Remediation of Heavy Metals with Poplar Trees

by
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Bachelor of Science, Islamic Azad University, Iran, 2010
Master of Engineering Science, Islamic Azad University, Iran, 2015

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Supervisory Committee

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Abstract

The increase in population and car fleets has led to a sharp rise in the generation of carwash wastewater (CWW). CWW contains heavy metals, detergents, oil and grease, and suspended solids, and is considered one of the most polluting industries in terms of water consumption and wastewater production. In various parts of the world CWW is not treated but left to drain and impair receiving waters. Numerous jurisdictions are examining how simple green infrastructure like low impact development (LID) technologies, such as rain gardens that treat polluted urban stormwater may be used to help treat the pollutant loads in CWW. Given that many of these green technologies use trees, this thesis examines how poplar trees are impacted by and remediate heavy metals that exist in CWW. The study was conducted at the University of Victoria, BC, Canada, and involved both laboratory work and field work conducted from 2021 to 2022. The research focused on tree health and heavy metal uptake and evaluated the performance of the designed treatment field in removing contaminants from CWW. The proposed methodology is grounded in a low-impact development (LID) approach tailored for wastewater treatment, particularly suited to remote, rural, and underserved areas, including developing nations like India, Malaysia, and other countries in the Middle East. The results demonstrate a decreasing trend in the concentration of zinc, cadmium, nickel, iron, copper, and lead from the point of application (point 1) at the field site to the effluent point (point 4), indicating good performance for removing these heavy metals. The removal rates for zinc, nickel, lead, iron, copper, and cadmium were 78.4%, 61.9%, 82.4%, 86.4%, 78.1%, and 98.95% respectively.

The study assessed the uptake of heavy metals by poplar trees by analyzing the concentrations in tree leaves. The data showed variations in heavy metal concentrations between different trees and leaf positions, with some metals exhibiting higher concentrations in the bottom leaves and others showing higher concentrations in the top leaves. The concentrations of heavy metals in the leaves were also influenced by seasonal variations and leaf turnover. Overall, the research findings indicate the impact to poplar trees in systems that use poplar trees for treating carwash wastewater, highlighting the importance of considering seasonal variations and leaf turnover when studying heavy metal uptake in trees. These findings carry significance for enhancing wastewater treatment

procedures and encouraging responsible approaches across a range of industrial and environmental contexts.

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Dedication

This dissertation is dedicated to my dearest husband, Mohsen. My best friend before being my life partner, I dedicate this dissertation to you. We embarked on this incredible journey together as immigrants and international students, driven by our shared aspirations to make a better life for ourselves and, hopefully, contribute to a better world. Your unwavering love, understanding, and support have been the pillars that have held me up during the challenging times of this research journey.

To my mother who hold a special place in my heart and have played integral roles in shaping my journey. I dedicate this work to my beloved mother, whose unwavering support, unwavering belief in me, and can-do attitude have been a constant source of strength and inspiration. Her love and encouragement have been the cornerstone of my success.

To my supportive sibling and inspiring late father, I am eternally grateful for your unwavering love, encouragement, and belief in my abilities. This work would not have been possible without your continuous support, and I dedicate it to you with deep appreciation and love.

Acknowledgments

I am immensely grateful to express my heartfelt appreciation to my esteemed supervisor, Dr. Caterina Valeo, for granting me the invaluable opportunity to pursue my MSc under her supervision and exceptional guidance. Dr. Valeo has consistently demonstrated an exemplary level of support, mentorship, and encouragement throughout this research endeavor, for which I am truly grateful. Her unwavering commitment and belief in my capabilities have been instrumental in the successful completion of this work.

I am particularly indebted to Dr. Valeo for providing me with the necessary freedom and independence to explore and define the direction of my research. Her trust in my abilities has allowed me to find my own path, a privilege for which I am deeply grateful. I would also like to express my profound gratitude for her patience during the period when I was searching for the research direction. Her unwavering support and understanding were invaluable during that time. Moreover, I would like to emphasize that my association with Dr. Valeo has been transformative not only in terms of my academic growth but also in imparting valuable life lessons. Her guidance, wisdom, and dedication have shaped me into a more competent researcher and an individual with an enhanced perspective on life.

I consider myself incredibly fortunate to have had the privilege of learning from Dr. Valeo, and I will forever cherish the knowledge and experiences gained throughout this journey.

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Acronyms

AGB	Above-Ground Biomass
BOD	Biochemical Oxygen Demand
CCI	Chlorophyll Content Index
CWW	Carwash Wastewater
EPA	Environmental Protection Agency
GI	Green Infrastructure
HAL	Hybrid Absorbable Landscapes
HPLC	High-performance Liquid Chromatography
LID	Low Impact Development
PH	Potential of Hydrogen
RPD	Relative Percent Difference
SLES	Sodium Lauryl Ether Sulphate
SS	Suspended Solids
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
VOC	Volatile Organic Compounds
WHO	World Health Organization

Chapter 1 Introduction

1.1 Background

The excessive growth of population and car fleet in recent decades resulted in a sharp rise in water consumption for washing vehicles and led to generating a large amount of carwash wastewater. Carwash stations are among the industries with high consumption of fresh water on daily basis and recycling water can be considered in carwash stations to overcome water crisis and eliminating contaminants from carwash wastewater (CWW). Although vehicles are not considered as a source of water pollution, they can contribute to entering a significant amount of pollution to the environment in the form of carwash wastewater (Bhatti *et al.*, 2011). Research conducted in various regions worldwide has revealed that the automobile service and maintenance industry possess the potential to contribute to environmental pollution in terms of soil, water, and air quality. The public's perception reveals a rising apprehension about the environmental impact of carwash shops in the car service sector. Car washing, characterized by its significant water consumption, draws considerable attention and scrutiny from the public and policymakers, especially in times of water shortage or drought. (Fall *et al.*, 2007). LID is gaining increasing popularity as a sustainable approach to managing stormwater, treating wastewater, and mitigating floods in urban areas. This is not only due to its water retention capabilities but also because it is environmentally friendly, easy to deploy, and cost-effective. It represents a smarter and more sustainable method for urban development and flood management. LID employs a combination of non-structural and structural measures to reduce flood risks. These measures involve reducing the number of impermeable surfaces, preserving natural resources and ecosystems, and implementing Green Infrastructure (GI). GIs, such as bioretention cells, green roofs, and permeable pavements, serve as examples of infrastructure designed and implemented for LID purposes. Based on the mentioned benefits of using low impact development systems, LIDs are becoming a popular and publicized treatment method in many regions, and they are considered as a great replacement for current traditional minor and major drainage systems equipped with underground systems and piped (Kaykhosravi, Khan and Jadidi, 2018; Kaykhosravi *et al.*, 2019). As the utilization of LIDs for improving water quality continues to gain prominence, there is a pressing need for further research and evaluation to adequately assess the efficacy of this approach in effectively removing contaminants from water and wastewater. Canadian researchers introduced a novel interdisciplinary strategy for urban wastewater treatment. This method employed double filtration: primary filtration utilized a stable, environmentally safe, permeable surface, while secondary filtration involved phytoremediation via trees' extensive root systems. The stable surface was achieved using Silva Cells®, modular blocks that promote plant growth and manage stormwater. These Silva Cells® were combined with cement-free porous Geopolymerised pavers, situated on a 12 mm maximum size aggregate layer. The modular system included a base, deck, and two posts (600 x 1200 x 784 mm dimensions), all sourced from DeepRoot Corporation in Canada (Garg *et al.*, 2018). The mentioned Canadian research using Silva Cells® was the inspiration for conducting this research by using the similar phytoremediation treatment site to remove contaminants such as heavy metals, carwash shampoo and total suspended solids (TSS) from Carwash wastewater and evaluate the potential and performance of this treatment system.

The suggested approach revolves around low-impact development for wastewater treatment, tailored for distant and rural regions, including developing countries like India. This eco-friendly technique employs locally sourced materials, and its ease of construction and management makes it well-suited for carwash stations in these nations. The study underscores the efficacy of utilizing LID methodologies to combat water contamination. The research's significance lies in addressing the composition of carwash wastewater, known to contain hazardous elements like heavy metals, oil, grease, detergents, and pollutants. The unregulated release of such wastewater into the environment carries substantial risks. Developing countries urgently require affordable, practical solutions. This research plays a pivotal role by offering a straightforward yet highly effective method, effectively mitigating these complex contamination issues at a minimal cost.

1.2 Research Objectives

This research has the following research objectives:

1) Test the potential for poplar trees in an LID with structural soil (designed to prevent soil compaction while allowing roots to grow, and for both supporting heavy structures like pavements and promoting plant growth) for removing heavy metals from carwash wastewater through a laboratory and field study using Poplar trees exposed to loadings of simulated carwash wastewater.

2) Relate a surrogate measure (specifically chlorophyll) to the health of the tree and the uptake or remediation of metal contamination).

This thesis layout highlights the potential of utilizing poplar trees in engineered LID systems for the treatment of carwash wastewater. The research findings provide valuable insights into the reduction of heavy metal concentrations and the relationship between tree health and metal uptake. This study contributes to the understanding of eco-friendly approaches to address the challenges associated with carwash wastewater pollution in underdeveloped countries.

Chapter 1 serves as the introduction, providing background information, stating research objectives, and outlining the thesis structure. Chapter 2 of this thesis presents a comprehensive literature review that critically examines and synthesizes the existing body of scholarly work related to the research topic. Chapter 3 explains the research materials and methods, including simulating carwash wastewater, evaluating heavy metal concentration, and measuring chlorophyll. Chapter 4 presents the results and discussion, including heavy metal concentrations, contaminant removal, and chlorophyll measurements, and discusses the implications of the results, compares them with existing literature, and acknowledges limitations. Chapter 5 concludes the thesis, summarizing key findings, reflecting on research objectives, and providing recommendations for future research and practical applications.

Chapter 2 Literature Review

In recent years, the substantial increase in both population and the number of vehicles has led to a significant surge in water usage for vehicle cleaning. Consequently, this has given rise to the creation of a considerable volume of wastewater from car washing (Abagale *et al.*, 2013). The role of vehicles in contributing to a region's wastewater production is often underestimated. Aside from their involvement in air pollution, vehicles can significantly add to environmental contamination through liquid wastewater release. The composition of wastewater pollutants varies depending on the activity that generates the wastewater stream. Municipal and industrial wastewater, stormwater runoff, and agricultural wastewater streams differ in terms of their daily volume production, the types of contaminants they contain, and their concentrations. These disparities predominantly hinge on factors like the intended service level driving the wastewater generation, the physical size of the system, and its geographic location (Al-Odwani, Ahmed and Bou-Hamad, 2007; Zaneti, Etchepare and Rubio, 2012). Among the diverse range of substances present in these wastewater flows, a particular type of contaminant that raises apprehension in numerous regulated areas is the group of chemicals commonly known as heavy metals. These pollutants have the potential to create significant issues for both the environment and human well-being, even when encountered at minimal levels of contact (Zaneti, Etchepare and Rubio, 2012). Global research has revealed that industries associated with cars, spanning servicing, production, maintenance, and cleaning, are acknowledged as notable sources of air, soil, and water pollution. Vehicles contribute to the creation of wastewater across different sectors: within residential areas through car-washing facilities, within industries and agriculture where vehicles require periodic cleaning for maintenance, and through stormwater runoff, which includes instances of individuals washing vehicles in driveways that then flow into minor stormwater systems alongside rainwater runoff from impermeable surfaces (Talebzadeh *et al.*, 2021). These wastewater streams encompass a wide range of pollutants due to the vehicle's degradation and the substances it accumulates from its operational environment. Among these pollutants are various contaminants and an array of heavy metals (Boussu *et al.*, 2021).

Traffic-born heavy metals pollution usually attaches to the vehicles and enters water bodies through CWW. Heavy metals contaminants including wear and tear of brake parts, tires, surface of roads, and street dusts will be combined with water through the process of washing vehicles in carwash stations (Talebzadeh, Valeo and Gupta, 2021). The generated carwash wastewater (CWW) eventually will be discharged to the environment, surface and sub-surface water bodies or heads to the city sewer pipes. CWW includes high concentrations of contaminants and toxic elements such as heavy metals which could be a significant source of both water and environmental pollution (Blumenthal et al., 2000; Al-Odwani, Ahmed and Bou-Hamad, 2007). The carwash industry is considered as one of the most pollutant industries in both water consumption and wastewater production includes various types of contaminants and detergents. Several studies have demonstrated that the most common CWW compositions are heavy metals, detergents, oil and grease, and suspended solids (SS). Heavy metals are one of the pollutants that is a concern for many regulated regions (Bazrafshan et al., 2012), this contaminant can become strongly toxic in water, soil, and air, and living organisms could be exposed to them through water pollution or food chain. Heavy metal contaminants can affect almost any organs in the body, and may be lethal to human, wildlife and ecosystems even at low exposure levels (Abagale et al., 2013). Carwash stations can contribute to generating wastewater in various sections such as municipalities, industrial, and agricultural activities through residential car-wash facilities, and maintenance and regular washing in agricultural and industrial sectors. Due to the vehicle functionality, degradation of the vehicle, and what the vehicle picks up from the surrounding environment, the wastewater stream can be contaminated by a myriad of pollutions and various heavy metals (Boussu et al., 2021). Due to the surge in urbanization, the carwash industry is predicted to experience a significant boom, propelled by the escalating human population and industrialization. Consequently, the impact of carwash wastewater (CWW) discharge on the environment has garnered heightened scrutiny and has emerged as a pressing environmental issue in recent times. This upswing in the carwash sector, driven by urbanization and rapid population growth, has spurred a newfound awareness surrounding the consequences of CWW discharge. As a result, environmental concerns associated with the release of CWW into ecosystems have gained substantial traction. The increasing prevalence of urban lifestyles, coupled with the rapid expansion of industrial activities, has led to a marked increase in attention being paid to the environmental ramifications of CWW discharge. It is imperative to address and mitigate the adverse effects of CWW discharge on the environment, considering the projected surge in the carwash industry, urbanization trends, and the expanding human population (Kuan et al., 2022). A car wash refers to a facility specifically designed for the external cleaning of vehicles, excluding residential settings. During the car washing process, a significant volume of wastewater is generated, estimated to range between 150 and 350 liters per car, which ultimately finds its way into the environment. Streetcar washing activities contribute to the release of various pollutants, including oil and grease from engine cleaning, elevated levels of suspended solids derived from brake linings, the removal of sand and dust, and small amounts of surfactants that degrade slowly in natural surroundings. Furthermore, these contaminants will find their way into the carwash wastewater during the vehicle washing procedure. Specific elements of automobiles, such as the engine block, intake manifold, and brake drums, have been identified as surpassing permissible thresholds for releasing heavy metals, including iron, copper, zinc, and lead. (Hashim and Zayadi, 2016a). The release of contaminated water from carwash stations can have severe environmental impacts on surface water and underground water bodies, affecting aquatic life. Carwash wastewater (CWW) contains a range of pollutants, including heavy metals, surfactants, oil and grease, phosphates, sand and dust, and petroleum hydrocarbon waste. It also exhibits high levels of turbidity and acidity, further exacerbating its harmful effects. Proper management and mitigation strategies are necessary to protect water quality and preserve the well-being of ecosystems in the face of these pollutants (Zaneti, Etchepare and Rubio, 2012). In underdeveloped countries and under-served communities, when the accumulated sediments are washed away, they are carried by the gutter system and enter the stormwater system without undergoing any treatment. This poses a significant risk to the ecosystem as these pollutants make their way into drainage systems, streams, and ultimately reach the receiving waters. As a result, environmental pollution is heightened, leading to adverse impacts on the ecosystem (Perkowski *et al.*, 2006). Due to this high volume of contaminants, some regions have a regulation for the generated CWW, and this wastewater cannot be directly discharged from the carwash station to the environment or sewage system and requires going through an acceptable level of pre-treatment such as filtration. CWW may have a great potential for being recycled and being reused as a recycled graywater in the same carwash facility or even for various purposes which recycled water can be acceptable (Nadzirah, Nor Haslina and Rafidah, 2015). Several research and studies have been done on carwash wastewater treatment and the performance of various methods had been evaluated such as membrane technologies. The cost of implementing and operating of some methods are very high, and some developing countries rarely could produce membranes (Bhatti et al., 2011; Rodriguez

Boluarte et al., 2016). Cost-effective, eco-friendly, and sustainable innovations are required to treat carwash wastewater to a level that makes the CWW acceptable by World Health Organization (WHO) standards, and to an acceptable range that provides for water reuse. CWW treatment is easier, more efficient, and cost-effective to treat at the source. To be efficient and sustainable, CWW treatment method needs to be designed and developed by using native materials in an environmentally friendly manner which is nature based and uses little to zero energy. several studies have highlighted innovative methods that align with the specified criteria. These methods can be found in the literature and encompass approaches such as wetland treatment systems and low-impact development (LID) technologies (Al-Gheethi et al., 2016; Kaykhosravi, Khan and Jadidi, 2020; Pishgar et al., 2020; Huang et al., 2012).

Low impact development technologies are made by native materials which work by gravity drainage, and no energy input at the source of CWW production. This green and efficient solution not only can treat CWW, but also provides effective solutions for stormwater management, and recreates the original permeability of the landscape prior to urban development. The process of these systems includes retaining and holding water in the storage, filtration through a filter system that slows the outflows and can remove pollution in the inflow. Moreover, LID technologies strive to restore the original permeability of landscapes before urbanization, contributing to the preservation of natural hydrological processes (Kaykhosravi, Khan and Jadidi, 2020). Known examples of this treatment systems are bioretention cells or rain gardens, green roofs, permeable pavements, and grassy swales (Huang et al., 2012). The performance of LIDs depends on climate, location, design, and the type of LIDs which could be vegetated or unvegetated. Vegetated systems are living engineered structures that need to reach the maturation point prior to using them. So, a wait time should be considered in designing this kind of treatment system. Leaching of nitrogen and phosphorus are very likely to happen in vegetated LID systems, and due to clogging of structural components such as valved drainage lines, particle loading, maintenance cost, and weeding they might show a change in drainage qualities and quantities over time. Although some studies and sources go far as recommending using complex and specialized equipment to monitor LIDs, regular low-cost monitoring and maintenance demonstrated an acceptable performance. However, there are some uncertainties around the long or short-term maintenance and requirements to maintain a good performance in LID systems (Valeo and Gupta, 2018). LIDs can be categorized in two main types: vegetated and unvegetated, and each one had its own benefits and drawbacks. The vegetated LIDs called bioretention systems conduct treatment processes through physical, chemical, and biological processes. The wastewater or runoff is directed to the system and goes to the infiltration system and percolate in the vegetated surface followed by gravel or mulch. The final step of this system would be a drainage system if the LID system is lined, bioretention system examples are green roofs and grassy swales. Unvegetated LIDs are examples are stormwater collection systems, rain barrels, rain harvesting systems, and permeable pavements. The role of the vegetation and plants in this LID systems are to improve water quality through heavy metal uptakes and microbial interactions (biological), and filtration and sedimentation(physical), and precipitation and adsorption (chemical), moreover, a vegetated LID provides a system to hold and retain the water or wastewater to give the system the required length of time to make the treatment system more effective and protect the soil from water erosion (Rycewicz-Borecki, McLean and Dupont, 2017). Water retention capacity is typically higher in vegetated Low Impact Development (LID) systems compared to non-vegetated (unvegetated) ones. Low Impact Development refers to an approach to land use planning and design that seeks to manage stormwater runoff in a more sustainable and environmentally friendly manner. This storage capability enables the system to effectively reduce levels of total suspended solids (TSS) and total dissolved solids (TDS), leading to a decrease in turbidity (Zhao *et al.*, 2018). Low impact development shows a high performance in removing contaminants includes heavy metals, total suspended solids, detergents, oil and grease, and turbidity from carwash wastewater, and eliminate the negative impacts of urbanization which result in increasing the impervious surface in urban areas by managing wastewater and stormwater runoff quantities. LIDs are sustainable, eco-friendly, cost effective and nature-based solutions, and can be considered as decentralized designs to control flow rates and removing contaminants from wastewater at the source (Zhao *et al.*, 2018). The drawbacks of LID systems differ based on the LID type, location, design, and climate. Vegetated LID systems, being living structures, are mainly designed to manage stormwater quantity rather than quality. This is because the understanding of effective designs for treating water quantity is more developed compared to water quality treatment approaches (Kaykhosravi *et al.*, 2019).

Chlorophyll is a green natural multifunctional substance in all plants and phytoplankton which is vital for photosynthetic. Several studies claimed that the importance of chlorophyll in plants is the same as hemoglobin in the human body. Chlorophyll has a crucial role in developing above-ground biomass (AGB) and could be considered to evaluate the health of plants and various environmental conditions such as temperature, soil condition, sunlight, participation, and environmental stressor, environmental pollution, and anthropogenic activities. Chlorophyll content and the color of leaf change in response to nutrient deficiencies, environmental conditions, and changes in contaminant concentration in canopy and above-ground biomass (Ali *et al.*, 2017). The color of leaves will be determined by the amount of chlorophyll contents and pigment types. These changes have been used in several research to evaluate and determine the relation between chlorophyll content and environmental stressors. Various studies conducted various statistical correlations and analyses to determine how climate, environmental pollution and stressors, and anthropogenic conditions can affect the plants' health. Chlorophyll content is a reliable parameter to evaluate the plants' resistance to environmental contaminants and harsh changes in the surrounding environment such as temperature, humidity, pH, and changes in the pollutant level (Sims and Gamon, 2002). Generally, there are two different methods for chlorophyll measurement. The first method is traditional chlorophyll measurement are being done by using HPLC (High-performance liquid chromatography) called spectrophotometric technique. The traditional method is a destructive method means it requires the destruction of leaves. Leaves need to be separated from the tree and go through some laboratory process to be ready for being evaluated by HPLC machine. So, it is not possible to measure the chlorophyll contents of a single leave during any specific time frame or season while doing the experiment at field. The second method for chlorophyll measurement is called non-destructive method which is introduced by advanced environmentally friendly technologies. This method is easy and fast and allows to measure the chlorophyll content of a single leave several times to be able to compare the chlorophyll contents in different situations and in contact with different level of environmental contaminants and stresses. Moreover, chlorophyll measurement is becoming more prevalent as it can be conducted easily at the field without harming the plant. Thus, non-destructive chlorophyll measurement is more than ever likely candidate to evaluate the effects of environmental contaminants and stresses (Mavromatis *et al.*, 2002; Sims and Gamon, 2002).

Generally, obstacles to the widespread use of vegetated LID systems encompass uncertainties about costs, both short and long-term maintenance needs, inconsistent performance, insufficient comprehension and knowledge for effective design, as well as a lack of community trust in this non-traditional infrastructure (Pishgar *et al.*, 2020).

Chapter 3 Materials and Methods

This research procedure includes three main steps to simulating carwash wastewater, evaluating heavy metal concentration and the performance of removing CWW contaminants, and chlorophyll measurement to evaluate both the effect of heavy metals on trees' health and heavy metals uptake by the trees. Each step has a procedure and purpose which will be explained in the following sections.

3.1 Field Site and Carwash Loading Simulations

Several literature reviews had been conducted to find information and data about the CWW characteristics and water consumption at carwash facilities to simulate carwash wastewater more accurately. CWW contains solid particles that originated from the road dust and dirt on vehicle's surfaces, oil and grease from interior parts and car wax, detergents, petroleum, hydrocarbons, heavy metals, volatile organic compounds (VOCs), and unacceptable levels of alkalinity or acidity. It is investigated in several literature reviews that no matter carwash wastewater generated in what kind of carwash facility, it is always high in COD, and it is reported up to 1295 mg/L in different locations around the globe. Suspended solids (SS), turbidity, detergents, and oil and grease are mentioned as other significant contaminants that are always present in CWW. Carwash wastewater is evaluated in different countries, and all the conducted research claimed that there is no relation between the value of COD, SS, and turbidity (Bhatti *et al.*, 2011; Hashim and Zayadi, 2016a). In general, a significant range of detergents and cleaning products are being used at carwash facilities, and the use of detergents have been increased recently which results in sharply greater amount of CWW contaminants associated with using cleaning material in car washing process. Environmental Protection Agency (EPA) has provided a limit for pH, COD, and BOD in CWW which are 6-9, 50(mg/L), and 20(mg/L) respectively (Bhatti *et al.*, 2011). The quantity of water used, and the volume of carwash wastewater produced in carwash establishments are influenced by two elements. The initial factor pertains to the size and purpose of the vehicles, while the second factor is the facility's geographical location. Different countries have reported varying levels of water usage per vehicle, which is closely connected to the water usage trends specific to each region. Typically, carwash facilities, whether self-service or automatic, utilize approximately 45-227 liters of water for washing a single car in different countries (Fall *et al.*, 2007). This amount is way more for heavy vehicles such as different kinds of trucks, loaders, graders, saloon cars, buses, vans, heavy articulators, sport utility vehicles, and waste containers which is reported 250-1200L. Almost the whole of this amount will be converted to CWW (Al-Odwani, Ahmed and Bou-Hamad, 2007). Water consumption ranges vary in different locations. In India, the range of water used per car is between 35 to 40 liters or 40 to 50 liters. Pakistan uses approximately 100 liters of water per car. In Malaysia, the water consumption can vary between 40 to 120 liters. The United States utilizes around 170 liters, while Australia uses 200 liters of water per car. Kuwait has the highest water consumption, with a range of 200 to 400 liters per car depending on the size, type, and use of the vehicle.

It's important to note that these values represent the average water usage per car in carwash centers in these respective locations. The variations can be attributed to factors such as local regulations, available water resources, carwash technologies, and consumer preferences. Understanding these differences is essential for managing water resources efficiently and implementing sustainable practices in the carwash industry (Talebzadeh *et al.*, 2021).

The first step of the field work in this research was applying carwash wastewater on the designed LID system. The used LID system in this research is part of the Hybrid Absorbable Landscapes (HAL) project which is an ongoing study to evaluate the performance of low impact development technology. This site is in parking lot 6 on the University of Victoria campus and consists of permeable pavement systems and bioretention cells. Figure 1 shows a view of this site. The site is fully lined with control trees, each closed off from the rest of the site. The drainage point indicated by the blue triangle has a control valve that is closed during the tests but remains open year-round. The site is slopped so that all points drain to the valve. During the tests, the site was dry because the valve was opened and there was no rain prior to the tests. During the tests, the valve was closed. The circles indicate sampling points which are long rods inserted to the bottom of the site from which liquid is pumped. Point 4 is directly in front of the valve and represents the outlet.

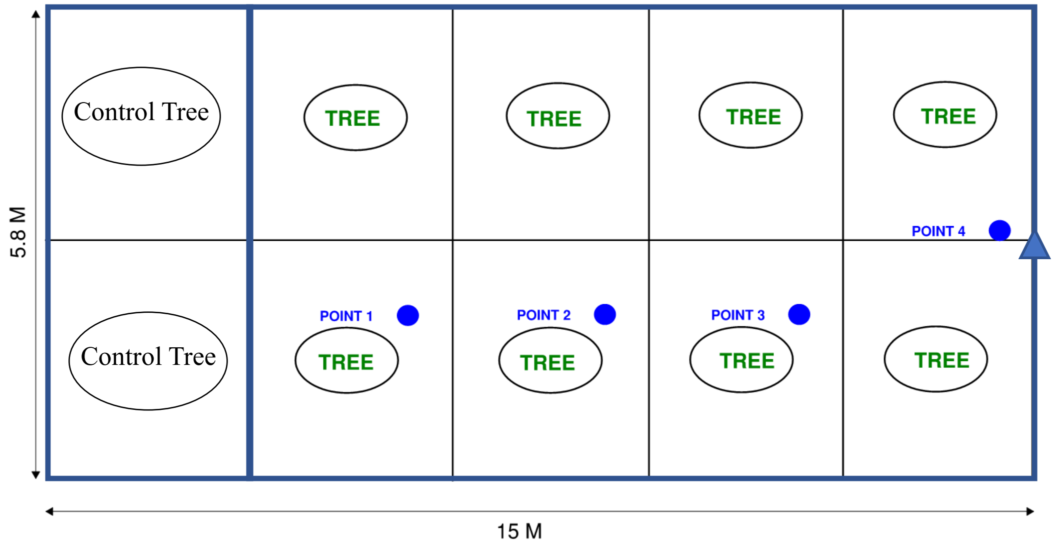
CWW could be collected from random carwash facilities in urban areas or could be simulated in the lab by using water, chemicals, detergents, and dirt. The second method was selected in this research. Although simulating CWW added extra time-consuming tasks to this research in comparison with collecting CWW from carwash stations, it has several advantages such as simulating the CWW in a specific range of selected contaminants. The total amount of 1200 ml Carwash shampoo, and 750gr potting soil were used in the process of carwash wastewater simulation.

For each carwash simulation, the volume of 30 liters of simulated CWW and a total of 12 simulated CWW were applied by using a hose that was connected to a tank containing the simulated carwash wastewater on 3 different points at the site: Point1: first poplar tree, Point2: large poplar tree, Point3: smaller poplar.

In this study, the level of remediation is computed using Equation (1):

$$\frac{(C_{in}-C_{out})}{C_{in}} \times 100\% \qquad (1)$$

and is used to assess the removal rate of heavy metals. Heavy metals are known to pose environmental hazards, and it is essential to evaluate their efficient elimination for effective pollution control. By applying this equation, the initial concentration of heavy metals (C_{in}) was compared with the concentration after the removal process (C_{out}). The resulting fraction, when multiplied by 100, provided a quantitative measure to determine the effectiveness of the treatment method in eliminating heavy metals. This equation served as a valuable tool to evaluate the extent to which the system successfully reduced the presence of heavy metals, contributing to the overall assessment of the study's environmental remediation efforts.



(a)

(b)

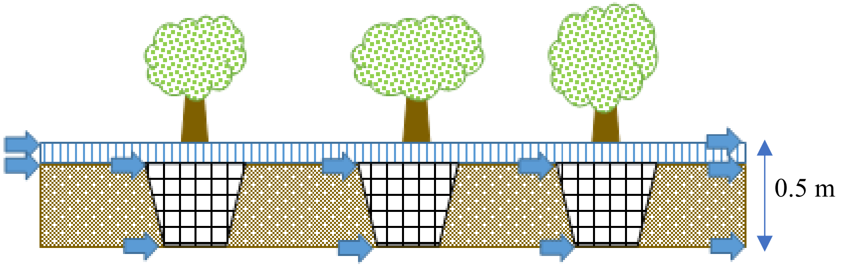


Figure 1. (a) A real view of the field site located at the University of Victoria, Victoria, BC; (b) cross-sectional view of three of the cells (left most tree represents point 1). The site drains from the left to the right and to the valve indicated with the blue triangle. The site lined and shown in blue with two control trees, which are each lined separately and closed off from the rest of the site. The circles in (a) indicate sampling points which are long rods inserted to the bottom of the site from which liquid is pumped. Point 4 is directly in front of the valve and represents the outlet. In (b) the site is composed of silva cells mostly filled with structural soil. The hashed markings represent the tree root ball in organic soil and the beige shading represents the structural soil which is a mix of aggregate and some sand.

Concentrations of heavy metals in this research are taken from several articles who evaluated CWW contaminants around the world (Al-Odwani, Ahmed and Bou-Hamad, 2007; Torkashvand *et al.*, 2020, 2021). Cadmium, zinc, iron, lead, copper, and nickel were evaluated in this study. Pure heavy metals are not soluble in water, so metal salts were used to simulate CWW including cadmium sulfate (CdSO4), zinc sulfate (ZnSO4), ferric chloride (FeCl3.6H2O), Lead Chloride (PbCl2), cupric sulfate (CuSO4), nickel sulfate (NiSO4). The desired concentration of each heavy metal in simulated CWW, and the amount of metal weight is listed in Table 1. For this purpose, molecular weight of each salt, and the fraction of metal weight was calculated, and the required mass for each test and the total mass needed for the whole test were obtained.

The procedure for calculating the quantity of heavy metal salts required to replicate carwash wastewater with the necessary metal concentrations was carried out through the following outlined steps.

1. Determining the mass of metal required in milligrams (*mg*): *Mass (mg) = Concentration (mg/L) × Volume (L)*
2. Converting the mass of metal salt to grams (g): *Mass (g) = Mass (mg) / 1000*

3. Calculating the amount of metal salt in moles: *Amount (moles) = Mass (g) / Molar Mass of the metal salt (g/mol)*
4. Converting moles of the metal salt to milligrams of the metal: *Amount (mg) = Amount (moles) × Molar Mass of metal (g/mol)*

Table 1. Information on the concentration of heavy metals used in CWW simulation.

Parameter	Metal	Desired concentration (mg/L)	Metal molecular weight	Total mass Given formula	Fraction of metal weight	Mass for 4 CWW (4*30L) applications (mg)
CdSO4	Cd	0.01	112	208	0.538461	1.2
ZnSO4	Zn	3	65.39	161.39	0.405167	146
FeCl3.6H2O	Fe	5	55.8	270.15	0.206551	600
PbCl2	Pb	1.2	207	277	0.747292	144
CuSO4	Cu	4	63.54	159.54	0.398270	480
NiSO4	Ni	1	58	154	0.376623	120

A total of 12 tests had been conducted at the site during July and August 2021. Before and after each CWW application, EC, temperature, moisture, and pH were measured to evaluate the effect of the wastewater on the site. The results of these measurements and other test results will be presented in the result section. Carwash wastewater samples were collected from 4 sampling points called point1 to ponit4 including Point1, Point2 (includes the big poplar tree), point3, and Point4 which was the last point in the treatment site. Samples were collected and stored in the lab in 500 ml and 1000ml high-density polyethylene wide mouth bottles which are suitable for holding and shipping liquids for applications in the lab or field. The carwash wastewater sampling and sample preservation were based on examination of wastewater standard methods (APHA, 2012), and the samples stored at 4C until analysis(Hashim and Zayadi, 2016).

3.2 Evaluating Carwash Wastewater Contaminants – Lab Data

Heavy metals, COD (Chemical Oxygen Demand), Detergent, and TSS (Total suspended solids) were evaluated in this research.

Samples were evaluated in the lab to evaluate TSS and heavy metals concentration. The volume of a well-mixed CWW sample measured and filtered through a pre-weighted filter paper, then heated in oven in 105 C, and dried 1 hour to constant weight. Post weight of the filter was measured, the mass increase of the filter per liter would be TSS (mg/L)(Chaitanya, 2018).

Heavy metals concentrations were evaluated in bioretention lab at University of Victoria by using Hach test kits for each metal (Zinc: method 8009, Nickel: method 8150, Lead: method 10216, Iron: method 10229, Copper: method 8026) following the standard method for each metal provided by the kits.

COD and cadmium contaminant are other parameters that needed to be evaluated in CWW, samples were sent to a commercial lab for evaluating these parameters.

Although the amount of heavy metals concentrations in CWW would vary and depends on the different factors such as type of vehicle usage, detergent is a factor that is always present in CWW, and carwash shampoos will be added in the process of washing a car in carwash stations. To evaluate the performance of LIDs in removing detergents from CWW, Chemetrics K-9400 Colorimetric Detergent Test Kit was used in this experiment. By using this kit, the color of each sample could be compared to standards using a comparator and provides accurate visual analysis. All the results and analysis will be presented in the result and discussion section.

Total suspended solids (TSS) which is a measurement of the quantity of suspended particles present in a liquid, such as water or wastewater was measured in the laboratory by the following method called gravimetric method.

The sample should be collected large enough to perform multiple measurements. In this research 500ml of the applied carwash wastewater was collected from point 1 and point 3 in 3 weeks. Samples were filtered in the lab using a pre-weighted filter with 0.45-micron filters to remove any large particle that could clog the measuring instrument. The filters were dried in an oven at 105 degrees Celsius for an hour to reach a constant weight to ensure that all the moisture has been removed. The dried filters were weighted and TSS was calculated by subtracting the weight of the dry filter from the weight of the filter plus the solids and dividing by the volume of the original sample using the following formula. The gravimetric method was used to determine TSS concentrations in mg/L (where TSS equals the weight (mg) of solids after filtration divided by the volume of the sample (L).

3.3 Tree Health Data

In this study, we employed the CCM-200 Chlorophyll Content Meter to assess the chlorophyll content in leaves. This instrument enabled a rapid and non-destructive method to quantify the amount of chlorophyll present, both prior to and after the application of Carwash Wastewater (CWW) on the LID (Low Impact Development) and bioretention carwash treatment site. The measurements of chlorophyll content were conducted from June to October 2021, as well as from June to October 2022, on trees situated at point 2 and point 3. Each measurement involved three sets of data, obtained from the assessment of ten leaves per tree daily.

In August 2021, after the application of carwash wastewater, the chlorophyll content of the largest poplar tree at the experimental site (located at point 2) was examined using the same methodology. Notably, measurements were taken at three different heights of the tree, namely the bottom, middle, and top, with the objective of elucidating the impact of heavy metal uptake on chlorophyll content in the leaves. The trees' leaves were also sent and tested in in commercial laboratory to evaluate the amount of heavy metals concentrations. Additional specifics regarding the chlorophyll measurements and heavy metals concentrations in leaves can be found in the results section.

Chapter 4 Results and Discussions

4.1 Lab Analysis: Heavy Metals in Carwash Wastewater

Heavy metals concentrations were measured in the lab to determine the concentration of the metals at each sampling point to evaluate the performance of the designed treatment field in removing contaminants from CWW, and all the data were used to create this graph. Figure 2 demonstrates the concentrations of heavy metals in sampled wastewater from point 1, point 2, and Point 4, and the level of each heavy metals concentrations in the applied carwash wastewater (CWW).

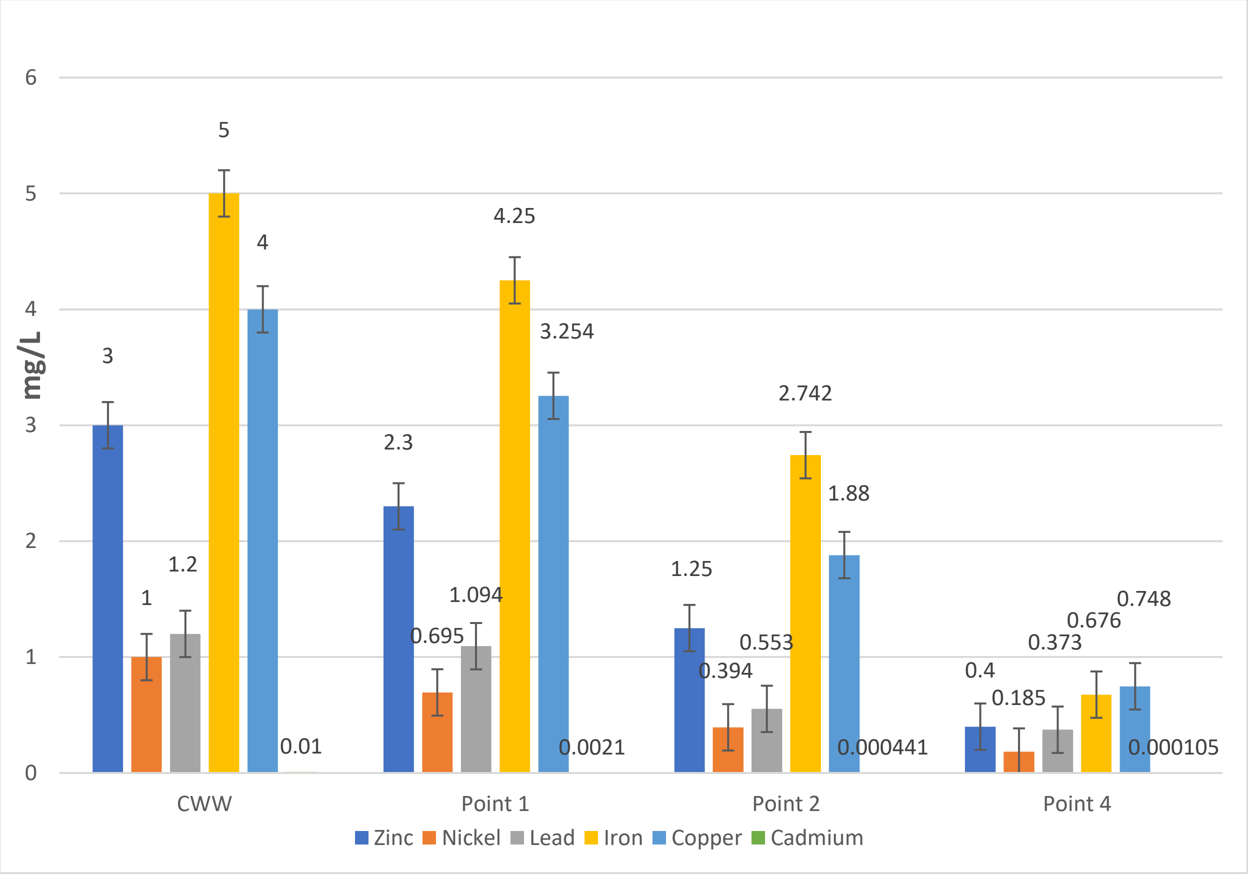


Figure 2. Heavy Metals Concentration Changes in Carwash Wastewater: A Comparative Analysis of CWW and Evaluated Concentrations at Point 1, 2, and 4 Across the Experiment site.

Figure 2 depict the concentrations of heavy metals in the CWW, Points 1, 2, and 4. Point 4 represents the drainage location in the experimental area. It is evident from the graph that there is a substantial decrease in the concentration of all metals from Point 1 to Point 4. This observation indicates that the bioretention cells exhibited exceptional performance in effectively removing all six evaluated heavy metals in this study.

In Table 2, the experiment measured the removal rates of zinc, nickel, lead, iron, copper, and cadmium. The results indicate that cadmium exhibited the highest removal rate of 98.95%. Additionally, iron demonstrated a comparable high removal rate of 98.65%. These findings highlight the effectiveness of the LID system in reducing the concentrations of cadmium and iron in carwash wastewater. This underscores the potential of using LID systems for treating carwash wastewater and mitigating environmental pollution.

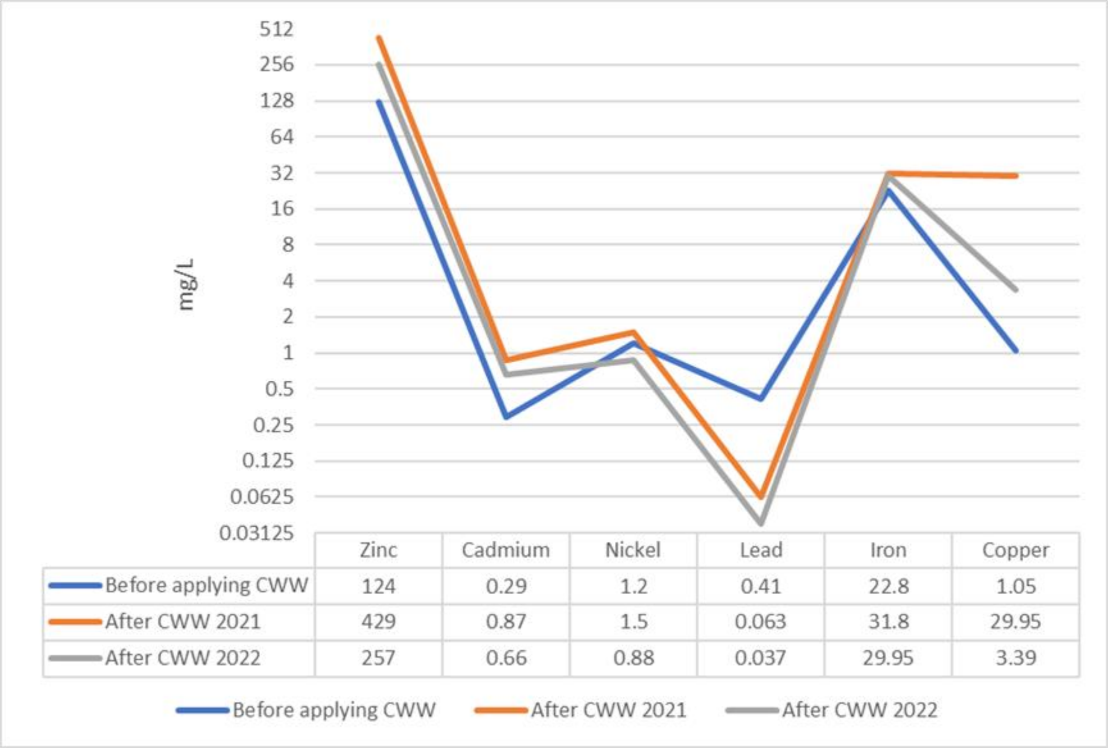
Table 2. Contaminant Removal Rates.

Parameter	**Total Removal Rate (%)**
Zinc	86.67
Nickel	81.5
Lead	68.92
Iron	98.65
Copper	81.3
Cadmium	98.95

The implemented treatment field effectively achieved the removal of heavy metals from carwash wastewater (CWW). Analysis of the data revealed a notable decrease in metal concentrations as the wastewater progressed from Point 1 to Point 4, indicating the successful elimination of all evaluated heavy metals through the phytoremediation process. The extended duration of carwash wastewater within the phytoremediation system allowed for chemical, physical, and biological reactions to occur, contributing to the enhanced removal rates of heavy metals. The removal rates of zinc, nickel, lead, iron, copper, and cadmium were evaluated. Notably, cadmium, the heaviest metal, exhibited the highest removal rate of 98.95%, while iron showed a similarly high removal rate of 98.65%. These findings highlight the efficiency of the engineered LID system, utilizing poplar trees, in reducing the concentrations of cadmium and iron in carwash wastewater.

4.2 Lab Analysis: Heavy Metal Concentrations in Trees Leaves

The concentrations of various heavy metals such as zinc, cadmium, nickel, lead, iron, and copper in tree leaves were determined as a means of assessing the degree of uptake of these metals by the trees. These measurements were conducted in 2021 for three trees (numbered 1, 2, and 3) in the field after the application of carwash wastewater that contained heavy metals. Figure 3 demonstrates the concentration of heavy metals in the leaves of trees number 1-3 (at points 1-3) before applying CWW, and after applying CWW in 2021 and 2022.



	Zinc	Cadmium	Nickel	Lead	Iron	Copper
Before applying CWW	124	0.29	1.2	0.41	22.8	1.05
After CWW 2021	429	0.87	1.5	0.063	31.8	29.95
After CWW 2022	257	0.66	0.88	0.037	29.95	3.39

Figure 3. Concentration of Heavy Metals(mg/l) in Tree Leaves Before and After Carwash Wastewater Application.

The data indicates that the highest concentrations of heavy metals were observed in 2021 after the application of carwash wastewater (CWW). In contrast, the concentrations decreased in 2022. There could be several reasons for this trend, one of which could be the natural process of leaf turnover. In many tree species, leaves shed in the fall and new leaves grow in the following year. This cycle of leaf turnover can have an impact on heavy metal concentrations. In 2021, the leaves that were present during the application of CWW might have absorbed and accumulated a higher concentration of heavy metals from the wastewater. However, in 2022, as new leaves grew, the heavy metals might have been diluted or distributed differently among the leaves, resulting in decreased concentrations. The process of missing leaves in the fall and the subsequent growth of new leaves in the next year can contribute to the observed decrease in heavy metal concentrations from 2021 to 2022. It highlights the importance of considering the seasonal variations and leaf turnover when studying heavy metal uptake in trees or plants.

In 2022, sampling was conducted for two trees (numbered 1 and 2) in the field at three different heights to not only determine the extent of heavy metal uptake by the trees but also to investigate potential differences in heavy metal concentrations among leaves located at different heights on the trees (i.e., bottom leaves below 50 cm, and top leaves above 150 cm). The sampled leaves were sent to a commercial environmental lab Environmental for analysis. Table 3 shows the results of heavy metals concentrations measurements in leaves in 2022.

Table 3. Heavy metals concentrations (mg/kg wwt) in trees' leaves in 2022. (*Relative Percent Difference (RPD) is a percentage measure that quantifies the difference between the original and duplicated test results)

Metal	RPD(%) or Difference*	Tree #1, July, Bottom	Tree #1, July, Top	Tree #2, October, Bottom	Tree #2, October, Top
Zinc	0.7%	257	135	234	182
Cadmium	3.1%	0.574	0.31	0.567	0.423
Nickel	2.4%	0.934	0.752	0.885	0.575
Lead	19.6%	0.0571	0.0376	0.038	0.0176
Iron	0.5%	34.7	19.02	39	27.1
Copper	2.08%	1.74	1.58	4.36	3.43

The results show that both trees have absorbed varying levels of heavy metals, with tree 2 generally having higher concentrations compared to tree 1. For example, in October, tree 2 had a zinc concentration of 234 mg/kg in the bottom leaves, which was higher than the concentration in tree 1 bottom leaves (257 mg/kg). Similarly, in the top leaves, the zinc concentration in tree 2 (182 mg/kg) was higher than that in tree 1 (135 mg/kg).

Regarding differences in metal concentrations among leaves located at different heights, the results are not consistent across all metals. For zinc and iron, the concentrations in the bottom leaves of both trees were generally higher than those in the top leaves. However, for copper and nickel, the concentrations in the top leaves were higher than those in the bottom leaves. The concentrations of cadmium and lead did not show a clear pattern of variation between the top and bottom leaves.

Based on the data, there are differences in heavy metal concentrations between the two sampling months, with generally higher concentrations in October compared to July. This could be due to seasonal variations in environmental factors that affect the uptake of heavy metals by the trees. Additionally, there are differences in heavy metal concentrations between the different trees and leaf positions, with generally higher concentrations in tree #2 and in the bottom leaves compared to the top leaves. It is important to consider that tree #2 has a bigger size, which might explain why it has higher concentrations, as it could be using more water and consequently taking up more heavy metals.

4.3 Lab Analysis: TSS

The experiment aimed to observe the trend of changes in the total suspended solids (TSS) concentrations from point 1 to point 4 in the wastewater sample collected from a carwash facility over three weeks, Figure 4 demonstrates the results of the TSS tests in this experiment. The removal rate from an initial concentration of 250 mg/L to a final concentration of 36 mg/L is approximately 86.4%. This indicates a significant reduction in the concentration of the substance, highlighting the efficiency of the removal process. These results provide valuable insights into the effectiveness of the carwash wastewater treatment system (phytoremediation system) in removing TSS and may have implications for improving wastewater treatment processes in various industrial and environmental settings.

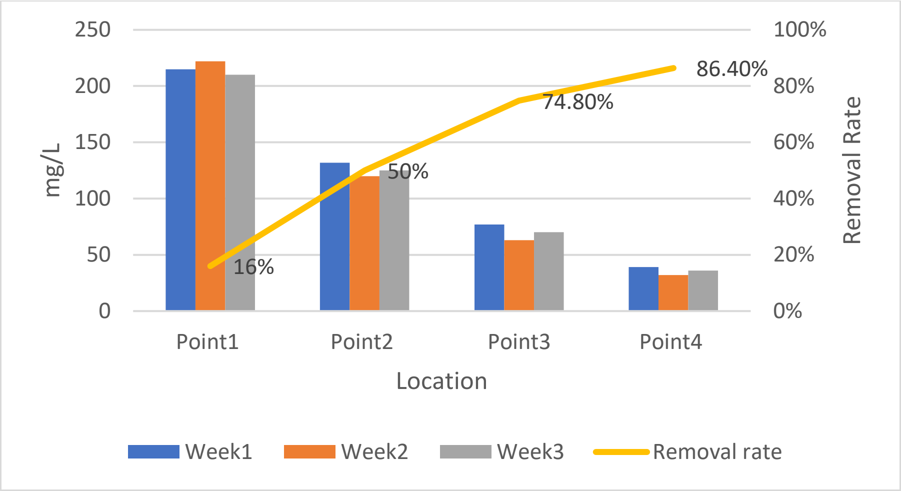


Figure 4. Total Suspended Solids (TSS) Concentration and Removal Rate Analysis across Sampling Points.

Therefore, the removal rates for Point 1, Point 2, Point 3, and Point 4 are approximately 16%, 50%, 74.8%, and 86.4% respectively. These values represent the percentage reduction in TSS concentration at each point compared to the initial concentration of 250 mg/L. The reduction in Total Suspended Solids (TSS) across the treatment site is due to the effective removal processes employed, such as settling, filtration, and chemical treatments. These processes progressively remove suspended solids, resulting in lower TSS concentrations from the first to the last sampling location.

4.4 Lab Analysis: Carwash Shampoo Containing Sodium Lauryl Ether Sulphate (SLES)

Based on the samples collected from three points at the treatment site, our analysis revealed a consistent decreasing trend in carwash shampoo concentration from Point 1 to Point 4. This trend signifies the efficiency of the treatment process in removing the shampoo from the carwash wastewater. The removal rates, visually represented in Figure 5, provide a quantitative measure of the reduction in concentration between the sampling points. Understanding the changes in carwash shampoo concentration and removal rates is crucial for evaluating the effectiveness of the treatment process and ensuring the site's environmental sustainability.

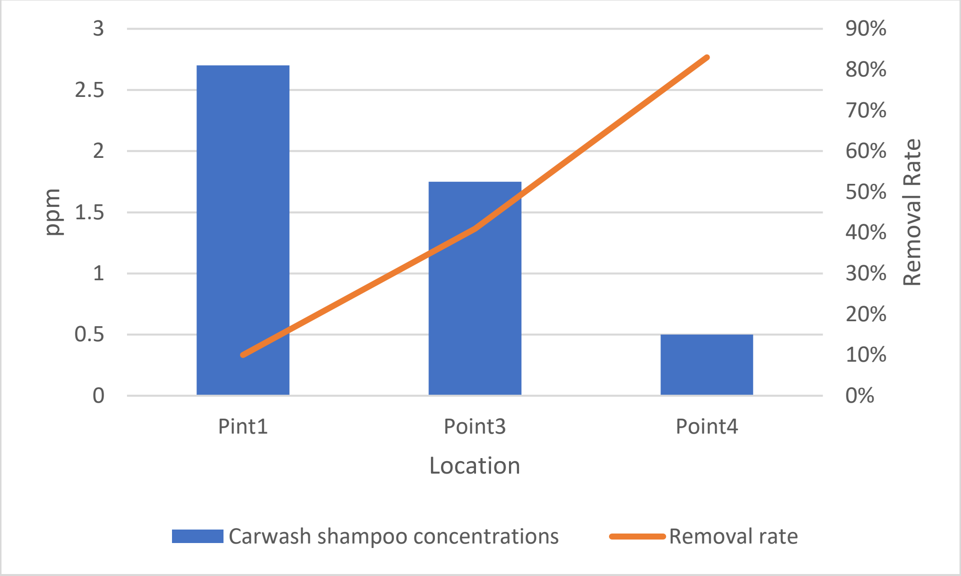


Figure 5. Carwash Shampoo Concentration and Removal Rate Analysis across Sampling Points.

This trend of decreasing carwash shampoo concentration from the first to the last sampled point could be due to several factors, including the dilution of the detergent solution, degradation of the detergent over time, or the removal of detergent from the solution through various mechanisms, such as adsorption or precipitation. The table shows the concentration of carwash shampoo (in ppm) at different sampling points (Point1, 3, 4) during three carwash applications. The concentrations varied between various locations, and some fluctuations observed across the sampling points with the total of 83% removal.

4.5 Lab Analysis: Chemical Oxygen Demand (COD)

Figure 6 presents the findings from an experiment designed to assess the performance of a phytoremediation system in reducing Chemical Oxygen Demand (COD) in carwash wastewater, and COD of the simulated CWW was 385 mg/L. The study was conducted over three weeks, during which water samples were collected from Point1,2 and 4. The COD concentrations of the samples were measured in milligrams per liter (mg/L) in 3 weeks. The data provided shows COD concentrations at Point1, Point2, and Point4. The COD concentration at Point1 was 328 mg/L, while the COD concentration at Point4 was 87 mg/L. This represents a significant decrease of 73.7% in COD concentration from Point1 to Point4.

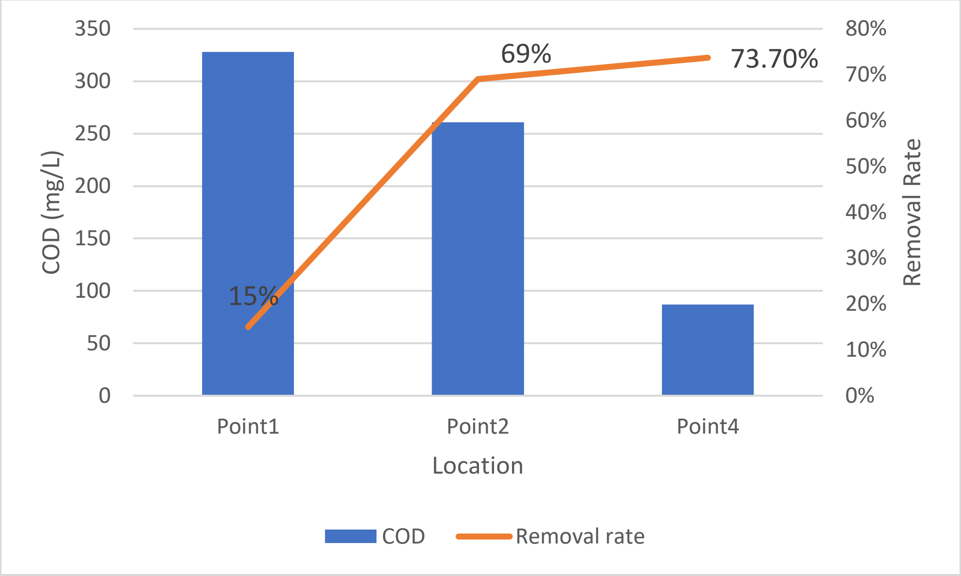


Figure 6. Comparison of COD Concentration and Removal Rate at Different Sampling Points.

The significant decrease in COD concentration from Point1 to Point4 indicates that the phytoremediation system was effective in removing COD from the carwash wastewater.

4.6 Field Chlorophyl Measurements

The chlorophyll contents decreased significantly in August after the application of carwash wastewater containing heavy metals, as compared to the measurements taken in July. This can be observed from the data showing a decrease in the chlorophyll content of all five poplar trees in August, as compared to their respective measurements in July.

Based on the measurements, it appears that the chlorophyll content decreased after applying the contaminated carwash wastewater in August. The measurements taken in July show relatively high levels of chlorophyll in all 5 poplar trees, with values ranging from 14.52 to 27.32. However, the measurements taken in September after the application of the contaminated water show significantly lower levels of chlorophyll in all 5 trees, with values ranging from 4.84 to 16.8. This decrease in chlorophyll content is likely due to the heavy metals present in the carwash wastewater, which can be toxic to plants and can inhibit their ability to photosynthesize.

This study focuses on the assessment of chlorophyll content in two Poplar trees, specifically Tree Number 2 (the largest Poplar tree) and Tree Number 3, located at Point 2 and 3 respectively. By conducting detailed chlorophyll measurements, we aim to understand the variations and potential effects of heavy metals uptakes results in influencing chlorophyll levels in these trees. The analysis encompasses multiple time periods, including measurements taken in June and July 2021, prior to the application of carwash wastewater, as well as subsequent measurements from August to October. Additionally, to assess any potential long-term effects, chlorophyll measurements were continued from June to October 2022. Through this investigation, we aim to gain valuable insights into the chlorophyll dynamics and the possible impact of carwash wastewater on these Poplar trees' health. Figure 7 demonstrates the variation of chlorophyll content across three different heights (bottom<50cm, Middle=150cm, Top>200cm) of the Poplar Tree at point2 before and after applying CWW at the site in 2021.

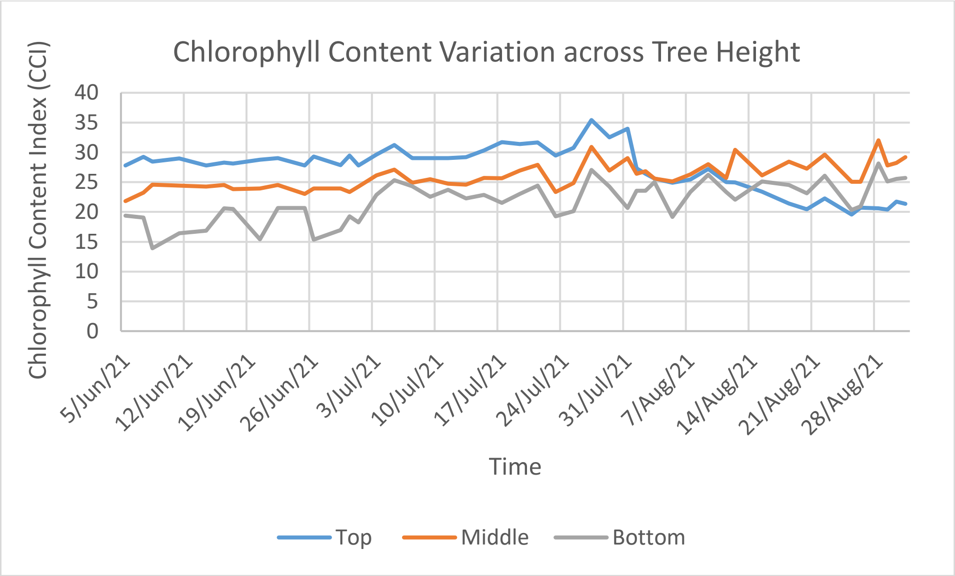


Figure 7. Chlorophyll Content Variation across Tree Number 2 Height Before (Jun & July) and after (August) applying carwash wastewater in 2021 at point2.

The analysis of the data depicted in the Figure 8 reveals notable patterns regarding the chlorophyll content in leaves following the application of carwash wastewater across various heights (bottom, middle, and top). The findings indicate a consistent decrease in chlorophyll levels after the implementation of carwash wastewater, irrespective of leaf position. Notably, prior to the wastewater application, bottom leaves consistently exhibited lower chlorophyll content, potentially attributable to reduced exposure to sunlight compared to top leaves.

Furthermore, observations in June indicate a general decrease in chlorophyll content across all leaves, which can be ascribed to the initial growth phase and smaller size of leaves during this month. Subsequently, chlorophyll levels experienced an increase in July, likely driven by leaf growth, favorable summer weather conditions, and increased sunlight availability.

In contrast, August witnessed a sudden decline in chlorophyll content. This decline was more pronounced in bottom leaves, as their proximity to the pollutant source and the weight of heavy metal uptake likely contributed to higher levels of contamination. Towards the end of August, a drastic decrease in chlorophyll content was observed, indicative of overall tree health disturbance and a potential reduction in the tree's capacity to provide shade and sustenance to the higher leaves. Figure 8 show the average chlorophyll content at points 2 and 3 respectively and the average of temperature during June2021- October 2022.

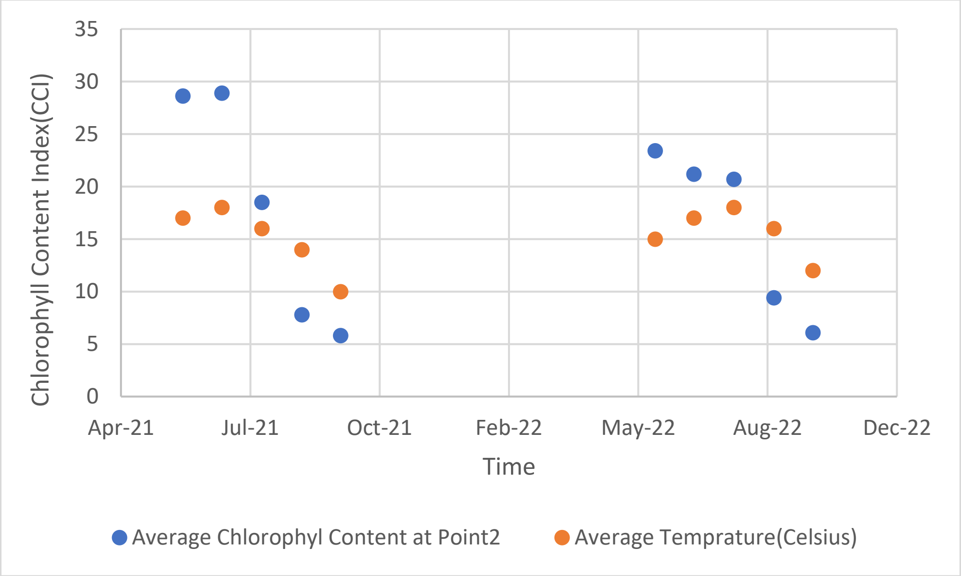


Figure 8. Average Chlorophyll Content at Point 2 and Average Weather Temperature from June 2021 to October 2022.

Figure 9 demonstrates that the average chlorophyll content at both Point 2 and 3 showed fluctuations over the given period. However, overall, there was a decline in chlorophyll content, indicating potential stress on the vegetation results from heavy metals uptake after applying Carwash Wastewater on the experiment site. The average temperature remained relatively stable throughout the timeframe. It is important to note that factors such as sunlight exposure, nutrient availability, seasonal changes, and other environmental conditions can also play a significant role in chlorophyll production and vegetation health.

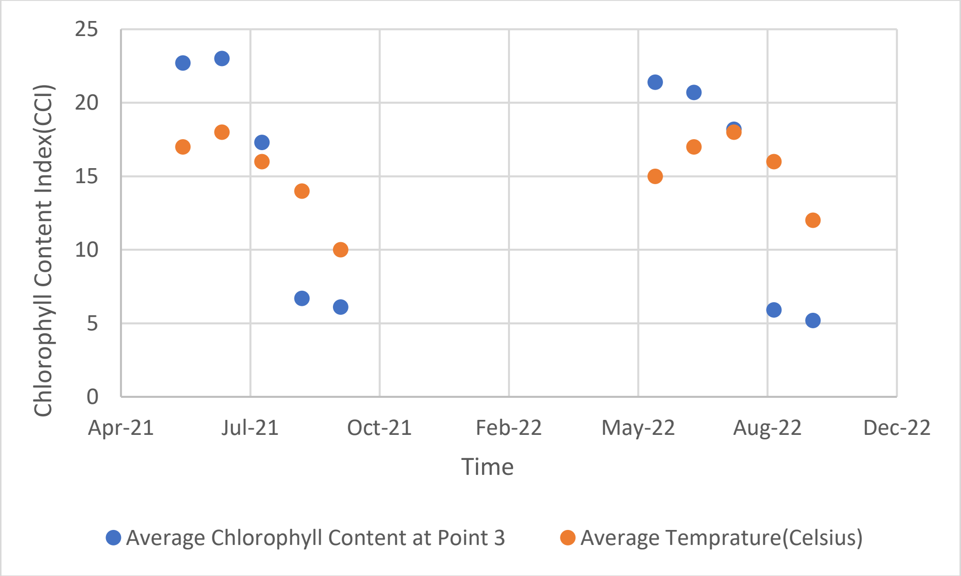


Figure 9. Average Chlorophyll Content at Point 3 and Average Weather Temperature from June 2021 to October 2022.

In summary, the study demonstrates the efficiency of the phytoremediation system in treating carwash wastewater by significantly reducing heavy metal concentrations, total suspended solids, and carwash shampoo content. The observed decrease in these parameters from Point 1 to Point 4 can be attributed to prolonged contact time, increased distance traveled, and a combination of physical, chemical, and biological processes taking place within the treatment system. These findings emphasize the system's capability to improve water quality and its potential to serve as an effective method for treating carwash wastewater.

Chapter 5 Conclusions

Carwash industry's water use produces harmful carwash wastewater (CWW) with heavy metals and detergents. Study proposes low-impact development (LID) solutions like phytoremediation for treating CWW in underdeveloped regions.

The study effectively removed heavy metals from CWW using the treatment field. Data highlights metal levels at sampling points and initial CWW concentrations. Notably, a significant drop in metal levels from Point 1 to Point 4 demonstrates successful removal via bioretention cells, with cadmium (98.95%) and iron (98.65%) showing the highest removal rates. Metal concentration variations in leaves post CWW application were observed, with zinc, nickel, copper, cadmium, iron, and lead showing different levels. Tree #2 exhibited higher metal concentrations, possibly due to size and exposure. Metal concentrations varied by sampling month and tree, useful for strategies like phytoremediation. The study offers insights into phytoremediation's efficiency for CWW treatment, with effective heavy metal and suspended solids reduction from Point 1 to Point 4. Average metal concentrations decreased gradually, with the most significant drop in nickel. Furthermore, there was a substantial decrease (83% removal rate) in carwash shampoo concentration from Point 1 to Point 4, indicating successful detergent removal, likely due to various processes like dilution or adsorption. Moreover, the study also assessed the performance of the phytoremediation system in reducing chemical oxygen demand (COD) in carwash wastewater. The significant decrease in COD concentration from Point1 to Point4 indicated that the system was effective in removing COD from the wastewater, which can have implications for improving wastewater treatment processes in various industrial and environmental settings. Furthermore, the chlorophyll content measurements showed a significant decrease in August after the application of carwash wastewater containing heavy metals, as compared to the measurements taken in July. This decrease in chlorophyll content could be attributed to the toxicity of heavy metals, which can negatively impact plant growth and development in addition to weather effects and cooling off period in August. The COD concentration decreased from 328 mg/L at Point1 to 87 mg/L at Point4, indicating a significant 73.7% reduction. The study observed a significant decrease in chlorophyll content in poplar trees after the application of carwash wastewater containing heavy metals in August, compared to July measurements. The decrease in chlorophyll content was consistent across different tree heights and likely attributed to the presence of toxic heavy metals. The findings highlight the negative impact of carwash wastewater on chlorophyll dynamics and tree health, indicating potential stress on vegetation due to heavy metal uptake.

In conclusion, the study highlights the success of the phytoremediation system in effectively purifying carwash wastewater. This includes removing heavy metals, suspended solids, detergents, and chemical oxygen demand. The practical implications span various industries, especially carwashes, and promote a cost-effective and environmentally friendly wastewater treatment solutions.

While we have made every effort in this research to explore the impact of heavy metals on tree growth and the effectiveness of recycled water, there is still room for further investigation in these areas. Future research should focus on studying the impact of heavy metals on tree health and developing maintenance systems that allow for the efficient reuse of recycled water.

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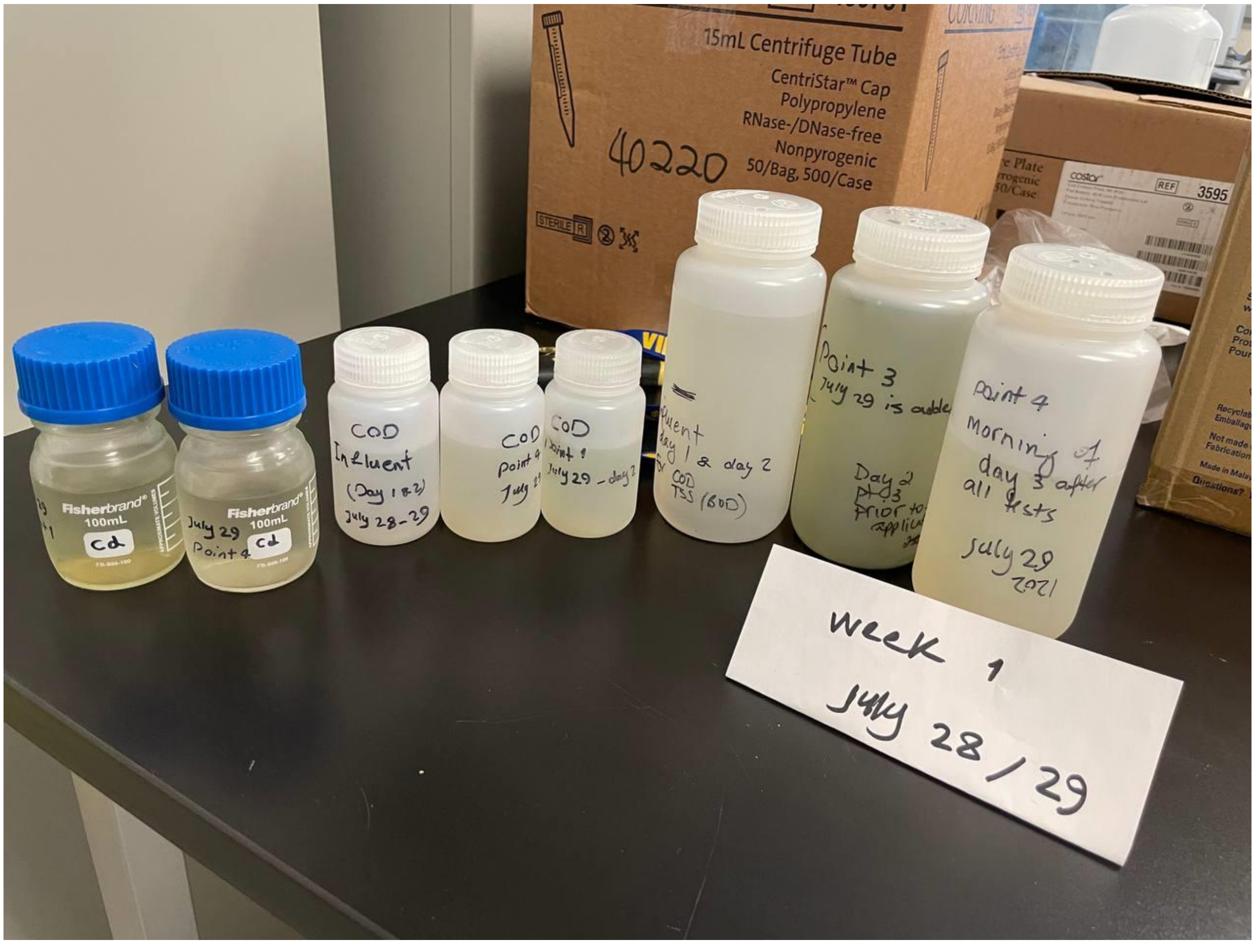
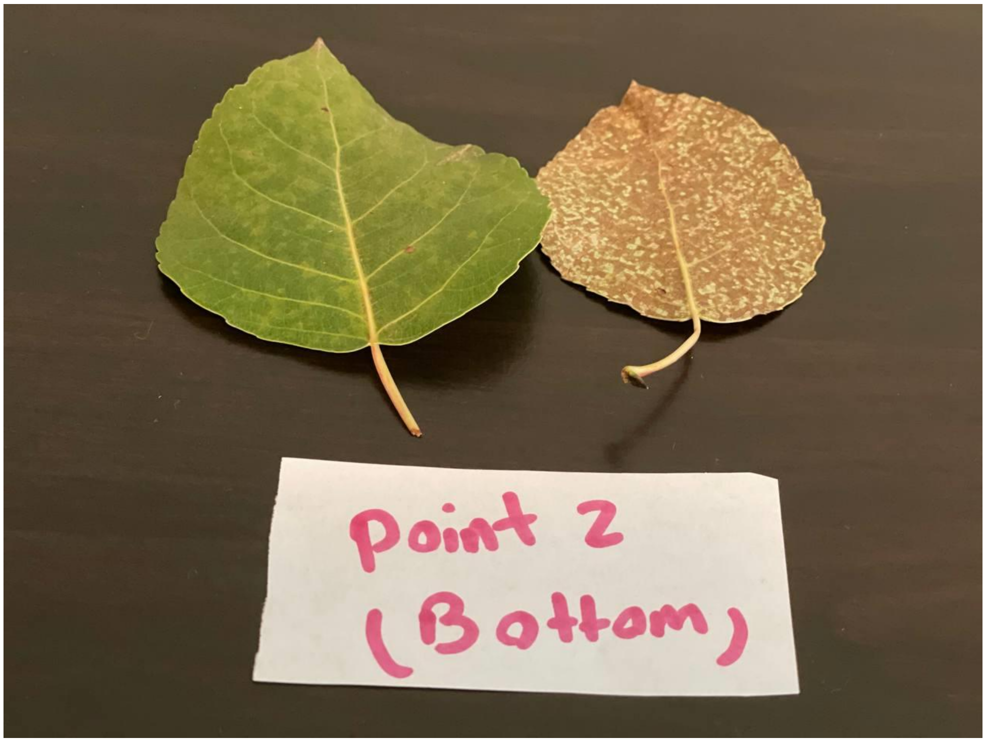
Appendix

Picture1. Sampled ready to be transferred to the lab

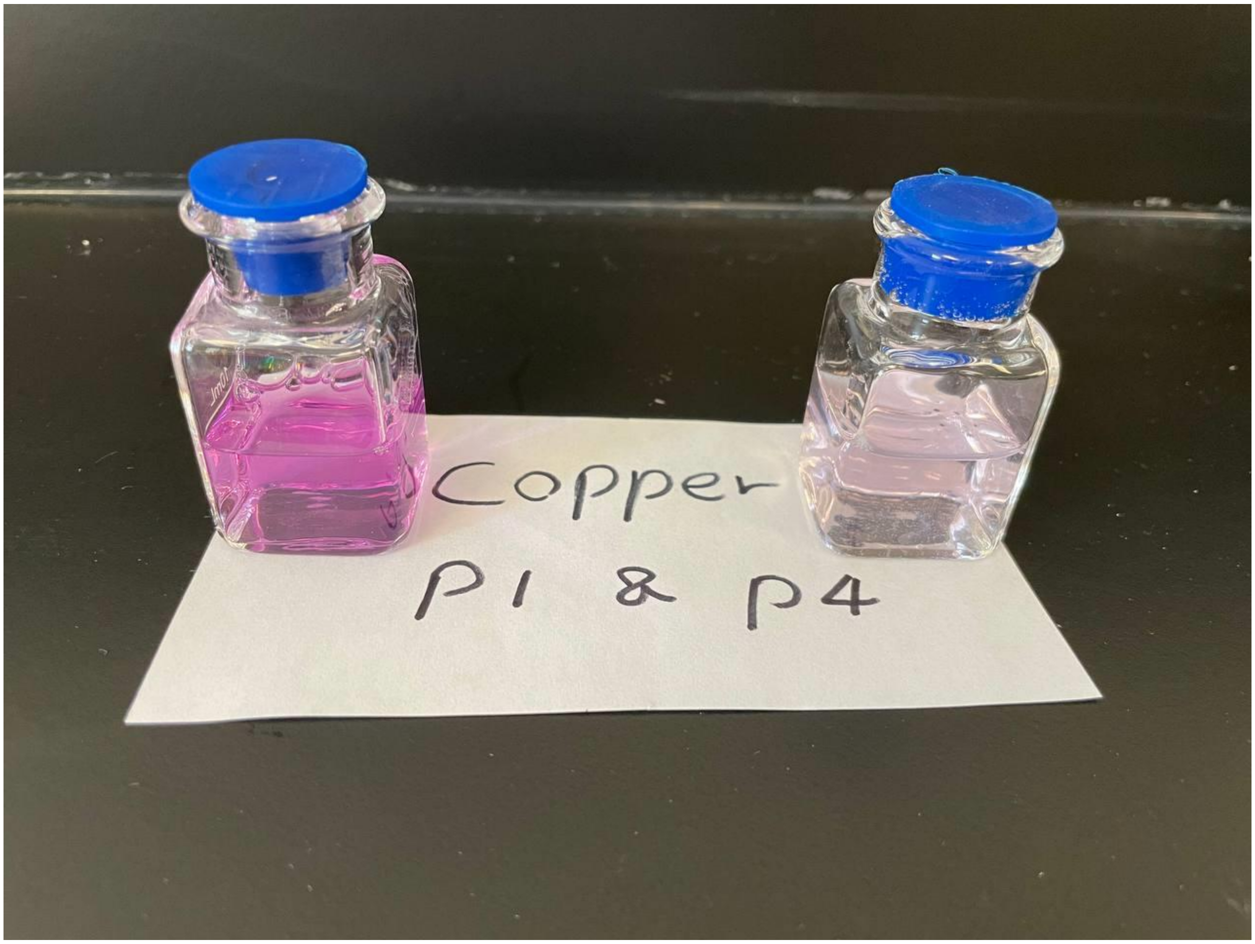


Picture2. Samples in the lab

Picture3. Heavy metals uptake in the top leaves



Picture4. Heavy metals uptake in the bottom leaves



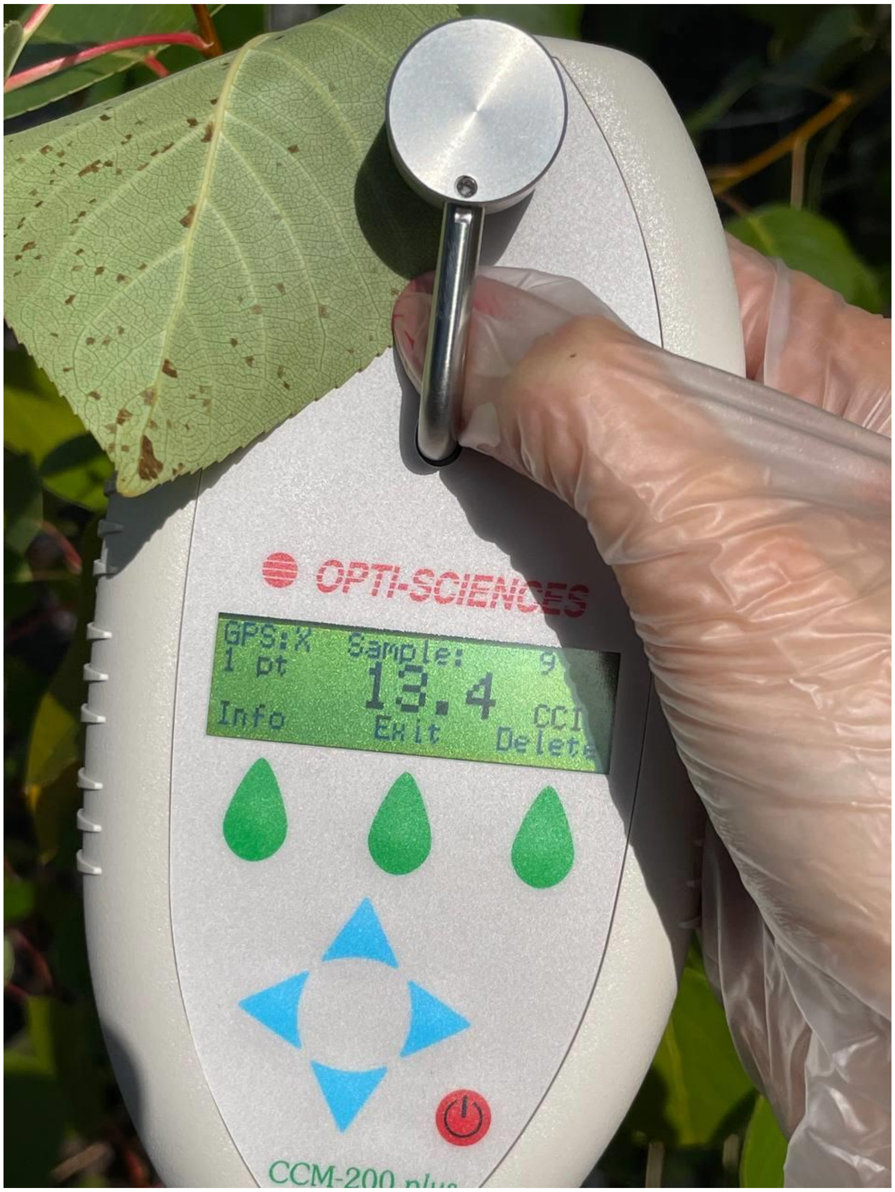
Picture5. Samples from point 1 and 4, ready to analyze copper concentration.

Picture6. Analyzed sample to evaluate the concentration of iron in CWW

Picture7. Samples ready to analyze and evaluate the concentration of Iron

135 Copper Bicin. 560nm
0.67 mg/L Cu
5.00
0.00
1 0(855)
05:21:36
TALEBZADEH
17-8-2021

Picture8. Analyzed sample to evaluate the concentration of copper in CWW



Picture9. Chlorophyll measurements in the top leaves of the big poplar tree

Picture10. Chlorophyll measurements in the bottom leaves of the big poplar tree

Picture11. Chlorophyll measurement at the field

Picture12. TSS test