg/ha.day. A successful vertical flow SSF wetland can remove organic matter, total N, and total P of >96%, 36%, and 63% respectively (Fitriarini, 2002). With an average medium level of Indonesian domestic wastewater characteristic of BOD of 220 mg/L, total N of 40 mg/L, and total P of 8 mg/L (Djajadiningrat, 1992), this wetland system could produce good quality of effluent. The area of the old wetland was planned to be extended to 24 m x 30 m, with the addition of floating and subsurface tanks.

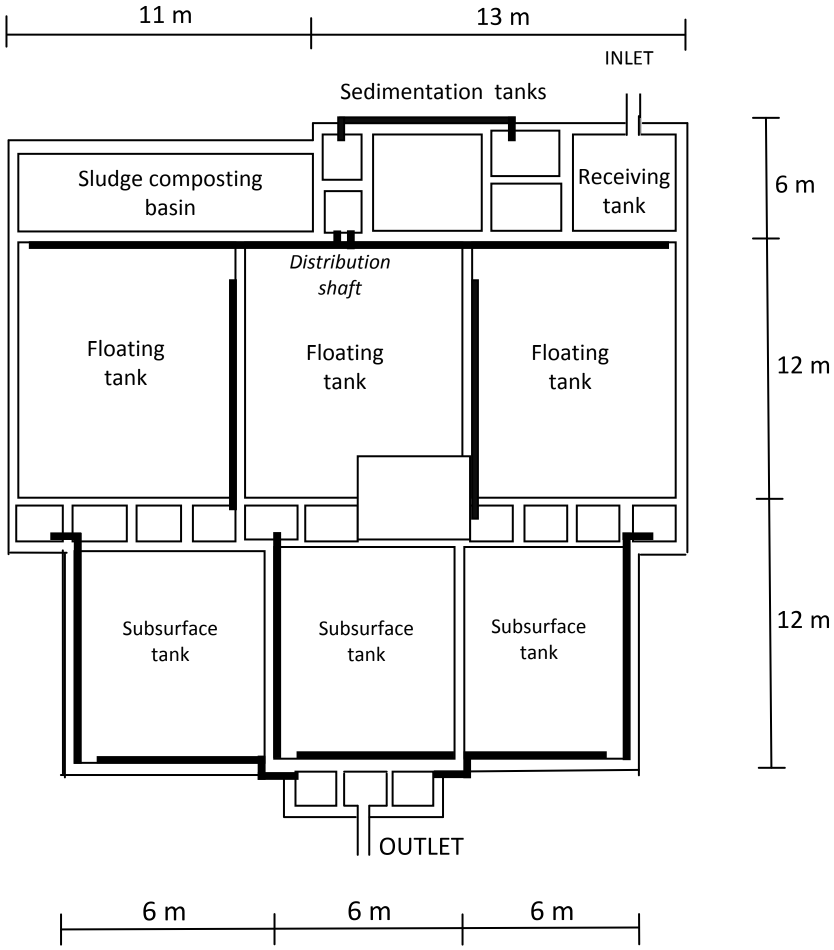

Figure 1. Lay out of wetland SSF system for treating domestic water in Malang City, Indonesia (After Gunarto, 1999; in Fitriani, 2002).

Study on wetland technology for treating waste water from yarn dyeing industry

Batch bioreactors were prepared in a green house for testing the potential of water lettuce, water hyacinth and *Canna sp* in removing persistent pollutants of the yarn dyeing wastewater, collected from Sidoarjo town, East Java Province, Indonesia. The wastewater had black colour and high pH, COD, and total suspended solid (TSS) values (Table 2), which exceed the quality standards. This waste water is usually discharged to the surface water without any treatment. The Range Finding Tests for determining the plant tolerance to the wastewater, resulted in much low levels of COD, BOD, and TSS levels, in which the plants could grow satisfactorily (Table 2).

Table 2. Yarn dyeing wastewater charateristics and the tolerable pollutant levels for water lettuce, water hyacinth and *Canna sp.*

No.	Characteristics	Waste water	Wastewater characteristic which is suitable for the plant growth
1.	Colour	Black	Black
2.	pH	11,58	9,5
3.	COD (mg/L)	26.800	400
4.	BOD (mg/L)	10.720	160
5.	TSS (mg/L)	24.216	464

Application of the three plant species in the batch reactors within 30 day detention time showed significant removal efficiencies of organic matter and TSS, with the highest values in *Canna* reactor (Table 3). Yet the effluents did not meet the waste water quality standards. Moreover, none of these plants showed tolerance in the original waste water. Therefore, phytotreatment technology can only be applied in the final or tertiary treatment stage in such a kind of waste water, which contains recalcitrants. Due to the high COD levels, a combined four compartment anaerobic baffled reactor (ABR) and wetland system are thought to be appropriate for treating the waste water, before it enters the plant reactor or wetland (Figure 3). Selection of the ABR system is based on the cost effective and easy operation and maintenance considerations (Bell and Buckley, 2003). This system can be applied as a communal wastewater treatment facility from similar industries.

Table 3. Influent and effluent characteristics and the removal efficiencies of COD, BOD, and TSS in water lettuce, water hyacinth and *Canna* reactors.

No.	Parameter	Influent	Pollutant levels in effluent and removal efficiency			Wastewater quality standards
			Water lettuce	Water hyacinth	*Canna sp*	
1.	Colour	Black	Clear	Clear	Clear	-
2.	pH	9,5	7,2	7,4	7,2	6-9
4.	COD [(mg/L, (%)]	400	200 (50)	216 (46)	120 (70)	100
5.	BOD [(mg/L, (%)]	160	64 (60)	77 (52)	33 (79)	50
6.	TSS [(mg/L, (%)]	464	139 (70)	154 (67)	107 (77)	50

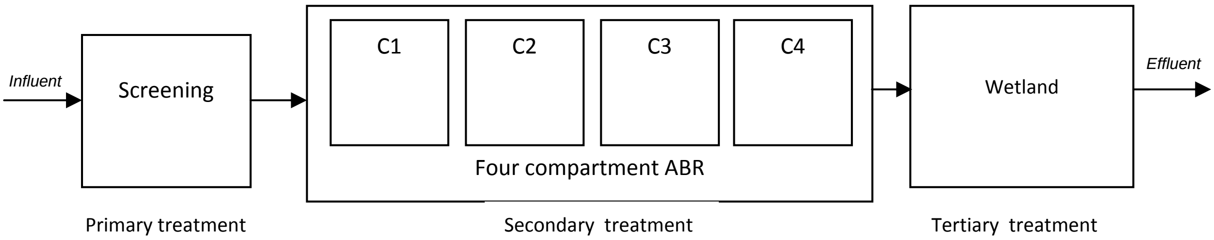

Figure 2. Scheme of ABR and wetland system for treating small scale yarn dyeing waste water.

Former studies showed that the ABR system could remove 70-90% COD, BOD and TSS, and colour removal of 86% (Bell and Buckley, 2003, and Haris, 2007). Using assumed removal efficiencies in the ABR reactors of 70-80%, the combined ABR and wetland system can be expected to produce effluent, which meets the quality standards (Table 4).

Tabel 4. Estimated combined ABR and wetland performance for communal treatment of textile dyeing industries.

Parameter	Influent	Estimated effluent quality in each treatment unit									
		ABR Compartment I		ABR Compartment II		ABR Compartment III		ABR Compartment IV		Wetland	
		Efficiency (%)	Effluent (mg/L)	Efficiency (%)	Effluent (mg/L)	Efficiency (%)	Effluent (mg/L)	Efficiency (%)	Effluent (mg/L)	Efficiency (%)	Effluent (mg/L)
COD	26.800	80	5.360	70	1.608	70	482,40	70	144,72	50	72,36
BOD	10.720	80	2.144	70	643	70	192,96	70	57,89	61	22,61
TSS	24.216	72	6.780	72	1.898	72	531,59	72	148,85	70	44,43

Discussion

The above mentioned case studies show that phytotechnology can be applied for communal treatment of domestic and small scale industrial waste water. However, this technology may be suitable for supporting a secondary treatment facility in the domestic waste water treatment, but is more suitable to be applied as a tertiary treatment facility in the industrial waste water treatment plant. Table 5 summarizes the comparison of the application of phytotechnology in domestic and small scale industrial waste water treatment.

Table 5. Comparison of domestic and small scale industrial wastewater treatment and the possibilities of the application of phytotechnology.

Item	Domestic wastewater treatment	Industrial waste water treatment
Primary treatment	Screening for solid particles removal	
Secondary treatment	Phytotechnology using highly tolerant plants or biological waste water treatment technology	Chemical or anaerobic waste water treatment
Tertiary treatment	Phytotechnology using less tolerant plants	Phytotechnology using highly tolerant plants
Plant tolerance	Considerably high. Low tolerance may appear in concentrated waste water	Generally low, particularly in waste water which contains recalcitrants.
Pollutants which are removed	Organic matter, macro- and micro-nutrients, TSS	Organic matter, heavy metals, TSS, colour.
Harvested biomass	Can be used as raw material for energy and compost production using biological treatment	Energy and compost production using biological treatment requires determination of recalcitrant contents in the biomass

Future perspectives of phytotechnology

As plants have been used as natural cover blanket of the earth, its application is not limited only for remediating polluted water and soils, but also for stabilizing eroded slopes. Studies on the remediation of degraded water, soil, and land using plants (lately known as *bioengineering*) have been extensively implemented and applied. Vetiver grass (*Vetiveria zizanioides,* or *Chrysopogon zizainoides*), a *super-absorbent* and deep rooted perennial grass, could be used for landfill rehabilitation, erosion and leachate control in particular (Truong and Stone 1996). Because of the high tolerance of this grass species to high acidity, alkalinity, heavy metal levels, this grass species is also recommended for the rehabilitation of mining areas (Truong, 1999; Grimshaw). Therefore, phytotechnology is not merely applicable for water sanitation, but can also be also involved more to water conservation.

The harvested plants from the application of phytotechnology, however, needs additional measure in a completed treatment cycle. Particular cultivation treatment, such as cutting and harvesting of the plants are needed for maintaining the pollutant removal efficiency. The plants from nutrient, greywater and blackwater treatment facilities may not pose a problem for disposal. These nutrient accumulating plants may be used for composting and for energy production. In many cases, the harvested plants are dried and incinerated. The heat released from the incineration is used for energy generation. However, plants from remediated sites, which are polluted by hazardous waste, are generally suspected to contain significant amount of hazardous pollutants and need careful disposal measures (Kramer, 2005). Incineration of the plants may be costly, and is believed to become hazardous gas and ash emmission sources. Fermentation technology for biogas production is one of the solutions of these problems. In addition to this bioenergy production alternative, biodiesel can be produced from rich oil seed producing plants (e.g. sunflower and *Jatropha curcas*), when they are used for environmental remediation. A conceptual scheme of energy transformation and phytotechnology is shown in Figure 3.

Future R&D activities in phytoremediation are multidisciplinary, and may involve various expertises, such as environmental engineering, hydrology, environmental chemistry, plant ecology and physiology, microbiology, and molecular biology. Current research activities in western countries are focused on genetically modifed organisms (GMO) for inventing tolerant plant species to particular environmental pollutants with high removal efficiencies. A number of research works are done today to seek bioenergy production feasibilities from the harvested plants.

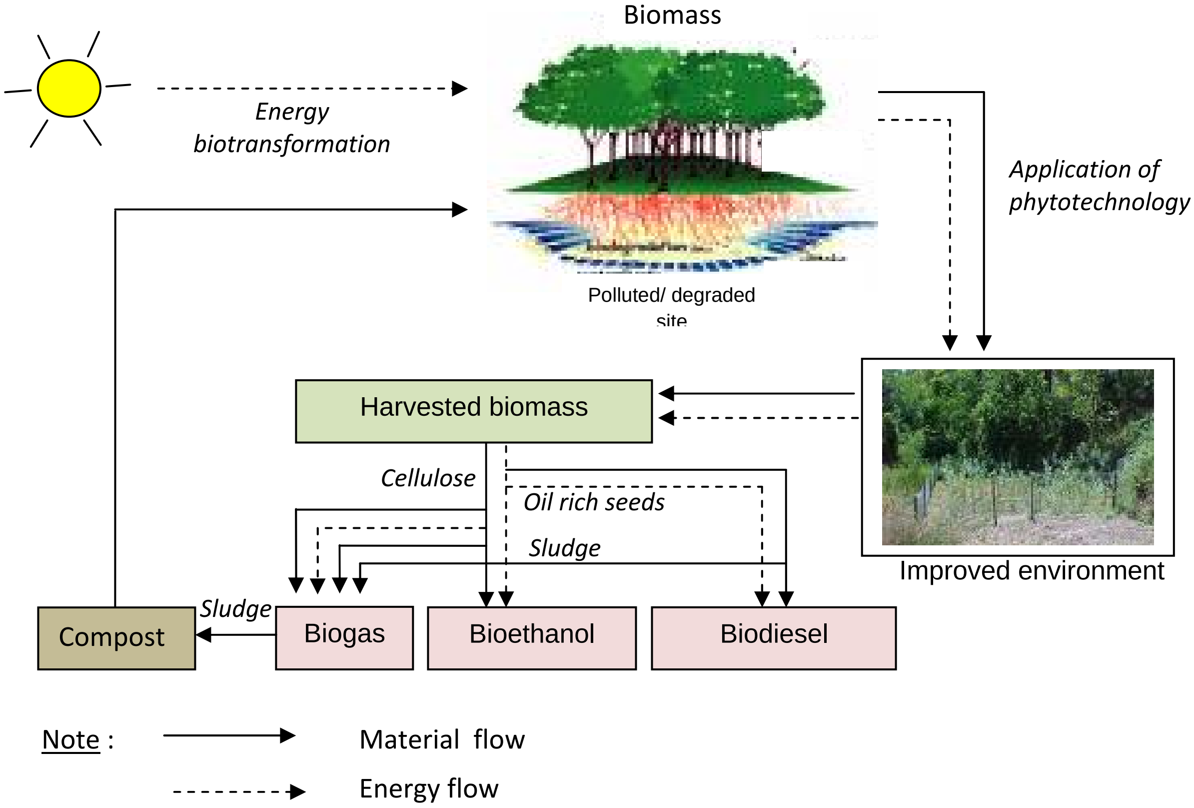

Figure 3. Conceptual scheme of phytotechnology application and energy biotransformation

To end, phytotechnology is a promising, cost effective and environmentally sound technology for water sanitation and conservation. The remarkable capabilities of the plants in water pollutant removal and rehabilitation of degraded environment, together with the biomass and energy recovery potentials, provide a nature-based technology which supports sustainable development program in Asian countries.

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