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Report

Environmental pollution in Malaysia: Are medicinal plants potential phytoremediation agents?

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Abstract: Phytoremediation is a plant-based approach to controlling pollution, an alternative to the conventional physical and chemical remediation techniques. In Malaysia many small-scale studies on phytoremediation have been conducted. However, the establishment of phytoremediation strategy at larger field sites is rather lacking. Depending on plant species and existing environmental factors, bioactive compounds from medicinal plants have the potential for remediating specific pollutants. The wealth of plant resources in Malaysia presents an opportunity for the phytoremediation technique to be applied as part of the environmental management programmes in future. Nevertheless, the ability of medicinal plants to accumulate pollutants has led to safety concerns when the plants are used as therapeutic agents or medicine. This paper reports the current status of environmental pollution in Malaysia and the potential uses of medicinal plants to treat pollutants in the environment.

Keywords: pollution, medicinal plants, phytoremediation, Malaysia

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INTRODUCTION

Phytoremediation is a natural, non-invasive pollutant clean-up technique by means of plants and their associated microbes [1]. Many plant species have their own adaptation mechanisms that allow them to survive under a highly polluted environment. Indeed, some plants known as hyperaccumulators are able to survive or thrive on heavy-metal-polluted soils despite high levels of metals in their tissues [2, 3].

Plants also exhibit valuable therapeutic properties and various species have been recognised as a prominent source of traditional medicine. The medicinal properties of plants are normally derived from various secondary metabolites, which may also be important for plant protection under stressful environmental conditions [4, 5]. Thus, medicinal plants may be potential phytoremediating agents, although this application is still underexplored.

Although phytoremediation techniques have been implemented in some countries, it is still considered new in Malaysia. In developed countries such as the United States, phytotechnologies have the possibility to clean 30,000 of the contaminated waste sites, while in Asian countries such as Bangladesh, India and Pakistan, this method has been used to clean up pollutants mainly from sewage water and industrial wastes [6]. A review on phytoremediation techniques applied in some selected countries has been published recently by Sharma and Pandey [6]. In Malaysia numerous phytoremediation-related studies are still being conducted at the laboratory level or on small-field scale for research purposes. Large field-scale phytoremediation work has not been reported yet. As a country that is endowed with immense plant resources, it is conceivable that at least some of the local plant species can be used for treating contaminated soil and water bodies.

This report aims to gather updated information on the environmental status in Malaysia and provide an assessment of the potential use of medicinal plants in phytoremediation in the country. Safety issues that may arise from using phytoremediating medicinal plants for subsequent human use or consumption are also discussed.

ENVIRONMENTAL QUALITY IN MALAYSIA

As a rapidly developing country, Malaysia is facing enormous environmental challenges. Activities in manufacturing, agro-based industries, land development and transportation release many kinds of pollutants to the environment. Prevention and control of pollution is a great challenge for the nation. Realising the importance of good environmental quality, the Department of Environment (DOE) was formed under the Ministry of Science, Technology and Environment to manage environmental-related issues [7]. Environmental Quality Act 1974 was introduced and subjected to several amendments in 1985 [8]. To date, many guidelines have been set to monitor the quality of air, water, groundwater and coastal areas in the country [9].

The level of air quality is monitored based on several parameters. This includes carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide, particulate matter and heavy metals. The air pollution problems in Malaysia stem from not only local human activities, but also a series of haze problems from a neighbouring country that occur during a certain period of the year [10, 11]. In June 2013, Malaysia experienced a short but serious haze problem, with one district in the Southern region of Peninsular Malaysia recording the air pollution index of more than 500 [11].

In 2013 the percentage of clean rivers in Malaysia was reduced by 1 % [11]. The groundwater from agricultural and industrial sites is still contaminated when assessed based on the parameters in the National Guidelines for Raw Drinking Water Quality [9, 11]. The levels of total coliform, phenol and metals such as arsenic, iron and manganese are found to exceed the safe limits stated in the guidelines.

In the coastal area in 2010, assessment of marine water quality showed that mercury and cadmium were 30.5% and 18.5% respectively higher than the permitted levels in the Malaysian Water Quality and Standards, i.e. 0.5 μg/L and 2 μg/L respectively for Class E (mangrove, estuarine and river-mouth water) [9, 12]. Mercury is a highly toxic metal and its presence even in small quantities may bring serious toxic effects to living organisms [13]. Similarly, the concentration of copper in coastal water also poorly met the standard of 2.9 µg/L for Class E in 2011 [14]. Besides metals, oil and grease, total suspended solids and *Eschericia coli* are the source of pollutants in the water bodies. The presence of various pollutants in the environment heightens the need for remediation. From the latest Environmental Quality Report, the number of sampling points categorised as 'polluted' increased from nine stations in 2012 to 11 stations in 2013 [11].

CURRENT APPROACHES FOR POLLUTION MANAGEMENT IN MALAYSIA

Environmental issues in Malaysia necessitate serious attention, although the problem is not as severe as those in some other industrialised countries. For different types of pollutants, different management strategies have been adopted. Currently, the conventional physical and chemical treatments are widely used to treat pollutants in Malaysia.

The agricultural sector is one of the biggest industries in the country that produce various organic and inorganic pollutants. Most agricultural wastes are treated using the pond system and chemical degradation [15]. On the other hand, petroleum-based pollutants generated by many heavy industries are often treated with soil vapour extraction, a technique that removes harmful vaporised chemicals such as volatile organic compounds [16]. Other petroleum-based pollutants are removed using the containment method to prevent the spread of contaminants. Soil vapour extraction and containment methods are also applicable for chlorinated hydrocarbons produced from non-petroleum-based industries [16]. Currently, research on the use of 'biostructure' to treat wastewater from petrochemical industries has been started with continuous improvements in various aspects including the use of modelling and statistical approach [17].

Other methods such as incineration, solidification and secure landfill disposal are normally used to manage certain types of hazardous wastes. Crude landfill technique, for instance, has been used for the disposal of solid wastes. However, it may increase the chances of pollutants spreading to adjacent areas through leaching and vaporisation. Thus, to reduce this problem, sanitary landfill was suggested as a better way for solid waste management [18].

Heavy metals are also considered as the main pollutants in the environment. Industries such as petroleum refining, wood-processing, smelting and metal plating produce wastes containing heavy metals that are commonly treated with chemical means such as precipitation, ion exchange, reverse osmosis, electrodialysis and ultrafiltration [19, 20]. For less harmful and visible pollutants such as trashes in the rivers, gross pollutant traps have already been applied, for example in the Klang river [21].

Overall, the aforementioned physico-chemical methods are often very costly, complicated and sometimes ineffective. Due to environmental concerns and the urge to reduce cost, natural remediation has become an alternative way to treat various pollutants. Microbes, fungi and plants are organisms normally involved in bioremediation processes. Although it is still at an early phase, phytoremediation technique has now been incorporated as part of the pollution management strategies in Malaysia.

PHYTOREMEDIATION IN MALAYSIA

In Malaysia most of the phytoremediation and related work reported over the past ten years was based on studies conducted in the laboratory. Most studies have focused on evaluating the ability of plants to take up pollutants, with emphasis on determining the levels of pollutants in various plant tissues. Bioremediation studies conducted on the actual contaminated sites are still

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lacking [22]. This could be due to the need to consider various factors such as plants species and environmental conditions prior to the scale up of lab-based experiments to the field-based phytoremediation.

Nonetheless, fundamental experiments conducted to date have revealed the capacity of various plants to take up pollutants, especially heavy metals. These studies could be the stepping stones for future phytoremediation research. Table 1 shows a number of representative studies carried out in Malaysia, which investigated the phytoremediation potential of various plant species.

Table 1. Studies of phytoremediation potential of Malaysian plant species with emphasis on medicinal plants

Type of pollutants	Plant species used	Polluted conditions simulated in laboratory	Experiments using pollutants sampled from contaminated sites	Reference
Heavy metals from soil	*Centella asiatica**	√		[23]
Heavy metals from sewage sludge	*Orthosiphon stamineus**	√		[24]
	*Acacia mangium**	√		[25]
Heavy metals from sawdust sludge	*Pluchea indica**	√		[26]
	*Jatropha curcas**	√		[27]
Lead-contaminated soil	*Hibiscus cannabinus **	√		[28]
Aqueous medium containing copper (II)		√		[29]
Diesel pollutants in synthetic wastewater	*Salvinia molesta**	√		[30]
Hydrocarbon-contaminated soil	*Paspalum vaginatum**	√		[31]
Chromium from electroplating waste	*Nymphaea spontanea**	√		[32]
Heavy metals from agricultural soil in Cameron Highlands and Sepang	*Solanum melongena**, *Ipomoea batatas**, *Allium cepa**		√	[33]
Heavy metals from petroleum refinery effluents on west coast of Peninsular Malaysia	*Eichhornia crassipes**		√	[34]
Leachate of contaminated landfill from Burung Island			√	[35]

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Table 1. **(**Continued)

Type of pollutants	Plant species used	Polluted conditions simulated in laboratory	Experiments using pollutants sampled from contaminated sites	Reference
Aquaculture wastewater from fish pond in Semanggol, Perak	*Eichhornia crassipes**, *Pistia stratiotes**		√	[36]
Textile wastewater from Senawang Industrial Estate, Negeri Sembilan	*Chlorella vulgaris**		√	[37]
Heavy metals from Chini Lake	*Lepironia articulate*, *Pandanus helicopus*, *Scirpus grossus**, *Cabomba furcata*, *Nelumbo nucifera**		√	[38]
PAH from North-South Expressway in Johor	*Ficus microcarpa**, *Ixora coccinea**, *Baphia nitida**		√	[39]
Heavy metals from tin tailings	*Cyperus rotundus**, *Imperata cylindrical**, *Nelumbo nucifera**, *Phragmites australis**, *Pteris vittata**		√	[40]
Leachate of sanitary landfill in Puchong	*Moringa oleifera**		√	[41]

* Plants with documented medicinal values

PROPERTIES AND CRITERIA OF MEDICINAL PLANTS IN RELATION TO PHYTOREMEDIATION

Besides their traditional uses, medicinal and aromatic plants have important economic values in many industries such as pharmaceuticals, food, cosmetics and ornaments. Medicinal plants exhibit therapeutic properties due to the presence of bioactive compounds derived from secondary metabolites such as phenolics, terpenoids and compounds containing sulphur and nitrogen [42]. Phenolic compounds, for example, are good solubilisers and metal chelators for plants in contaminated areas [43, 44]. Phenolic compounds can be released as plant root exudates containing organic acids such as lactates and acetates [45]. These compounds can facilitate bioremediation of pollutants, provided that other environmental factors such as pH, temperature and soil conditions are also suitable for the process to happen [46].

The mechanism of pollutant uptake and accumulation varies depending on the type of plant tissues. Pollutants normally enter plants through foliage or root system prior to undergoing oxidation or storage in other compartments such as vacuoles [47]. In response to pollutants, plants usually increase the production of reactive oxygen species [48]. However, high levels of these species are harmful; thus, antioxidants are produced to alleviate the cellular oxidative stress [49, 50].

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Since secondary metabolites produced by medicinal plants normally contribute to various biological roles, this could be a way for plants to adapt to the polluted environment [4]. Secondary metabolites could contribute to the protection of plant against toxin stress and could be involved in the detoxification of some toxic metals [51]. The ability of certain plants to survive in a contaminated area suggests that they may be able to tolerate or even hyperaccumulate pollutants [52]. Table 2 shows the roles of some secondary metabolites in phytoremediation.

Table 2. Roles of some secondary metabolites as phytoremediating agents

Compound	Role in phytoremediation	Plants investigated	Reference
Phenolics	Aluminium chelator	*Zea mays* *	[53]
	Lead and copper chelator	*Brassica juncea**	[54]
	Cadmium chelator	*Hyperium perforatum** *Matricaria recutita**	[55]
	Nickel chelator	*Matricaria chamomilla**	[56]
	Biodegradation of polychlorinated biphenyls and polyaromatic hydrocarbons	*Morus rubra**	[57]
	Biodegradation of polyaromatic hydrocarbons	*Miscanthus giganteus*	[58]
Terpenoids	Induction of biodegradation of polychlorinated biphenyls in bacteria	*Mentha spicata**	[59]
Sulphur- or nitrogen-containing compounds	Cadmium detoxification	*Arabidopsis thaliana**	[60]

* Plants with documented medicinal values

Apart from the roles of secondary metabolites, plant species and environmental conditions are important factors to ensure the success of phytoremediation process. For some susceptible plants, their medicinal properties may be affected due to exaggerated growth and development and alteration of their chemical composition under polluted conditions [61]. Normally, plants for bioremediation have to be robust and able to survive under a stressful environment. In addition, their ability to take up pollutants in a reasonable time frame is also important. Such characteristics as rapid growth and development resulting in height and abundant branches and leaves that lead to the production of high plant biomass under polluted conditions indicate the fitness or suitability of the plants for bioremediation [62]. Medicinal plants such as *Heliantus annus* and *Pteris vittata* are good phytoremediators as they are fast-growing species, less prone to diseases and have the ability to accumulate heavy metals in plant tissues [63, 64].

Currently, plant tissue-culture technology is available to assist researchers in obtaining basic information related to phytoremediation in a shorter time, facilitating the investigation of suitable conditions for plant growth and optimum production of secondary metabolites for remediation purposes [65]. Thus, the knowledge from studies based on cultured tissues may be applied when growing plants at field sites [66].

HEALTH CONCERNS FOR MEDICINAL PLANTS USED IN PHYTOREMEDIATION

There are more than 6,000 species of Malaysian plants with known medicinal values. Tongkat Ali (*Eurycoma longifolia*), Kacip Fatimah (*Labisia pumila*), Misai kucing (*Orthosiphon stamineus*), Hempedu bumi (*Andrographis paniculata*), Dukung anak (*Phyllanthus niruri Linn)* and Pegaga (*Centella asiatica*) are among the common species that have been traditionally used to promote healthy body functions and cure diseases such as diabetes, hypertension and sex-related problems [67]. A decade ago, studies on medicinal plants in Malaysia were scarce [68]. However, this field has been slowly expanding with increasing researches conducted by various agencies in the country. Research on medicinal plants that previously focused on the search of bioactive compounds for drug development has now expanded to modern phytotechnologies including phytofortification and phytoremediation [69]. In phytofortification, the accumulation of essential elements such as selenium, zinc and iron in the edible parts of medicinal plants makes them suitable as a source of supplementary nutrition [70, 71, 72]. Their ability to take up pollutants, on the other hand, has made them suitable for bioremediation purposes [73].

From another point of view, the ability of certain medicinal plants to accumulate pollutants has provoked safety concerns among consumers. As highlighted by Bagdat and Eid [74], several species of herbal plants normally used in food preparation, such as mint, lavender, thyme, pot marigold, hollyhock, garden sorrel and black nightshade, also have the capacity to take up metals. This is a big concern among consumers as herbs for cooking will be directly consumed without any extraction process. The problem may be less serious when medicinal plants grown on contaminated sites are subjected to further extraction and purification steps before their active ingredients are used for human consumption. For example, essential oil products are normally free from pollutants after the extraction process [75]. The problem will arise when people have no idea that the plants they use for medicinal purposes are contaminated.

Several important guidelines have been published by the World Health Organisation, covering the whole spectrum of procedures for herbal medicine preparation including aspects of safety, quality, agricultural practices and manufacturing of medicinal plants [76]. The aforementioned aspects are important for sustainable herbal market worldwide [77]. Malaysia also has its own national pharmaceutical control bureau to ensure that therapeutic substances approved for the local market are in high quality and safe [78]. In 2001 a national policy on traditional medicine and alternative or complementary medicine was launched and its licensing was enacted under the control of Drugs and Cosmetics Regulations 1984 [77]. Generally, materials prepared will be subjected to quality control analysis including toxicological, pharmacological and pharmacokinetic studies, while materials for the manufacturing process will be followed by clinical studies [79].

Nonetheless, the implementation of the regulations needs to be strengthened, especially among manufacturers. A study by Ang and Lee [80] revealed that 26% of the Tongkat Ali Hitam (*Eurycoma longifolia*) products contained mercury exceeding 0.5 ppm, the accepted level for traditional medicine, and these products were not registered with the Drug Control Authority. This may be an isolated case, but it has raised serious concern as the cultivation and use of medicinal plants has to be done by taking into consideration the potential hazard to humans and the environment [81].

MEDICINAL PLANTS: FUTURE PROSPECTS FOR PHYTOREMEDIATION AND CHALLENGES

Although phytoremediation incorporates the ability of plants to remove pollutants from different sources, many studies nowadays have been emphasising on phytoremediation of heavy metals and organic pollutants from soil and water. There is lack of attention towards other pollutants such as air-polluting toxic gases despite their prevalence in the environment. Future research should investigate the ability of medicinal plants to take up both organic and inorganic pollutants. Furthermore, field-scale phytoremediation should be intensified with the goal of evaluating the effectiveness of the technology at the real contaminated sites.

In addition, many species currently tested for phytoremediation have certain medicinal properties. However, the correlation between the ability of plant to remove pollutants and the involvement of bioactive compounds in this process requires more concrete scientific evidence. Since the main issue in bioremediation is the time consumption, the introduction of transgenic plants with relevant phenotypes, the acceleration of remediation with the addition of microbes, and the combination of biological and chemical methods can all be attempted to identify a more time-efficient solution [82, 83].

Furthermore, the negative effects of consuming plant-based medicine could be avoided if consumers only use the products that have been approved by recognised bodies or agencies. For raw plant usage, consumers should choose plants from low-risk sources, for example medicinal plants harvested from unpolluted sites. It is preferable to use plants that are not accumulating pollutants in the parts that will be eaten later. In a study conducted using kenaf, lead was highly accumulated in the root, followed by stem and seed capsule, exceeding the safe level in food, which is 2 mg/kg. However, it was not detected in the leaves; hence it can be use for cattle feed [28]. However, for human it must be confirmed that a metal level in plants is safe for usage. Some species of plants such as *Pteris vittata* also have the ability to absorb and evaporate pollutants into the atmosphere [84, 85]. It was reported that *Pteris vittata* produces harmful compounds to animals. However, some of the local people in India have used this plant for wound healing or treatment of cold, cough and fever [86]. Considering the priority of human safety, we believe that the best practice is to use plants that are free from contamination to prevent poisoning or further complications from the pollutants.

Taken together, phytoremediation using medicinal plants have an immense potential in Malaysia. Although there are challenges that need to be tackled, it is not impossible to implement this technique if all parties involved could work it out collaboratively.

CONCLUSIONS

In implementing clean technologies for environmental sustainability, phytoremediation is a method of choice for removing pollutants. Available resources in Malaysia including vast varieties of herbal and medicinal plants may be used in remediating organic and inorganic pollutants. However, more studies are needed to identify promising plant species and optimum environmental conditions suitable for phytoremediation. Further efforts are also needed to make this technique applicable in the field scale. If phytoremediation is successfully applied, cost reduction and clean environmental conditions could be achieved. With that, the full potential of Malaysian medicinal plants, not only as traditional medicine but also as phytoremediation agents, can be exploited.

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