Phytoremediation of Soil Contaminated with Petroleum Hydrocarbons: A Review of Recent Literature

Kuok Ho Daniel Tang

Department of Environmental Engineering, Curtin University Malaysia, Miri, Sarawak, Malaysia

*Corresponding Author: Bioprocess & Technology Research Cluster, Department of Environmental Engineering, Curtin University Malaysia, CDT250, 98009 Miri, Sarawak, Malaysia, Email: daniel.tang@curtin.edu.my

Received Date: Nov 29, 2019 / Accepted Date: Dec 04, 2019 / Published Date: Dec 06, 2019

Abstract

Booming anthropogenic activities is the main reason of widespread contamination of soil by petroleum hydrocarbons, resulting in environmental, health and socio-economic concerns. Remediation of contaminated soil has received much attention including phytoremediation which has the advantages of being low cost and technologically uncomplicated. Numerous papers on phytoremediation have been published and this review aims to examine selected studies on phytoremediation in the past five years to deduce the study trend and make recommendations for the way forward. The review shows an increasing number of studies combining phytoremediation with other methods particularly the physical methods such as soil amendment, electrokinetic remediation and surfactant application, as well as bioremediation using fungi and bacteria. There is increasing interest to investigate the synergy of these methods which leads to co-applications of one or more remediation methods with phytoremediation. Such co-applications often yield higher petroleum hydrocarbons removal rates in shorter time. Future studies can also include chemical remediation in the synergistic studies of phytoremediation and other remediation methods.

Keywords: Phytoremediation; Bioremediation; Crude oil; PAHs; Petroleum Hydrocarbons

Cite this article as: Kuok Ho Daniel Tang. 2019. Phytoremediation of Soil Contaminated with Petroleum Hydrocarbons: A Review of Recent Literature. Glob J Civil Environ Eng. 1: 33-42.

Copyright: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. Copyright © 2019; Kuok Ho Daniel Tang

Introduction

Increasing urbanization, industrialization, agriculture and transportation have resulted in widespread soil contamination, which has been made worse by a lack of regulation and law enforcement. While burgeoning anthropogenic activities cause accidental leakage and spillage of contaminants into the environment, inadequate regulation and enforcement provide loopholes for intentional disposal and discharges of contaminants which often lead to large scale pollution [1,2].

Soil contamination is generally defined as the occurrence of a substance above the normal concentration in soil, thus causing deleterious effects on non-target organisms. The contaminants are organic and inorganic in nature, each consisting of a myriad of substances. The most common organic contaminants are petroleum hydrocarbons

www.raftpubs.com
consisting largely of the aliphatic and aromatic compounds [3,4]. Petroleum-derived non-hydrocarbons such as sulphur compounds, metallo-porphyrins and asphaltenes also constitute the organic contaminants. These contaminants are released into the environment primarily via the combustion and use of fossil fuels as well as the use of solvents, pesticides and pharmaceutical [2].

Trace elements are the main inorganic soil contaminants. Trace elements are cationic metals and oxyanions originating from rock formation and weathering, usually present as natural components of soil at concentration less than 1g kg⁻¹ [4]. Trace elements such as zinc, copper, iron and manganese are crucial to support living processes but could raise health concerns at elevated concentrations. Other instances of trace elements like lead, mercury, arsenic and cadmium are toxic to organisms even at low concentrations [5]. Though natural processes such as volcanic activities and rock weathering contribute to high background levels of trace elements in soil, anthropogenic activities including mining, smelting, construction and agriculture aggravate inorganic soil pollution, particularly due to unnaturally high levels of lead, chromium, arsenic, zinc, cadmium, copper and mercury in soil [4].

Soil contamination is a serious threat to soil functions especially in the Europe, Eurasia and North Africa. In the 1990s, the area of contaminated soil was estimated at 22 million hectares [6] but later regional data showed that the figure was most likely underestimated. Based on a report in 2015, the Chinese Environmental Protection Ministry estimated 16% of soil in China and 19% of its agricultural soil fell in the ‘polluted’ category [7]. In the European Economic Area and its allied West Balkan countries collectively known as EEA-39, there were about 3 million sites likely to have been polluted [8] whereas in the US, the number of polluted sites classified as Superfund National Priorities was approximated at above 1300 [9]. An approximated total of 80000 contaminated sites scattered over Australia in 2010 [10]. The extent of global soil contamination underscores the severity and extensiveness of the problem which demands attention and action.

Soil contamination is linked to environmental and health concerns which have socio-economic implications. Aromatic hydrocarbons, particularly the polycyclic aromatic hydrocarbons (PAHs) are hydrophobic and are persistent in the aquatic and terrestrial environment where they frequently form a film on water surface or adsorb to sediment particles [11]. PAHs are known to demonstrate mutagenic and carcinogenic properties [11]. Trace metals such as ionic arsenic, cadmium, mercury and lead are highly toxic and methylated mercury exhibits higher toxicity than ionic mercury [5]. Toxicity associated with these contaminants can render the affected lands unsuitable for agriculture and habitation. This affects food production which impacts food security, and concurrently impedes residential and commercial development [4]. Bioaccumulation and biomagnification of the contaminants in the food chains, as well as direct exposure to the contaminants, can cause health problems such as poisoning and illnesses [2].

Rising demand for and use of fossil fuels and petrochemicals result in more and more lands being contaminated with petroleum hydrocarbons [12]. However, due to comparatively more widespread contamination of soil by trace elements, there is higher proportion of literature dedicated to phytoremediation of trace elements or heavy metals in soil. With mounting concerns on the impacts resulted from the presence of petroleum hydrocarbons in soil, there is a need to examine studies related to phytoremediation of soil contaminated with petroleum hydrocarbons. This review therefore aims to present the recent progress made in phytoremediating soil polluted by petroleum hydrocarbons and make recommendations for the way forward.
Methods of Remediating Soil Contaminated by Petroleum Hydrocarbons

Three groups of methods are commonly used for remediation of soil contaminated by petroleum hydrocarbons, i.e. physical methods, chemical methods and biological methods [11]. Physical methods include physical sorting, soil washing and electrokinetic remediation but soil washing using solvents and surfactants are more suitable for removal of petroleum residues [13]. Electrokinetic remediation was initially intended for removal of trace elements from soil using low intensity direct current discharged into soil via an array of electrodes [14]. The electric current induces electric gradient which propels movement of contaminants via mechanisms such as electro-osmosis and diffusion [15]. Electrochemical remediation was later modified to enable removal of organic contaminants particularly the water-soluble fractions and was used with other methods such as soil flushing to treat soil contaminated with both PAHs and trace elements [15].

Chemical methods are characterized by redox reactions, photochemical degradation and thermal desorption. These methods are often better-suited for remediation of petroleum hydrocarbons compared to the physical methods [11]. The redox remediation uses oxidizing agents like hydrogen peroxide and permanganate to break down aromatic hydrocarbons while photochemical degradation is a natural process where PAHs absorb ultraviolet rays of the sun and undergo photodimerization and photooxidation in the degradation pathways [16]. Thermal desorption is more accurately a physico-chemical method using heat to degrade and volatilize contaminants from the soil without combustion. This method is appropriate for removal of gaseous trace elements and volatile organic compounds [12].

Biological methods can be further classified into bioremediation and phytoremediation. Bioremediation applies microorganisms especially bacteria and fungi to remove soil contaminants or break them down into harmless compounds via, for instance mineralization during which contaminants are used to produce carbon and energy [17]. Bioremediation is effective against 2-ring and 3-ring PAHs but has limited ability to remove more resistant contaminants which eventually form toxic metabolites in the microorganisms [18]. Phytoremediation removes contaminants from the environment by using plants and their micro-symbionts. It also facilitates contaminants removal via amendment of soil and agronomic practices [18]. A few mechanisms are involved in phytoremediation, namely phytovolatilization, phytodegradation, phytoextraction, phytostabilization, phytostimulation and rhizofiltration (Figure 1).

Figure 1: Mechanisms of Phytoremediation [2,4].

Phytovolatilization is fundamentally the release of metabolites from the leaves and stems of plants into the air after the contaminants are absorbed by the roots (Figure 1). The contaminants might have been metabolized into less hazardous compounds or, in the case of the recalcitrant ones, might not have been rendered harmless. Therefore, phytovolatilization only
transfers contaminants from the soil to the air [14]. Phytodegradation uses plant enzymes such as dehalogenase and nitrilase to break down organic compounds (Figure 1). Symbiotic microorganisms also play crucial role in phytodegradation [2]. Rhizofiltration facilitates adsorption or precipitation of contaminants at the root zone and is the main mechanism for remediation of contaminated water bodies (Figure 1) [19]. Phytostimulation or rhizodegradation on the other hand, utilizes microorganisms attached to the rhizosphere of plants to break down organic contaminants and they benefit from the symbiotic relationship by having access to nutrients in root exudates secreted by plants (Figure 1) [2]. Phytostabilization and phytoextraction are more relevant to remediation of trace elements, via immobilizing the elements in the root zone in the former, as well as extracting and hyperaccumulating the elements in the latter [4].

**Phytoremediation of Petroleum Hydrocarbons**

Many plant species have been identified to possess the ability in remediating soil contaminated with petroleum hydrocarbons and phytoremediation has been subject to extensive studies over the years. Due to the number of studies conducted in this area, this review focuses on the studies conducted in the past 5 years starting from the most recent ones as shown in Table 1 below and does not attempt to cover all studies published in the period.

| Source | Soil contamination | Plant | Method | Parameter and Removal Rate | Duration |
|--------|--------------------|-------|--------|----------------------------|----------|
| Zhen et al., 2019 [20] | Petroleum | *Spartina anglica* | Spartina anglica cultivation with and without biochar, rhamnolipid and rhamnolipid-modified biochar | Total petroleum hydrocarbons (TPHs): Planted soil (19.1%); planted soil with biochar (27.7%); planted soil with rhamnolipid (32.4%); planted soil with rhamnolipid-modified biochar (35.1%) | 60 days |
| Baoune et al., 2019 [21] | Crude petroleum; pure PAHs (phenanthrene, pyrene and anthracene) | *Zea mays* | *Zea mays* seedlings inoculated with *Streptomyces* sp. Hlh1. | Petroleum crude hydrocarbons (70%); phenanthrene (61%); pyrene (59%) and anthracene (46%) | 14 days |
| Iqbal et al., 2019 [22] | Diesel | *Lolium perenne*; *Arabidopsis thaliana* | Plant-microbe phytoremediation system by inoculating the plants with *Pseudomonas* | TPHs: *L. perenne* (small variant) system (45.6%); *L. perenne* (jumbo variant) system (24.5%); *A. thaliana* system (6.2%) | 20 days |
| Author(s)                          | Contaminant | Plant(s)                              | Method/Screening Study                                      | TPHs:                                                                                       | Days |
|-----------------------------------|-------------|---------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------------------------------------|------|
| Tang & Angela, 2019 [12]          | Crude oil   | *Pteris vittata*; *Epipremnum aureum*; *Mucuna bracteata*; *Imperata cylindrica* | Screening study with plants commonly encountered in Malaysia at 5% crude oil contamination by weight | *Epipremnum aureum* (50.4%); *Imperata cylindrica* (39.5%); *Pteris vittata* (36%); *Mucuna bracteata* (30.9%) | 42   |
| Tang & Law, 2019 [7]              | Crude oil   | *Mucuna bracteata*                    | 5% contamination with fertilizer (36.8%) and without fertilizer (26.5%); 10% contamination with fertilizer (27.5%) and without fertilizer (26%); 15% contamination with fertilizer (32.4%) and without fertilizer (22.5%) | 63   |
| Rocha et al., 2019 [23]           | Petroleum   | *Helianthus Annuus*                   | Phyto remediation (PR), electrokinetic remediation (ER) – Reverse Polarity (RP), ER-direct current (DR), ER-PR-DR, ER-PR-RP | *PR* (16%); *ER-RP* (68%); *ER-DC* (57%); *ER-PR-DC* (76%); *ER-PR- RP* (84%) | 20   |
| Huang et al., 2019 [24]           | Diesel      | *Alternanthera philoxeroides*         | Soil diesel concentration: Without Se (20.1±0.55%); with Se (35.2±3.6%) | 60   |
| Hussain et al., 2018 [25]         | Crude oil   | Italian ryegrass (*Lolium multiflorum*) | Italian ryegrass (IR) cultivated with and without a combination of biochar (BC), compost (CM) and microbial consortia (MC) | *IR* with no amendment (47%); *IR+BC* (65%); *IR+CM* (70%); *IR+MC* (73%); *IR+BC+CM* (75%); *IR+BC+MC* (82%); *IR+CM+MC* (84%); *IR+BC+MC+CM* (85%) | 75   |
| Asemoloye et al., 2017 [26]       | Crude oil   | *Megathyrsus maximus*                 | Total polyaromatic hydrocarbons (TPAHs): Soil+plant (44.3%); soil+fungi-SMC mixture | 90   |
| Authors          | Type of Oil  | Species/Strain | Methodology                                                                 | Results                                                                                           | Time |
|------------------|--------------|----------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|------|
| Liao et al., 2016 [13] | Crude oil    | *Zea mays*     | Phytoremediation facilitated by two biosurfactants (rhamnolipid and soybean lecithin) and a synthetic surfactant (TWEEN 80) | TPHs: Soybean lecithin (62%); rhamnolipid (58%); TWEEN 80 (52%)                                    | 3 months |
| Kösesakal et al., 2016 [27] | Crude oil    | *Azolla filiculoides* | Azolla filiculoides cultivated in nitrogen-free Hoagland nutrient solution spiked with increasing crude oil from 0.005% to 0.5% by volume | Azolla filiculoides tolerant to 0.1% to 0.2% of crude oil. 0.05 – 0.2% oil contamination: Total aliphatic (94-73%); phenanthrene (81-77%) | 15 days |
| Hou et al., 2015 [28] | Petroleum    | *Testuca arundinacea* | Fertilized and unfertilized soil with and without *Testuca arundinacea* (TA) as well as with and without inoculation with plant growth promoting bacteria | Aliphatic hydrocarbons: Control – no fertilizer (28.5%); fertilizer (F) (43.1%); F+TA (52.9%); F+TA+ Klebsiella sp. (D5A) (62.6%); F+TA+ Pseudomonas sp. (SB) (67.9%) | 4 months |
Table 1 shows an increasing trend of studies on the synergistic effects of phytoremediation with other remediation methods such as bioremediation, surfactants and electrokinetic remediation though conventional phytoremediation studies with and without addition of fertilizer have also been conducted [13,21,23]. Phytoremediation studies have conventionally been associated with biostimulation via addition of fertilizers [7], but have lately been increasingly linked to bioaugmentation with bacteria or fungi [26,28]. There is also interest to examine the effect Se in increasing the efficiency of phytoremediating plant [24]. The common plants used for phytoremediation studies are Zea mays, Helianthus Annuus, Sorghum bicolor, and Lolium multiflorum though the list of plants with phytoremediating ability is growing with new additions from screening studies. Examples of the new additions are Azolla filicuïlodes, Mucuna bracteata and Epipremnum aureum.

The duration of phytoremediation studies in Table 1 ranges from 14 days to 5 months and the hydrocarbon removal rates do not correspond with the duration of study. In fact, the methods and plants used have greater influence on hydrocarbon removal. For instance, in 14 days, Baoune et al. reported removal of up to 70% of petroleum crude hydrocarbons and 61% of phenanthrene from soil [21]. Kösesakal et al., however, reported up to 94% total aliphatic removal from liquid medium contaminated with 0.05–0.2% crude oil and the removal rates decreased with increasing levels of contamination [27]. In the case of soil contamination, higher removal rates are often achieved when phytoremediation is used with bioaugmentation particularly with selected
Conclusion

This review demonstrates that current phytoremediation studies are moving in the direction of examining the synergy between phytoremediation and other remediation methods. This review also underscores the potential discovery of new plants with ability to phytoremediate soil contaminated with petroleum hydrocarbons. It recommends that future studies can continue to look into applying phytoremediation with other remediation methods particularly electrokinetic method. Further studies can also explore the potential synergy between phytoremediation and chemical remediation which has not received as much attention as the association of phytoremediation with physical remediation and bioremediation.

References

1. Tang KHD, Dawal SZM, Olugu EU. 2018. A review of the offshore oil and gas safety indices. Safety Science.109: 344-352. Ref.: https://bit.ly/2OIEJLX
2. Germida JJ, Frick CM, Farrell RE. 2002. Phytoremediation of oil-contaminated soils. Elsevier. 28: 169-186. Ref.: https://bit.ly/34NKaoM
3. Tang DKH, Dawal SZM, Olugu EU. 2018. Actual safety performance of the Malaysian offshore oil platforms: Correlations between the leading and lagging indicators. Journal of Safety Research. 66: 9-19. Ref.: https://bit.ly/384XuN
4. Dickinson N. 2017. Phytoremediation. In Encyclopedia of Applied Plant Sciences (Second Edition). B. Thomas, B. G. Murray and D. J. Murphy, Eds. Oxford, Academic Press, 327-331. Ref.: https://bit.ly/33FWq32
5. Agnello AC, Bagard M, van Hullebusch ED, et al. 2016. Comparative bioremediation of heavy metals and petroleum hydrocarbons co-contaminated soil by natural attenuation, phytoremediation, bioaugmentation and bioaugmentation-assisted phytoremediation. Science of The Total Environment. 563-564: 693-703. Ref.: https://bit.ly/2qYW1R9
6. Oldeman L. 1991. World map on status of human-induced soil degradation. Wageningen, Netherlands. Ref.: https://bit.ly/2sHuejz
7. Tang KHD, Law YWE. 2019. Phytoremediation of Soil Contaminated with Crude Oil Using Mucuna Bracteata. Research in Ecology.1: 20-30. Ref.: https://bit.ly/2DGuOjy
8. EEA. 2014. Progress in management of contaminated sites. [Online]. Ref.: https://bit.ly/2OJHkW0
9. US EPA. 2013. Projecting and restoring land: Making a visible difference in communities: OSWER FY13 end of year accomplishment report. [Online]. Ref.: http://tiny.cc/itq6gz
10. DECA. 2010. Assessment levels for soil, sediment and water. [Online]. Ref.: http://tiny.cc/huq6gz
11. Abdel-Shafy HI, Mansour MSM. 2016. A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. Egyptian Journal of Petroleum. 25: 107-123. Ref.: http://tiny.cc/qq6gz
12. Tang KHD, Angela J. 2019. Phytoremediation of crude oil-contaminated soil with local plant species. IOP Conference Series: Materials Science and Engineering. 495: 12054. Ref.: http://tiny.cc/fsq6g2
13. Liao C, Xu W, Lu G, et al. 2016. Biosurfactant-enhanced phytoremediation of soils contaminated by crude oil using maize (Zea mays. L). Ecological Engineering. 92: 10-17. Ref.: http://tiny.cc/e0q6g7
14. Pazos M, Rosales E, Alcántara T, et al. 2010. Decontamination of soils containing PAHs by electroremediation: A review. Journal of Hazardous Materials. 177: 1-11. Ref.: http://tiny.cc/svs6gz

15. Moghadam MJ, Moayedi H, Sadeghi MM, et al. 2016. A review of combinations of electrokinetic applications. Environmental Geochemistry and Health. 38: 1217-1227. Ref.: http://tiny.cc/89s6gz

16. de Bruyn WJ, Clark CD, Ottelle K, et al. 2012. Photochemical degradation of phenanthrene as a function of natural water variables modeling freshwater to marine environments. Marine Pollution Bulletin. 64: 532-538. Ref.: http://tiny.cc/det6gz

17. Guarino C, Spada V, Sciarrillo R. 2017. Assessment of three approaches of bioremediation (natural attenuation, landfarming and bioaugmentation – assisted Landfarming) for a petroleum hydrocarbons contaminated soil. Chemosphere. 170: 10-16. Ref.: http://tiny.cc/1gt6gz

18. Wang MC, Chen YT, Chen SH, et al. 2012. Phytoremediation of pyrene contaminated soils amended with compost and planted with ryegrass and alfalfa. Chemosphere. 87: 217-225. Ref.: http://tiny.cc/ijt6gz

19. Sánchez-Galván G, Bolanos-Santiago Y. 2018. Phytofiltration of anaerobically digested sugarcane ethanol stillage using a macrophyte with high potential for biofuel production. International Journal of Phytoremediation. 20: 805-812. Ref.: http://tiny.cc/vlt6gz

20. Zhen M, Chen H, Liu Q, et al. 2019. Combination of rhamnolipid and biochar in assisting phytoremediation of petroleum hydrocarbon contaminated soil using Spartina anglica. Journal of Environmental Sciences. 85: 107-118. Ref.: http://tiny.cc/int6gz

21. Baoune B, Aparicio JD, Acuña A, et al. 2019. Effectiveness of the Zea mays-Streptomyces association for the phytoremediation of petroleum hydrocarbons impacted soils. Ecotoxicology and Environmental Safety. 184: 109591. Ref.: http://tiny.cc/0qt6gz

22. Iqbal A, Mukherjee M, Rashid J, et al. 2019. Development of plant-microbe phytoremediation system for petroleum hydrocarbon degradation: An insight from alkb gene expression and phytotoxicity analysis. Science of The Total Environment. 671: 696-704. Ref.: http://tiny.cc/jtt6gz

23. Rocha IMV, Silva KNO, Silva DR, et al. 2019. Coupling electrokinetic remediation with phytoremediation for depolluting soil with petroleum and the use of electrochemical technologies for treating the effluent generated. Separation and Purification Technology. 208: 194-200. Ref.: http://tiny.cc/rxt6gz

24. Huang Y, Song Y, Johnson D, et al. 2019. Selenium enhanced phytoremediation of diesel contaminated soil by Alternanthera philoxeroides. Ecotoxicology and Environmental Safety. 173: 347-352. Ref.: http://tiny.cc/bzt6gz

25. Hussain F, Hussain I, Khan AHA, et al. 2018. Combined application of biochar, compost, and bacterial consortia with Italian ryegrass enhanced phytoremediation of petroleum hydrocarbon contaminated soil. Environmental and Experimental Botany.153: 80-88. Ref.: http://tiny.cc/m1t6gz

26. Asemoloye MD, Ahmad R, Jonathan SG. 2017. Synergistic action of rhizospheric fungi with Megathyrsus maximus root speeds up hydrocarbon degradation kinetics in oil polluted soil. Chemosphere. 187: 1-10. Ref.: http://tiny.cc/35t6gz
27. Kösesakal T, Ünal M, Kulen O, et al. 2016. Phytoremediation of petroleum hydrocarbons by using a freshwater fern species Azolla filiculoides Lam. International Journal of Phytoremediation. 18: 467-476. Ref.: http://tiny.cc/cbu6gz

28. Hou J, Liu W, Wang B, et al. 2015. PGPR enhanced phytoremediation of petroleum contaminated soil and rhizosphere microbial community response. Chemosphere. 138: 592-598. Ref.: http://tiny.cc/pdu6gz

29. Moubasher HA, Hegazy AK, Mohamed NH, et al. 2015. Phytoremediation of soils polluted with crude petroleum oil using Bassia scoparia and its associated rhizosphere microorganisms. International Biodeterioration & Biodegradation. 98: 113-120. Ref.: http://tiny.cc/lfu6gz

30. Ribeiro H, Mucha AP, Almeida CMR, et al. 2014. Potential of phytoremediation for the removal of petroleum hydrocarbons in contaminated salt marsh sediments. Journal of Environmental Management. 137: 10-15. Ref.: http://tiny.cc/7hu6gz

31. Bramley-Alves J, Wasley J, King CK, et al. 2014. Phytoremediation of hydrocarbon contaminants in subantarctic soils: An effective management option. Journal of Environmental Management. 142: 60-69. Ref.: http://tiny.cc/aou6gz