PLANT STUDY OF PORTULACA GRANDIFLORA IN GREEN ROOF APPLICATION FOR RAINWATER HARVESTING

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PLANT STUDY OF PORTULACA GRANDIFLORA IN GREEN ROOF APPLICATION FOR RAINWATER HARVESTING

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ABSTRAK

Bumbung hijau merupakan salah satu teknologi atau pendekatan terkini untuk mengatasi kesan negatif pembandaran. Namun begitu, kebanyakan penyelidik percaya bahawa bumbung hijau dapat bertindak sebagai sumber pencemaran. Untuk mengatasi masalah ini, Portulaca Grandiflora dipilih sebagai komponen vegetatif yang berpotensi untuk mengurangkan pencemaran dalam sistem bumbung hijau dengan menggunakan teknik fitopemulihan. Oleh itu, model rumah hijau yang berukuran 20cm x 20cm x 45cm dibahagikan kepada dua jenis termasuk Sampel lajur kawalan dan Sampel lajur pokok. Peratusan penyingkiran parameter antara Sampel lajur kawalan dan Sampel lajur pokok diperhatikan selama 4 minggu. Dalam uji kaji ini, peratusan purata penyingkiran parameter yang direkodkan oleh Portulaca Grandiflora adalah 32.24% (Keperluan Oksigen Kimia), 44.79% (Jumlah Fosforus), 37.20% (Kekeruhan), 34.67% (Warna), 39.04% (Besi), dan 82.02% (Zink). Sebaliknya, julat purata nilai pH dalam sampel Portulaca grandiflora adalah dari 6.48 sehingga 7.16. Sementara itu, dalam jangka waktu uji kaji yang singkat, perubahan nilai TKN oleh Portulaca Grandiflora tidak dapat diperhatikan kerana sistem belum stabil. Hasilnya, nilai air hujan setelah dirawat untuk setiap parameter berada dalam nilai yang dapat diterima (kelas IIA/IIB) apabila dibandingkan dengan piawaian kualiti air kebangsaan dan hanya memerlukan rawatan konvensional untuk kegunaan bekalan air. Oleh itu, Portulaca Grandiflora sesuai digunakan sebagai tumbuh-tumbuhan dalam sistem bumbung hijau kerana mampu menyingkirkan bahan pencemar yang ada di dalam sistem.

ABSTRACT

A green roof is one of the current technology or approach to counter the negative impacts of urbanization. Instead of that, many researchers believe that the green roof can act as a source of contaminants. To solve this problem, the Portulaca Grandiflora was chosen as potential vegetative components to reduce the contaminants in the green roof system by using phytoremediation techniques. Thus, the greenhouse model with a size of 20cm x 20cm x 45cm was divided into two types which include Control column sample and Plant column sample. The percentages removal of the parameters between Control column and Plant column sample were observed for 4 weeks duration. In this experiment, the average percentage removal of the parameters recorded by the Portulaca Grandiflora was 32.24% (COD), 44.79% (TP), 37.20% (Turbidity), 34.67% (Colour), 39.04% (Iron), and 82.02% (Zinc). On the other hand, the average range of pH value in Portulaca grandiflora sample was from 6.48 to 7.16. In the short period of time experiment, the changes of TKN value by Portulaca Grandiflora could not be observed as the system was not yet stabilize. The after-treatment values for each parameter fell within class IIA/IIB when compared to the NWQS values, which will just require the conventional treatment for water supply usage. Therefore, the Portulaca Grandiflora has a potential to be used as vegetation in the green roof system as its capable of removing the contaminants in the system.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
HTC	Humid Tropic Centre
mg/L	Miligram per Litre
NTU	Nephelometric turbidity Unit
NWQS	National Water Quality Standard
pH	Potential Hydrogen
SUDS	Sustainable Urban Drainage System
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
UPW	Ultrapure Water
WHO	World Health Association
XRF	X-Ray Fluorescence

LIST OF SYMBOLS

Al	Aluminium
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Hg	Mercury
K	Potassium
Mg	Magnesium
Mn	Manganese
N	Nitrate
Na	Sodium
NH_4	Nitrogen Ammonia
Ni	Nickel
Pb	Lead
Se	Selenium
Ti	Titanium
V	Vanadium
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Background

Many nations, including Germany, Sweden, the United States, the United Kingdom, Japan, and Singapore, are becoming more interested in green roofs or also known as vegetated roofs (Vijayaraghavan *et al*., 2012). Nowadays, the green roofs, which are urban rooftops covered with plants, have inspired many researchers' attention due to their significant advantages and acknowledgment in many countries as a future best management practice. A vegetated roof is created by planting vegetation on the roof of a building using specific engineering techniques. It is a modern method to restore an environment that had been destroyed by rapid building expansion as a result of rural migration to urban areas (Vijayaraghavan *et al*., 2019). Green roofs are one choice for reducing the negative effects of urbanization while also providing various economic and social advantages. Moreover, it also gives more apparent environmental advantages (Vijayaraghavan and Joshi, 2014).

Besides, green roofs in various countries are now becoming increasingly popular because of their unique environmental, economic, and social advantages. The concept of this green roofs consist of planting vegetation in building ceilings above the growth medium (substrate) (Vijayaraghavan *et al*., 2017). Urban areas which have more radiation absorption, a higher capacity for releasing heat, and higher thermal conductivity, are rapidly increasing as the landscape is covered with buildings and paved surfaces such as roads and parking lots. The rising of thermal capacity of the urban areas in addition with lack of water lead to the increasing of local temperature of cities compared to the surrounding of rural parts. Generally, the cities contribute the most to the climate change as the number of urban buildings increased. Expanding the green infrastructure is required to recover or restore the urban areas to their environment functionality before the urban development (Jahangir *et al.*, 2020).

On the other hand, green roofs are also one of the best solutions for addressing flooding issues in high-density urban areas. As indicated by the Sustainable Urban Drainage Systems (SUDS) philosophy, modern stormwater management methods must control runoff quantity, resolve urban water quality issues, and provide amenity value. The green roofs have ability to accomplish all three goals simultaneously, and these truly represent an opportunity for engineering to collaborate with natural environmental processes to help create more sustainable urban environments (Stovin, 2010). It is because the development of a green roof demands sufficient engineering expertise, as all the vital design components should be incorporated, including system weight, the compatibility of suggested plants and the environmental aspects in the areas (Amala, 2020).

The green roofs have two major types, which are extensive roofs and intensive roofs. Commonly, green roofs with a substrate depth of 100 mm to 250 mm are classified as extensive roof while an intensive roof has more than 300 mm of substrate depth. The extensive roofs have light and a thin layer of vegetation. In contrast, the intensive roofs are heavier compared to the extensive roofs. The intensive roofs also have shrubs and small trees in a depth of more than 20 cm in their substrate (Jahangir *et al.*, 2020). While the hydrology of green roofs has received a lot of attention, few researchers have analysed the effect of water quality discharged from green roof systems (Razzaghmanesh *et al*., 2014).

Besides, the basic vegetated roof design consists of several components that include plants at the top, followed by growth substrate, filter component, drainage element, a water-proof membrane, and roof deck. Some cases also include a protection layer, a root barrier, which is the intensive roofs, and an insulation layer. Usually, the visual success of the vegetated roofs is determined by the plants on the uppermost layer. Several improvement issues such as the air quality, thermal performance, and heat-island are highly influenced by the type of plants grown and substrate on a vegetated roof (Vijayaraghavan *et al*., 2019). Thus, the vegetation and growth substrate are two of the most important factors in determining the quality of runoff. Generally, drought tolerance, ground covering ability, and aesthetics are the factors in selecting green roof plants (Vijayaraghavan and Joshi, 2014). On the other hand, the drainage layer has an important role in vegetated roofs because it keeps the substrate from becoming waterlogged and aerated, which is necessary for healthy plant growth. During dry periods, plants may use the water stored between the pores of the drainage material or in the compartments of drainage plastic modules (Vijayaraghavan *et al*., 2019).

Green roofs are beneficial for both cities and the environment (Jahangir *et al.*, 2020). It provides several positive effects in the urban setting and the most important effects of green roofs are their ability to retain and detain storm water, reduce urban heat islands, reduce building energy consumption by cooling roofs during summer months, create habitats for certain plants and animals, improve urban biodiversity and lastly, their aesthetic appeal. Thus, green roofs play a vital role in modern urban drainage due to their ability to slow down and reduce runoff volume (Vijayaraghavan *et al*., 2012).

1.2 Problem Statement

For all of that, there is an important factor which is often overlooked in design of green roof which is the runoff quality from green roofs. In theory, green roofs have the potential to act as pollution adsorbents and filters (Vijayaraghavan *et al*., 2012). However, Cristiano *et al.* (2021) mentioned that a green roof can also act both as a sink and source of pollution for rainwater. Some contaminants could be release from soil although they are designed to improve the water quality. In addition, Vijayaraghavan *et al*. (2012) also mentioned that nutrients emitted from soil, plants and fertilizers have the potential to degrade the quality of receiving water.

There are many researchers that investigated water quality and quantity issues which conducted on vegetated roofs have shown that vegetated roofs behave as a source of contaminants, particularly heavy metals (Vijayaraghavan *et al*., 2012; Razzaghmanesh *et al*., 2014). It is known that heavy metal usually considered as major pollutants of the environments which causing pollution of air, water, and soil (Mitra *et al.*, 2017). Moreover, heavy metals are of great concern because of their ability to accumulate and persist in the natural environment, as they are not biodegradable and tend to last longer (Gayatri *et al*., 2019).

Nevertheless, there have not been many attempts to improve the quality of green roof runoff (Vijayaraghavan and Joshi, 2014). Thus, it is vital to conduct further research into the quality of runoff from green roofs. There are few methods to enhance the water quality runoff which are in term of substrate and vegetation (Vijayaraghavan *et al.*, 2012). In this study, it will focus more on the vegetation to improve water quality runoff using the phytoremediation techniques.

As mentioned before, the degradation of the quality runoff water also come from the plants or vegetations of the green roof. There are some researchers who agree that various plant species give impact on runoff water quality. The investigation of many vegetation species by (Rowe *et al.*, 2012) observed that the efficiency of the plants and the overall performance of the green roof are influenced by the amount of moisture, the growth of the vegetation and biodiversity. As a result, plant species must be chosen in a way that is suitable for both the green roof ecosystem and runoff water quality requirements (Hashemi *et al*, 2015).

1.3 Objectives

The main objectives of this research are summarized as below:

a) To determine suitable plant for green roof application based on past research.
b) To determine the improvement on water quality runoff in green roof using phytoremediation techniques.

1.4 Scope of Work

This thesis is more focused on identifying any plant that can be used as a vegetation for a green roof to improve its runoff quality using phytoremediation techniques. Phytoremediation is the usage of plants and their associated microorganisms in the soil to remove pollutants or render them harmless, including organic compounds, radiological contamination, and heavy metals. This process provides an easy, cheap, and safe solution to remediate contaminated sites, and is based upon many considerations, including the pollutant toxicity and concentration effectiveness of pollutant removal or stabilization in a short period; in addition to public and environmental benefits of remediation process (Mouhamad *et al.*, 2020).

Vegetation plant of green roof can be divided into different parts of the plant which are root, stem and leaf. Green roof plants are usually selected based on their drought tolerance, ground covering ability and aesthetics. The identified selected plant also can be compared in term of their performance on water quality improvement from past researchers. Portulaca grandiflora have been chosen based on literature review to be tested as vegetation plant in this research for improving runoff quality for green roof application. Comparison of the efficiency of water treatment is based on Chemical Oxygen Demand (COD), pH, Turbidity, Colour, Heavy metal (zinc and Iron), Total Kjeldahl Nitrogen and Total Phosphorus.

1.5 Limitation of Work

All the laboratory testing cannot be completed for both samples in one day. This can give an effect on the data obtained. Besides, calibration of equipment is very important before starting any test. This is because the equipment will be used so many times during the project duration. Therefore, the reading will not be accurate if calibration work is not given attention. In addition, the entire reagent must be ready in the lab before starting any test. This is because the reagent is very important to be prepared early to run the required testing. The experiment will be delayed and take much longer time for completion if the reagent is not available. Furthermore, this research study also need rainwater, thus the experiment only can be conducted after rainy day. This research study is related to plant which required sufficient light to ensure the plant can survive. Therefore, for future research, make sure that the plant is properly exposed to enough lighting.

1.6 Dissertation Outline

This Dissertation outline contains of five chapters which are Chapter 1 (Introduction), Chapter 2 (Literature Review), Chapter 3 (Methodology), Chapter 4 (Result and Discussion), and Chapter 5 (Conclusion and Future Recommendation). The outline thesis of Chapter 1 consists of background of green roof for rainwater harvesting, the problem statement that have been identified, followed by research objectives to describe the desired goal, and scope of Work. Besides, Chapter 2 consist of literature review which describes various relevant case study from past research. This chapter focus on the explanation of contaminant that have been found in rainwater collected from rooftop, the process of phytoremediation techniques by the vegetation and possible plant that can be applied in this research study. While the Chapter 3 explains the experimental set up, water sampling, and the methodology or procedure during handling the material and equipment for testing in laboratory. Chapter 4 focussed on the explanation of the result and discussion of the data obtained in laboratory. The first section of this chapter describes the overview and the raw characteristic of rainwater in USM. The second section discussed the result and performance of removal contaminant by portulaca grandiflora to improve water quality in green roof application. The result of initial rainwater and plant column sample (after treatment) also have been compared with National Water Quality

Standard (NWQS). Lastly, Chapter 5 provides the conclusion and the recommendation for future work based on the research findings and comments.

CHAPTER 2

LITERATURE REVIEW

2.1 Rainwater Quality

Rainwater harvesting is an alternative water supply source that can be used for both potable and non-potable purposes (Rahman *et al.*, 2014). It could help in the storage of treated rainwater for more beneficial use as well as flood mitigation (Kasmin *et al.*, 2016). Microbes (heterotrophic plate count and coliform), organic content (carbon and nitrogen), heavy metal dust such as Hg, Pb, Cu, Fe, Mn, Zn, Cu, and Ni, fine particles (turbidity and solids), and ions (Ca, Mg, Na, K, nitrates, and sulfates) are the most common impurities or physicochemical qualities investigated in harvested rainwater (Shaheed *et al.*, 2017). Disinfection processes or the induction of a biofilm can be used to treat microorganisms, but particulate matter can only be effectively extracted with effective storage tank design parameters (Won *et al.*, 2019).

Rainwater is relatively impurity-free, but it becomes polluted during precipitation by contaminants in the atmosphere (Shaheed *et al.*, 2017). By using rainwater as an alternative, clean water can be saved and reused for other purposes. At the same time, it also reduces the need for clean water, which would result in lower water bills and water plant operating costs (Muhamad and Abidin, 2016). In general, the occurrence and concentrations of organic, inorganic, physical, and biological impurities are influenced by a number of factors, including roof characteristics, meteorological factors, roof location, hydrological aspects, substance chemical properties, and storage content (Shaheed *et al.*, 2017).

As Malaysian land is blessed with higher intensity rainfall, rainwater will be wasted, and downstream areas will be flooded if adequate management is not in place to handle the abundant water. Moreover, this could cause in scarcity of clean water (Kasmin *et al*., 2016). On the other hand, when dealing with rainwater applications, two crucial considerations must be considered which are water quality standards and potential applications (Muhamad and Abidin, 2016). Besides, the location where rainwater is collected is also critical in deciding the quality of the water collected. For instance, the water collected in rural catchment areas is often of higher quality than water collected near industrial areas (Shaheed *et al*., 2017). There were few researchers conducted studies on the quality of the rainwater runoff, which had defined a few important parameters or findings regarding the rainwater quality (Muhamad and Abidin, 2016; Igbinosa and Aighewi, 2017; Gav *et al.*, 2018; Sulaiman et al., 2018).

2.1.1 pH

The pH measurement is necessary to determine the chemical properties and behaviour of a material (Khan *et al.*, 2017). The pH measurement is designed to measure hydrogen ion activity in a solution (Gomori, 2011). The solution is acidic for pH ranges from 1 to 6, pH 7 is neutral, and the solution is basic for the pH range between 9–14. Therefore, pH control is vital to prevent and control undesirable chemical reactions and maximize the desired beneficial reactions (Khan *et al.*, 2017). A study was carried out by Muhamad and Abidin (2016) that the pH of rainwater ranged from 5.84 to 7.02. It can be observed that the value of pH is increases to normal value as the increase of duration of rain. There are many reasons due to changes of pH, which were rainwater that falls through is a little bit acidic because of the presence of CO_2 in the atmosphere, the emission of gasses from a vehicle and the mixed roof system in leaves, dust, and bird dung (Muhamad and Abidin, 2016).

While other researchers such as Sulaiman *et al.*, (2018) recorded pH of rainwater was marginally higher in the dry season, at 6.72, than in the wet season, at 6.39. Although the wet season's pH value was below the minimum suggested pH value (6.5), the rainwater collected was regarded as safe to consume. This is because the only pH of less than four (pH<4) or greater than eleven (pH>11) drinking water might have a negative impact on the consumers (Sulaiman *et al*., 2018). In addition, Osang *et al.* (2017) research demonstrates that the pH of gas is changing from highly acid (3.5-4.4) to slightly alkaline (7.9-8.4) away from gas flare-up points. Hence, the pH value was over the limit of WHO, which could have negative impacts on communities. Unacceptable pH limits, negatively affect human beings and the environment, particularly the socio-economic activities of residents. Besides, the pH readings for numerous gas flare areas were generally lower than 5.6 (WHO 1970 rain acidity limit) (Osang *et al.*, 2017).

Lastly, the rainwater collected from roofs that come into touch with cement and ceramic tiles could raise the pH of the rainwater to 7.0. This could benefit in minimizing the acidity of the water, but it raises the risk of producing bacteria that are harmful to health because a neutral pH is perfect for their multiplication (Zdeb *et al.*, 2020). As a result, pH is an important environmental monitoring indicator (water quality) (Khan *et al.*, 2017).

2.1.2 Turbidity

Turbidity is the ability of water to scatter and absorb light. Turbidity is crucial in water quality treatment processes such as coagulation, settling, and filtration of undissolved particles. The turbidity and nitrate concentrations are at the peak during significant rain events (Jabeen *et al.*, 2014). Material that becomes mixed and suspended in the rainwater will reduce its clarity and make the water turbid (Muhamad and Abidin, 2016). Low levels of turbidity and TDS concentrations show the rainwater is clear (Payus and Meng, 2015). Based on data reported by Muhamad and Abidin (2016), the range turbidity content in the samples of rainwater is 6 NTU to 19 NTU. The turbidity value is high at the early rainfall since the rainwater flushes the contaminant away from the roof.

When the duration of rain increases, the particle is flushed away. Hence turbidity decreases as the rain time increases (Muhamad and Abidin, 2016). The rainwater turbidity measurements provided indicate that this parameter is affected by the roughness of the roof-covering material. The rainwater turbidity increases with the roughness of the roof surface (Zdeb *et al.*, 2020). According to (Igbinosa and Aighewi, 2017), the rainwater samples' turbidity results ranged from 1.05 ± 0.01 to 7.24 ± 2.15 nephelometric turbidity unit (NTU). It is also stated that high turbidity for a short time is not as dangerous as low turbidity, which lasts for a long time.

2.1.3 Heavy Metals

Water pollution by heavy metals is a significant environmental issue for the modern world (Dushenkov *et al.*, 1995). It also cannot be destroyed by debasement or degradation. Heavy metals often contaminate the soil and water. It is usually exposed directly or indirectly to the environment through various human land and water activity (Urning *et al.*, 2016). In addition, the material in the roof can chemically pollute rainwater that contains heavy metals such as Pb and Zn. Besides, greater Pb and Cu detected in rainwater may also be attributed from traffic pollution, lead flashing and roof leaching (Payus and Meng, 2015). The data obtained by Muhamad and Abidin (2016) show that the average heavy metal parameter's reading of Fe^{2+} and Zn^{2+} obtained through this research is 0.1 mg/L and 0.05 mg/L. The present of Fe^{2+} and Zn^{2+} in the rainwater is influenced by the roof's material. Both heavy metals in the rainfall are caused by rusting of the gutter and the downpipe. The greater the rust in the gutter and downpipe, the greater the Fe^{2+} concentration (Muhamad and Abidin, 2016).

Moreover, (Gav *et al.*, 2018) observed that the concentration of Zn, Fe, Cu, and Cd in rainwater from rusted roofing sheets was highest, followed by corrugated roofing sheets. The least concentration was found in rainwater from ordinary roofing sheets. Therefore, the collected rainwater for human consumption is not safe from rusted roofing sheets. Lastly, Sulaiman *et al*. (2018) was carried research in terms of seasonal change, all Heavy Metals (Al, Cu, Mn, Zn) showed no major difference between seasons. It also has been observed that Al and Mn are more concentrated in the dry season than in the wet season, while Cu and Zn concentrations in rainwater are vice versa (Sulaiman *et al*., 2018).

2.1.4 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is an organic material concentration that can be chemically oxidized into inorganic compounds. When wastewater streams containing large-scale COD are discharged to natural waters, severe consequences such as the depletion of oxygen can occur, resulting in the death of fish from a shortage of oxygen consumed by bacteria. Therefore, it is essential that this organic substance is reduced to the degree considered appropriate for natural release (Zahler *et al.*, 2018). According to Muhamad and Abidin (2016), the rainwater quality for the COD concentration result is ranged between 1.0 mg/L and 35.0 mg/L. The COD measurement is high during the early interval. This is due to the high level of pollutant existed on the roof. With increasing rain intensity, the roof will be cleaned as the water washes the contamination off the roof. Therefore, the concentration of COD diminishes over time. The large range of organic compounds chemically oxidized on the roof will increase COD (Muhamad and Abidin, 2016). Moreover, (Igbinosa and Aighewi, 2017) reported that chemical oxygen demand (COD) values ranged between 3.87 and 30.26mg/L. The low COD means that biological materials or organic components are comparatively low in the rainwater that is collected. In general, COD showed the oxygen level used to oxidize the organic material in the water (Igbinosa and Aighewi, 2017).

2.2 Phytoremediation Techniques

Nowadays, phytoremediation is an emerging environmentally sustainable approach that can extract heavy metals from the soil as well as other chemical pollutants. Generally, phytoremediation is a concept that refers to the use of vegetation to clean up the ecosystem (Patel *et al.*, 2013). This method is commonly used to remove or contain different types of contaminants in water, soil, or sediments by using green plants (Suelee *et al.*, 2017). For instance, phytoremediation techniques help in the natural uptake of metals from polluted soils via the roots of vegetation using a combination of soil amendments. It also helps in accumulates the metals into the plant's harvestable parts, which, together with bioaccumulation, translocation, and the capability of the plant's body to degrade them (Gayatri *et al*., 2019).

Simply stated, the mechanism of this phytoremediation technique involves the absorption of pollutants through roots, accumulation in body tissues, decomposition, and transformation of contaminants into less harmful forms (Ansari *et al.*, 2020). According to Ansari *et al.* (2020), there are several phytoremediation methods which used in different media have been extensively discussed by various workers worldwide. Moreover, phytoremediation is a cost-effective method and relevant clean up technology for eliminating contaminants and harmful chemicals which is organic and inorganic pollutants from water (Suelee *et al.*, 2017) and also soils (Mouhamad *et al*., 2020).

Besides, in comparison to other traditional methods, phytoremediation is a low-cost, simple-to-understand, natural process (Awan *et al.*, 2020), and safe solution to remediate contaminated sites (Mouhamad *et al*., 2020). As a green invention, it is possible for various forms of natural and inorganic toxics, which offers stylish benefits to the world by planting trees and building green spaces (Awan *et al.*, 2020). On the other hand, phytoremediation has several other advantages that make it a globally feasible technology, such as the lack of high-tech equipment or materials, ease of maintenance in terms of supply and energy using solar power, suitability for shallow depth polluted water to hydrologic regulation of groundwater, and the ability to handle a number of contaminations at once (Farraji, 2016).

As mentioned before, the phytoremediation technique is using green plants for extracting the various type of contaminants in different mediums. Therefore, the effective technique for improving the green roof runoff quality is to choose plants with high phytoremediation potential. It is because the plants with a high potential of phytoremediation could degrade the soil metal concentration, hence enhance the runoff quality from green roofs. This approach is composed of four different plant-based methodologies which are phytostabilization, phytoextraction, phytovolatilization, and rhizofiltration, also known as phytofiltration (Vijayaraghavan *et al*., 2019).

2.2.1 Phytostabilization

Phytostabilization is the use of metal-tolerant plants to minimize airborne transport and contaminant leaching while avoiding bulk erosion. Ideally, in the presence of high heavy metal concentrations, plants can grow a robust root system and a large amount of biomass, thus minimizing root-to-shoot translocation (Alkorta *et al*., 2010). This technology is applied to reduce the bioavailability of contaminants in the atmosphere and to stabilize pollutants rather than eliminating them, usually the metallic elements through plants. Moreover, plants also can assist in the stabilization of contaminants by adsorbing them or accumulating them in their root systems and it is categorized by a restricted ability to relocate them to their above-ground pieces (Farraji, 2016; Radziemska, 2018). Thus, plant selection for phytostabilization is an essential issue, and commonly the perennial species that are well suited to their local climate, produce a lot of biomass, and have a lot of pollution resistance are recommended (Farraji, 2016).

Besides, phytostabilization is considerably less expensive than other remediation methods like capping and soil removal. However, it has significant setup and ongoing costs. Phytostabilization may be used to establish an ecosystem of native flora and fauna, thus increasing the site's ecological benefit. Phytostabilization can be boosted by increasing plant growth and adjusting metal(loid) bioavailability with organic and inorganic amendments as shown in Figure 2.1 (Bolan *et al.*, 2011). Furthermore, phytostabilization is also acknowledged as the most promising phytoremediation technique for mine tailings site remediation. It is because this approach increases the diversity of vegetation and microbial species in mine tailings, enhances soil fertility, decreases wind and water erosion, and increases heavy metal bioavailability (Luo *et al.*, 2019).

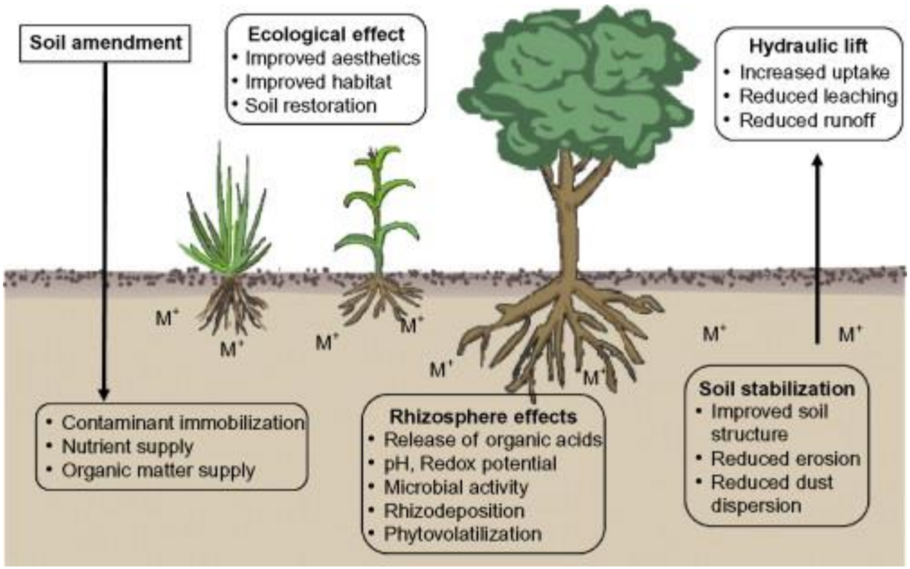

Figure 2.1: Schematic diagram illustrating the potential action of phytostabilization on contaminants in soil (Bolan *et al.*, 2011)

2.2.2 Phytoextraction

Phytoextraction is the process of removing Heavy Metal from a matrix by allowing a plant to absorb it (Suman *et al.*, 2018). It appears to be the most promising method, and researchers have been paying more attention to it since Chaney (1983) suggested it as a technology for reclaiming metal-polluted soils (Nascimento and Xing, 2006). Besides, phytoextraction also represents a green and environmentally friendly method of cleaning metal-polluted soils and water by making use of the harvestable parts of plants to remove pollutants as shown in Figure 2.2. Thus, this extraction method is dependent on the ability of selected plants to develop and accumulate metals in the remediated site's specific climatic and soil conditions (Nascimento and Xing, 2006).

Nowadays, there are some approaches which have been used for the extraction technique which includes the use of hyperaccumulators, plants with exceptional natural metal-accumulating ability, and high-biomass crop plants like corn, barley, peas, oats, rice, and Indian mustard with a chemically enhanced system of phytoextraction (Nascimento and Xing, 2006). According to (Suman *et al.*, 2018), there are three specific strategies can be considered by differing the plant’s species used which includes natural hyperaccumulators, fast growing plant species with high-biomass production, and genetically engineered plants.

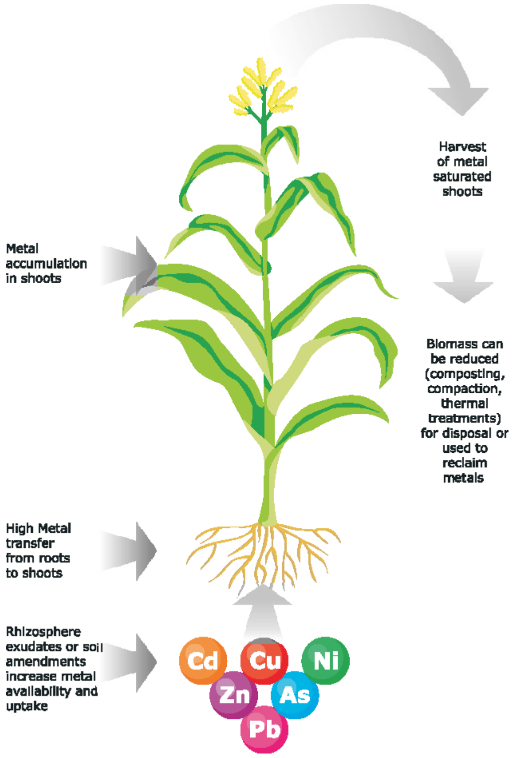

Figure 2.2: Diagram represents the process involved in phytoextraction of metals from soils (Nascimento and Xing, 2006)

Other researchers have identified other strategies or desirable characteristics of a plant species for effective phytoextraction, including an extended root system for exploring large soil volumes, good tolerance to high metal concentrations in plant tissues, a high translocation factor, adaptability to particular environments or areas, and ease of agricultural management (Sheoran *et al.*, 2016). Moreover, phytoextraction has a number of advantages over conventional techniques, including cost effectiveness, the ability to treat multiple heavy metals simultaneously, the lack of the need to excavate polluted soil, public acceptance, and the possibility of further processing of the biomass produced (Suman *et al.*, 2018).

2.2.3 Phytovolatilization

Phytovolatilization is a process in which pollutants are absorbed from the soil, transferred through the xylem, then converted to a less toxic and volatile form, and finally released into the atmosphere (Awa and Hadibarata, 2020). The phytovolatilization can take two forms which are direct and indirect phytovolatilization. The more intuitive and well-studied method is direct phytovolatilization, which occurs due to plant absorption and translocation of pollutants, ultimately leading to compound volatilization from the stem/trunk and leaves. While indirect phytovolatilization refers to a rise in volatile pollutant flux from the subsurface caused by plant root activities (Limmer and Burken, 2016).

The phytovolatilization technique can be used to remove organic contaminants as well as heavy metals such as mercury (Hg) and selenium (Se) (Ali *et al*., 2013). Phytovolatilization happens when growing trees absorb water as well as organic and inorganic pollutants. At relatively low concentrations, some of these pollutants will move through the plants to the leaves and volatilize into the atmosphere (Du *et al.*, 2014). For instance, plant such as B. Juncea is capable in extracting up to 95% Hg from polluted solutions through volatilization and plant absorption (phytofiltration). The roots are the source of the majority of Hg volatilization, which may have unanticipated environmental implications (Parmar *et al*., 2015). Moreover, (Awa and Hadibarata, 2020) discovered that the plant's transpiration rate influences the efficacy of phytovolatilization.

2.2.4 Phytofiltration

Phytofiltration is the process of using plants to remove contaminants from polluted surface waters or wastewaters, thus cleaning a variety of aquatic ecosystems (Parmar *et al*., 2015). It is characterized as the use of free-floating, submerged, or emergent aquatic plants to remove contaminants such as heavy metals via their root systems in a direct process. Therefore, plants with a thick root system and grown hydroponically should be able to consume the full amount of contaminants in phytofiltration. In short, the performance of phytofiltration is highly dependent on the plants' or photosynthetic surface microorganisms' physicochemical characteristics (Rezania *et al.*, 2016). Moreover, the process of plant roots, seedlings, or exercised plant shoots used in photofiltration to adsorb or absorb pollutants from the aqueous ecosystem are termed rhizofiltration, blastofiltration, and caulofiltration (Parmar *et al*., 2015).

Besides, for rhizofiltration, the preferable plant used in the process is a plant that accumulates and tolerates high concentrations of metals. It should also be easy to operate, low-maintenance cost, and generate little secondary waste that needs to be disposed of. For instance, Micranthemum umbrosum is an efficient as phytofiltrator and a moderate Cd accumulator without any phytotoxicity (Parmar *et al*., 2015). Other than that, according to Sut-Lohmann *et al*. (2020), Monosoleum tenerum is an effective plant for phytofiltration of Zn, Cu, Ni, Mn, and Fe-contaminated wastewaters. On the other hand, phytofiltration is based on exposure time, quantity, plant, and Heavy Metal species (Sut-Lohmann *et al*., 2020).

2.3 Possible plant application in Phytoremediation.

This section presents some of possible plant that have potential to be applied as vegetation plant for green roof using phytoremediation techniques. For example, Brassica Juncea, Chromolaena Odorata, Vetiver Grass and Portulaca Grandiflora. These possible plants have been observed and analysed their potential to remove contaminants based on past research studies.

2.3.1 Case Study 1: Phytoremediation Potential of Brassica juncea for removal of selected heavy metals in urban soil amended with cow dung.

A research was carried out by Gayatri *et al*. (2019) for 81 days in pot experiments, and analyses were conducted both in soil and plants. In this research, Indian mustard (Brassica Juncea) (Varun T-59) seeds belonging to the Brassicaceae family have been used for the experiment. The benefits of using Brassica Juncea is it produces high biomass and ideal for remediation studies. Phytoremediation is an important and cost-effective remediation technique that facilitates the removal of heavy metals from the soil as the object of the current research. The soil was examined for physicochemical parameters such as pH, electrical conductivity, organic matter, and organic carbon. The potting soil was replicated into six samples and synchronizing with the plant phenological stages which analyzed at 0d, 21d, 51d, and 81d. Besides, the heavy metal analysis was conducted in both plant and soil samples using ICP-MS. For determination of metal uptake by Brassica juncea, the translocation factor and metal extraction rate were examined. Lastly, the removal of metal efficiency was also determined to observe the phytoextraction efficiency of Brassica juncea in the experiment.

Table 2.1 shown that the Lead (151.4 ppm) had the highest metal absorption by the plant then followed by Zinc (55 ppm), Copper (15.4 ppm), Chromium (9.6 ppm), and Nickel (3.1 ppm). It was found that Brassica Juncea's absorption of Lead was greater than the other heavy metals. The Lead had a greater reduction in soil due to it is in readily available form. Besides, since lead does not support essential functions in plant, it is easily absorbed by roots from the soil solution. On the other hand, as shown in Table 2.1, the percent recovery of heavy metals by the plant was leading with Zinc (51.8%) which had the highest percentage followed by Copper (41.6%), Lead (20.8%), Chromium (11.5%), and Nickel (6.1%). Besides, the pH value for soil modified with the parameter of cow dung ranges from was ranged from 5.98 to 7.08. Research also revealed that the pH correlates negatively with electrical conductivity, organic carbon, and organic matter. However, it shows that pH has a direct effect on plant absorption capacity and regulates the above-listed parameters.

Table 2.1: The metal recovery percentage in soils amended with cow dung by Brassica juncea (Gayatri *et al*., 2019)

Parameter	Heavy metal concentration in whole plant on 81d (ppm)	Metal absorption by plant/pot (ppm)	% Recovery of heavy metal by plant
Cr	0.117	9.611	11.529
Cu	0.188	15.410	41.693
Ni	0.038	3.121	6.165
Pb	1.848	151.496	20.876
Zn	0.671	55.005	51.849

2.3.2 Case study 2: Phytoremediation Potential of Chromolaena Odorata in Heavy Metal Polluted Environments

A study was conducted by Urning *et al.* (2016) to evaluate the potential of Chromolaena Odorata in heavy metals accumulations. The study region includes the Enyigba Lead-Zinc mines in Ebonyi State's Abakaliki Local Government Area, which is one of the lead endemic areas of South-Eastern Nigeria. An X-Ray Fluorescence (XRF) Spectrophotometer was used to test Chromolaena odorata, which was chosen because of its invasiveness and ability to survive in almost all soils, as well as its apparent non-vegetative use in the Nigerian environment. The Chromolaena odarata were labelled 1until 3 to represent the composite sample, while the control sample was labelled 4 to represent the control sample. The control Chromolaena odorata leaf samples were obtained from the College of Health Sciences at Ebonyi State University, which is a relatively unpolluted region in Abakaliki. After clean and dry leaf samples, a 1.0 g pulverized leaf sample was measured, pelletized, and then inserted into the X-ray Fluorescence Analyzer for 20 minutes of irradiation with 25 KV voltages and 50 A energy. Each ion has a characteristic X-ray fluorescence spectrum and was analyzed into its respective concentrations, which were recorded in the digital reading device. Lastly, the average value of each metal ion has been compared with the control mean of the control sample and the WHO/FAO plant standards, as shown in Table 2.2.

Table 2.2: The mean concentration of total metal ion in C. odorata leave samples (mg/kg)

	Metals									
	Ti	Cr	Mn	Ni	Fe	Cu	Zn	V	Co	Pb
Mean ± SE of Composite Sample	193.50 ±8.47	55±3.27	477.3 ±7.89	91.17 ±2.31	1302.7± 10.58	130.0 ±2.50	113. ±2.12	43.17 ±3.46	33.50 ±1.35	789.67± 16.93
Mean ± SE of Control Sample	116.50 ±6.93	23.50 ±2.9	117.5 ±6.35	21.50 ±2.31	552.50± 6.93	32.00 ±2.31	12.00 ±0.00	12.00 ±3.46	8.50± 1.73	0.00±0.00
Percentage (%) Metal Uptake	39.80	57.90	75.40	76.40	57.60	75.00	89.40	72.20	74.60	100.00
WHO/FAQ	-	-	-	-	48.00	30.00	60.00	-	-	2.00