

PHYTO-ASSISTED SANITATION SYSTEM

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Abstract: This work presents a critical review on closing nutrients flow into loop waste management system. An integrated ecosystem management is used and valuable nutrients are conserved. Waste biodegradability can be improved prior to microbial treatment. Wastewater flow is distributed into environmental multimedia, avoiding excessive load on single medium. Phytoindicator performs environmental quality for management purposes. Phytoremediation can be conducted for polluted environment, preferably an integrated remediation – greening – compost use by which solid waste problems is partly solved. Rural area and housing estate of high income level in urban area are prioritized in phyto-assisted sanitation provision. The analysis supports the paramount importance of using plants for sanitation problems solving, however, interrelated factors between human component and environment component have to be taken into account, leading to sustainable environmental sanitation.

Keywords: Integrated approach, loop management, plant processes, sustainability

INTRODUCTION

Environmental sanitation has been defined by the Water Supply and Sanitation Collaborative Council as interventions to reduce people exposure to disease by providing a clean environment in which to live, with measures to break the cycle of disease [31]. Breaking the cycle of disease can include disposal or hygienic management of liquid and solid human waste, control of disease vectors, and provision of washing facilities for personal and domestic hygiene. However, the sources and pathways of disease are involving human activities and environmental multimedia, thus the cycle of disease can be broken at any stage. Hence, the primary mission of environmental sanitation is to provide clean, health and safe environment without space and time limitations, the so called sustainable environmental sanitation (SES). SES conforms to

sustainable development that is to meet the needs of the present status without compromising the ability of future generations to meet their own needs [32]. Environmental sanitation in connection to phytotechnology is given special attention as embedded in the five sustainable development priorities for which concrete results are both essential and achievable: water and sanitation, biodiversity and ecosystem management, energy, agricultural productivity and health [1].

The conventional approach to environmental sanitation was attributable by a linear waste management system. Waste generated at the source was fully disposed with or without treatment and thus kept the source of activity clean and healthy. However, the linear waste management potentially created pollution problems in receiving waters, spreading to wider area, in addition to wasting valuable nutrients. Recycling the nutrient flow by means of phytotechnology following waste treatment or source disposal is one of the main objectives of a more ecological approach to environmental sanitation [34]. Phytotechnology describes the application of science and engineering to examine problems and provide solutions involving plants [14, 34]. Therefore the aim of this critical review is to evaluate the potential function of plants in sanitation problem solving, the so called phyto-assisted sanitation system (PASS). The knowledge of PASS is aiming to change the social attitude from disposing a bulk of waste into disposing phytotreated residual waste. Hence, practical waste management paradigm will be deflected from linear into loop system, leading to SES.

PLANT PROCESSES

Phytotechnology

Plant is well known to be solar energy transformator as well as natural pump for soil water, producing chemical energy in its tissues. In addition to water, plant uptake chemicals both from air and soil environment. In areas where the environment is polluted, plant and/or in corporation with soil microbes have capacity to remove or destruct contaminants that have been well documented [14]. The removal process is known as phytoremediation, consisting of six processes [14, 35, 36].

Phytostabilization refers to contaminant immobilization in the soil. Rhizofiltration refers to contaminant adsorption or precipitation onto roots or absorption into the roots, whereas rhizodegradation is the breakdown of contaminants within the soil through microbial activity that is enhanced by the growth of yeast, fungi, or bacteria on the natural substances released into the soil by plant roots—sugars, alcohols, and acids—containing organic carbon. The organic carbon provides food for soil microbes which biodegrade contaminants as they consume the plant root exudates. Phytoextraction refers to contaminant uptake and translocation into plant parts whereas phytodegradation is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants [7, 8, 24, 25]. Contaminants are degraded, and may be incorporated into the plant tissues, or used as nutrients. Phytovolatilization describes the uptake by plants of contaminants that are, in turn, released from the plant in vapor form into the atmosphere. The contaminant may be modified chemically within the plant before release into the atmosphere. The remarkable contaminants target and processes are (1) conservative substances will be controlled by phytostabilization followed by rhizofiltration,

phytoextraction and phytovolatilization to some extent, and (2) non-conservative contaminants will undergo all processes.

The method of application processes is using the term of phytotechnology [14] that is helpful in promoting a broader understanding of the importance of plants. Phytotechnological applications employ ecological engineering principles [21] and are considered to be ecotechnologies. Ecotechnologies are dependent on the self-regulating capabilities of ecosystems and nature. The focus on, and use of, biological species, communities, and ecosystems distinguishes ecotechnologies from more conventional engineering-technological approaches, which seldom consider integrative ecosystem-based approaches [34].

Environmentally beneficial applications of phytotechnology can generally be divided into five components. There is integrated ecosystem management, the prevention component, the control component, the remediation and restoration components, and monitoring and assessment components; that can be found in UNEP [34]. All of the components are applicable for environmental sanitation and some are highlighted in the following review. In addition, the challenges of phyto-assisted sanitation system (PASS) are presented in relation to environmental problems solving and the provision of sanitation solutions.

Greenspace: an integrated ecosystem management

The integrated ecosystem management (IEM) on phytotechnology component focuses on the use of phytotechnology to augment the capacity of natural systems to absorb impacts by serving as natural buffers. It is one of several tools for making productive use of urban open spaces, treating urban waste, saving or generating income and employment, and managing freshwater resources more effectively [2, 3]. Therefore provision of sufficient greenspace area in a city could be included in the IEM. Modern redevelopment of land must include an element of greenspace.

Greenspace refers to an area that is a green within a city whatever the spatial function is. Greenspace is seen as essential for several reasons including landscape improvement and economic regeneration, provision of recreational and sport opportunity, connection with nature, and flood defence. Other societal claims for urban greenspace include enhancement of urban biodiversity, atmospheric pollution mitigation, reduction of the urban heat island effect, carbon sequestration. There is no doubt the beneficial value of greenspace for life such as creating aesthetic and wildlife habitat, increasing recreational value of lands, conserving water sources, preventing soil erosion and stream sedimentation, reclaiming poorly managed lands, remediating polluted environment, boosting local and regional economies. Greenspace program had been conducted in most countries and it was intensified to respond increasing level of atmospheric carbon dioxide causing global warming. Moreover, the implementation of a worldwide carbon emissions trading system has prompted the development of plants dedicated to sequestering carbon dioxide into their tissues.

The greenspace area is generally regulated in the range of 20 - 40 % of an area [28, 38], however, many cities in the world have difficulties to meet the required greenspace for many reasons. Samudro and Mangkoedihardjo [28] studied the greenspace area using water equivalent method which was dependent on population number instead of city area. The method suggests no single quantitative greenspace area could be generalized for all cities that should be regulated. The integration of greenspace as a part of phytotechnology and hydrology the so called ecohydrology is promising method to improve water quality and quantity as well as to stabilize the hydrological cycle [34]. To achieve this, phytotechnology should cover activities at all spatial

levels in the watershed, which include the landscape, land-water ecotone zones, freshwater bodies and estuaries. This can be regulated as greenspace distribution follows natural guidance [28].

Biodegradability improvement of wastes

Phytotechnology can be focused on waste treatment. Urban wastes as well as industrial wastes are considered the most serious and pressing urban environmental problems. Special attention was given to non-biodegradable organic waste due to persistence in environment. Organic matter content of wastewater is measured as the biological oxygen demand (BOD) and the chemical oxygen demand (COD). The extent of degradation by microbes can be evaluated by means of biodegradability quotient measured as BOD/COD ratio. This ratio is commonly used indicator of the degree of biodegradation of the wastewater. A high BOD/COD ratio should be considered sufficient condition to insure biodegradation. As wastewater is degraded, the concentrations of all two measures decrease. Since BOD decreases faster than COD the ratio can approach zero. There is some consensus that stabilized wastewater has a BOD/COD ratio of less than 0.1, a BOD ratio less than 100 mg L⁻¹, and COD less than 1000 mg L⁻¹ [5]. However, untreated industrial wastewater has typically a low BOD/COD ratio by which biological process is often ceased. This may indicate the presence either of organic matter that are hard to biodegrade or of toxic substance inhibiting the microbial activities.

Increasing biodegradability of a low BOD/COD ratio could be carried out by addition of organic chemicals which have high BOD/COD ratio such as glucose, methanol and acetic acid. Or, mixing the low biodegradable wastewater with high biodegradable wastewater would increase biodegradability of the low BOD/COD ratio. An option of using natural organic chemicals produced by plants which is released from roots would be promising. Plant roots release exudates such as short chain organic acids, phenolics, enzymes, and proteins which are highly biodegradable [11, 14]. A mixture of organic matter-containing wastewater with low BOD/COD ratio and organic matter-releasing plant roots with high BOD/COD ratio could be expected to increase biodegradability of untreated wastewater. To this purpose Mangkoedihardjo [18] used hyacinth to treat industrial wastewater having low BOD/COD ratio of less than 0.1. The concluding remarks were for the initial COD of more than 500 mg L⁻¹, BOD/COD ratios were shown to increase about 0.30, increasing rates were about 0.2 day⁻¹, and doubling time(s) were 4 days. For the initial COD of less than 500 mg L⁻¹, BOD/COD ratios were shown to increase 0.33 – 0.52, increasing rates were about 0.32 day⁻¹, and doubling time(s) were 2 days. The fact suggests that phytotechnology could be applied prior to microbial process for low biodegradability level of waste.

Wastewater flow distribution

Phytotreatment aiming to pump wastewater was far behind the progress of improving quality. Investigation on the capacity of plant to treat chemicals has been carried out intensively [4, 6, 11, 17, 18, 25, 26, 27, 29, 30, 39]. However, an upward flow through plant roots, the so called transpiration stream plays an important role aiming to divert wastewater flow into the air. The collective flow of transpiration stream within the plant and evaporation to the air is the so called evapotranspiration. This represents evaporated volume, or weight, of wastewater which detaches from wastewater surface. Therefore the overall treated effluent will be discharged to environmental multimedia, i.e. soil and/or water bodies and air.

Special attention is given to the transpiration stream that flows at high rate when a plant has its stomates open, normally during the sunny day for the exchange of gases in photosynthesis. Higher transpiration stream is an indication of enhanced chemical uptake by plants [6]. The stream still occurs at a much slower rate through the cellular path [23] when stomates are closed at night, suggesting low chemical uptake. Thus, transpiration stream loading is fluctuated during the day. Moreover, the chemicals-containing transpiration stream may undergo covalent bonding into the lignin of the plant (lignification), and, or transformation to carbon dioxide and water. As a result, a low chemical concentration will detach from the leaf surface. Hence, leaf area capacity should be defined to what extent of the evapotranspiration is partly evaporated from leaves surface. However, the fluctuation of transpiration stream loading may affect the leaf area capacity. In addition, the intensity of the stream may change substantially hydraulic properties of plant tissues and organs, leading to malfunction of leaf for carrying out transpiration. Accordingly, the effect concentration of chemicals should be determined to what extent the leaf area capacity is reduced, which needs investigation using ecotoxicological study.

Monitoring and ecotoxicological study

Monitoring involves the use of phytoindicators to follow up and assess conditions and changes in the environment due to natural and/or anthropogenic disturbances. Mangkoedihardjo [17] reported the results obtained from simple, direct and visual phyto-assessment of wastewater quality. Solutions in which waterhyacinth grown were characterized into two distinct qualities. The first group of solution contains organic matter of more than 60 mgBOD L⁻¹ and 200 mgCOD L⁻¹, and contains inorganic substances of less than 14 mgN L⁻¹, 0.9 mgFe L⁻¹, and 0.9 mgMn L⁻¹. The second group of solution contains organic matter of less than 50 mgBOD L⁻¹ and 100 mgCOD L⁻¹, and contains inorganic substances of more than 20 mgN L⁻¹, 1 mgFe L⁻¹, and 1 mgMn L⁻¹. During exposure the aerial parts of waterhyacinth, i.e. number of leaves and leaves area have significant respond to the waste qualities. The respond was measured as doubling time of leaves growth. Doubling time of leaves growth in organic-rich wastewater was about 8 days, twice longer than the doubling time in inorganic-rich wastewater (4 days). This approach can be considered for practical phyto-assessment of wastewater quality in particular, and monitoring water quality management in general. Moreover, predictive hazard assessment of chemicals toward plant growth, that is ecotoxicological study, has been intensively studied in response to increasing environmental pollution. Several studies have been conducted on the effect of chemicals containing wastes towards plants growth, representing potential function of plants to assess chemicals hazards [8, 9, 22].

Functional and spatial priority setting

The on-site system is used as a means of human wastes management in most developing countries. The system allows that the wastewater flows to septic tanks, and the effluent is disposed through the soil absorption system. The wastewater contains mostly nitrogen-rich organic matter which is biodegradable. In soil the multiple bioconversion of organic nitrogen is nitrate which can be converted partly to nitrite and dinitrogen gas [10]. The nitrite is toxic to living organisms including humans and thus could be suppressed in the soil absorption system using plants, the so called evapotranspiration bed. The evapotranspiration bed has dual function, i.e. evaporation of wastewater and absorption of wastewater by plants. Therefore wastewater infiltration and leaching of nitrate to groundwater are less [19, 40]. In addition to on-site sanitation

system, natural and/or constructed wetlands can be provided in sanitation system both communal on-site and centralized off site system.

The availability of land is prerequisite for application of evapotranspiration bed. Spatially, rural area is more suitable than urban area, and the provision of sanitation infrastructure can be addressed to the evapotranspiration bed. High income level houses in urban area have generally sufficient open space where phyto-assisted sanitation (PASS) can be addressed. Instead of sewerage system approach, an intensive use and extensive application of PASS in rural and urban area will significantly increase the provision of better sanitation infrastructure, conserve valuable nutrient, and healthy people; that are low cost.

Factors for sustainable environmental sanitation

The general principle of sustainable environmental sanitation (SES) should be easily understood, applicable in many contexts, transferable across scales, translate well into applied policy and practical action, and identify possibilities for radical transformative change. It needs extraordinary efforts however the following components and factors could be considered affecting SES. Human activities component comprises at least social, institutional, financial, economy, and technology. Environment component is complex in nature however it can be simplified into physiochemical consisting of air, water, soil, including chemicals; and biological compartment excluding human. This is nothing less than ecosystem management which is about people and environment, the way in which addresses the human dimension in ecosystem management will determine its ultimate impact.

CONCLUSIONS

Plant is a natural bioreactor that uptake contaminants – separate – translocate – transform – use – release lower level contaminants than uptake level – in addition to release low quantity of transpiration stream into environmental multimedia (air, water, soil) – and nutrient cycle begins without ending. These represent how plant is acting as loop contaminant manager and hence, making phytotechnology to be a loop waste management system. Loop system assures the nutrients containing waste are conserved. However, ecotoxicological study involving plant growth factors and effects – by which contaminant limitations and potential remediation are predicted – should be conducted in particular conditions. The integrated phytotechnology platforms of conservation – ecotoxicology – remediation are accelerating the speed to meet sustainable environmental sanitation. The remaining question for sustainable environmental sanitation is how human activities are in balance with environment without space and time limitations. The answers are open for further investigations and discussions.

References

1. Annan, K.A., 2002. Toward A Sustainable Future. *Environment*, 44 (7): 10-15. ProQuest, USC, Los Angeles, 8 May 2004. Available at <http://www.proquest.com/>
2. Bakker, N., M. Dubbeling, S. Guendel, U. Sabel-Koschella, and H. de Zeeuw, 2000. Growing Cities, Growing Food – Urban Agriculture on the Policy Agenda. DSE, Eurasburg, Germany.
3. Baumgartner, B., and H. Belevi, 2001. A Systematic Overview of Urban Agriculture in Developing Countries. EAWAG/SANDEC. Available at http://www.sandec.ch/urban_agri/Aindex.html.

4. Bich, N.N., M.I. Yaziz, and N.B.K. Bakti, 1999. Combination of *Chlorella vulgaris* and *Eichhornia crassipes* for wastewater N removal. *Water Research*, 33 (10): 2357-2362.
5. Borglin, S.E., T.C. Hazen, and C.M., Oldenburg, 2004. Comparison of Aerobic and Anaerobic Biotreatment of Municipal Solid Waste. *Air & Waste Management Association*, 54: 815-822.
6. Briggs, G.G., R.H. Bromilow, and A.A. Evans, 1982. Relationship between Lipophilicity and Root Uptake and Translocation of Non-ionized Chemicals by Barley. *Pesticide Science*, 13: 495-504.
7. Burken, J.G., and J.L. Schnoor, 1998. Predictive Relationships for Uptake of Organic Contaminants by Hybrid Poplar Trees. – *Environmental Science & Technology*, 32 (21): 3379-3385.
8. Burken, J.G., and J.L. Schnoor, 1999. Distribution and Volatilization of Organic Compounds Following Uptake by Hybrid Poplars. – *International Journal of Phytoremediation*, 1 (2): 39-151.
9. Caicedo, J.R., O.A. Van Der Steen, and H.J. Gijzen, 2000. Effect of Ammonia N Concentration and pH on Growth Rates of Duckweed. *Water Research*, 34 (15): 3829-3835.
10. Chung, J., and W. Bae, 2002. Nitrite Reduction by a Mixed Culture Under Conditions Relevant to Shortcut Biological Nitrogen Removal. *Biodegradation*, 13: 163-170.
11. Coleman, J., K. Hench, K. Garbutt, A. Sexstone, G. Bissonnette, and J. Skousen, 2001. Treatment of Domestic Wastewater by Three Plant Species in Constructed Wetlands. *Water, Air, and Soil Pollution*, 128: 283-295.
12. Donnelly, P.K., and J.S. Fletcher, 1994. Potential Use of Mycorrhizal Fungi as Bioremediation Agents. in *Bioremediation Through Rhizosphere Technology*. T.A. Anderson and J.R. Coats (eds.), American Chemical Society, Washington, DC.
13. Flathman, P.E, and G.R. Lanza. 1998. Phytoremediation: Current Views on an Emerging Green Technology. *Journal of Soil Contamination*, 7: 415-432.
14. ITRC (Interstate Technology Regulatory Council), 2001. Technical and Regulatory Guidance Document, Phytotechnology. Available at <http://www.itrcweb.org>.
15. Kumar, P.B.A.N., V. Dushenkov, H. Motto, and I. Raskin, 1995. Phytoextraction: The Use of Plants to Remove Heavy Metals from Soils. *Environmental Science & Technology*, 29: 1232-1238.
16. Llewelyn, R H., 2005. Development of Standard Laboratory Based Test to Measure Compost Stability. The Waste & Resources Action Programme The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH
17. Mangkoedihardjo, S., 2002. Waterhyacinth Leaves Indicate Wastewater Quality. *Jurnal Biosains*, 7 (1): 10-13.
18. Mangkoedihardjo, S., 2006. Biodegradability Improvement of Industrial Wastewater Using Hyacinth. *Journal of Applied Sciences*, 6 (6): 1409-1414.
19. Mangkoedihardjo, S., 2006. The Kinetics of Biodeconcentration for Nitrate: case study microbial denitrification and plants absorption. *Malaysian Journal of Soil Science*, 10: in press.
20. Martin, H.W., T.R. Young, D.I. Kaplan, L. Simon, and D.C. Adriano. 1996. Evaluation of Three Herbaceous Index Plant Species for Bioavailability of Soil Cadmium, Chromium, Nickel, and Vanadium. *Plant and Soil*, 182: 199-207.
21. Mitsch W., and S. E. Jorgensen, 2004. *Ecological Engineering and Ecosystem Restoraton*. John Wiley and Sons. Inc. USA. 411 p.
22. Moffat, A., and T. Hutchings, 2005. Greening of Brownfield Land. Environmental and Human Sciences Division Forest Research, Alice Holt Lodge, Farnham, Surrey, GU10 4LH. Paper presented to the SUBR:IM Conference, March 1st 2005.
23. Morillon, R., and M.J. Chrispeels, 2001. The role of ABA and the Transpiration Stream in the Regulation of the Osmotic Water Permeability of Leaf Cells. *Proceedings of the National Academy of Sciences*, 98 (24): 14138-14143

24. Newman, L.A., S.E. Strand, N. Choe, J. Duffy, G. Ekuan, M. Ruzaj, B.B. Shurtleff, J. Wilmoth, P. Heilman, and M.P. Gordon, 1997. Uptake and Biotransformation of Trichloroethylene by Hybrid Poplars. *Environmental Science & Technology*, 31: 1062–1067.
25. Newman, Lee A., and C. M. Reynolds, 2004. Phytodegradation of Organic Compounds. *Current Opinion in Biotechnology*. 15: 225-230.
26. Olson, P.E., and J.S. Fletcher, 2000. Ecological Recovery of Vegetation at a Former Industrial Sludge Basin and Its Implications to Phytoremediation. *Environmental Science and Pollution Research*, 7: 1-10.
27. Salt, D.E., M. Blaylock, P.B.A. Nanda Kumar, V. Dushenkov, B.D. Ensley, I. Chet, and I. Raskin, 1995. Phytoremediation: A Novel Strategy for the Removal of Toxic Metals from the Environment Using Plants. *Biotechnology*, 13: 468-474.
28. Samudro, G., and S. Mangkoedihardjo, 2006. Water Equivalent Method for Cityphytostructure of Indonesia. *International Journal of Environmental Science and Technology*, 3 (3): 261-267.
29. Schnoor J.L., L.A. Light, S.C. McCutcheon, N.L. Wolfe, and L.H. Carriera, 1995. Phytoremediation of Organic and Nutrient Chemicals. *Environmental Science & Technology*, 29: 318–323.
30. Shimp, J.F., J.C. Tracy, L.C. Davis, E. Lee, W. Huang, L.E. Erickson, and J.L. Schnoor, 1993. Beneficial Effects of Plants in the Remediation of Soil and Groundwater Contaminated with Organic Materials. *Critical Review in Environmental Science and Technology*, 23: 41-77.
31. Simpson-Hébert, M., and S. Woods (eds), 1998. *Sanitation Promotion*. World Health Organisation, Geneva.
32. Smit, J., 1996. *Urban Agriculture - Food, Jobs and Sustainable Cities*. UNDP United Nations Development Program, New York.
33. Speir, T.W., J.A. August, and C.W. Feltham, 1992. Assessment of the Feasibility of Using CCA (Copper, Chromium and Arsenic) -Treated and Boric Acid-Treated Sawdust as Soil Amendments. I. Plant Growth and Element Uptake. *Plant and Soil*, 142: 235–248.
34. UNEP, 2004. *Integrated Watershed Management Ecohydrology & Phytotechnology -- Manual* – Available at <http://www.unep.or.jp>
35. USEPA. 1999. *Phytoremediation Resource Guide*. EPA/542/B-99/003. Available at <http://www.epa.gov/tio>.
36. USEPA, 2000. *Introduction to Phytoremediation*. EPA/600/R-99/107. Available at <http://www.epa.gov/clariton/clhtml/pubtitle.html>
37. Wang, P., C.M. Changa, M.E. Watson, W.A. Dick, Y. Chen, and H.A.J. Hoitink, 2004. Maturity Indices for Composted Dairy and Pig Manures. *Soil Biology & Biochemistry*, 36: 767-776.
38. Wright, R. M., 2000. *The Evolving Physical Condition of the Greater Toronto Area: Space, Form and Change*. Toronto: University of Toronto, and the Neptis Foundation.
39. Yirong, C., and U. Puetpaiboon, 2004. Performance of Constructed Wetland Treating Wastewater from Seafood Industry. *Water Science & Technology*, 49 (5-6): 289 – 294.
40. Zuhriah, A., and S. Mangkoedihardjo, 2005. Comparison Model to Evapotranspiration Bed Using Upflow and Downflow of Domestic Waste. *Jurnal Purifikasi*, 6 (1): 1-6.