Visual, Near-Infrared, Short Wave Infrared Reflectance Spectroscopy for Microplastic Identification and Quantification in soils and the Environment

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jake Austin Carr
August 2025

Acknowledgements:

I would like to acknowledge and sincerely thank everyone who has supported and assisted me throughout my master's thesis research. This includes, but is not limited to, the dedicated lab team: Marius Charles, Maya Campos, Maya Moment, Esha Patel, Yusef Hussain, Reilley Swanson, and Mike McKinney, as well as the Department of Earth, Environment, and Planetary Sciences at the University of Tennessee, Knoxville. Furthermore, I extend my gratitude to my family, kind colleagues, and peers in both this department and the Department of Biosystems Engineering, who have provided valuable guidance and clarity throughout a challenging endeavor. I would also like to thank Sean Schaefer and Professor Douglas Hayes for generously sharing their expertise and facilities, which were instrumental in making this project possible.

A special thank you is owed to Dr. Jennifer Franklin from the Department of Wildlife and Fisheries for lending the PSR+ spectroradiometer used in this research. I am also deeply grateful to my final committee member, Dr. Anna Szynkiewicz, for her consistent guidance and encouragement as I completed my Master's project.This project was made possible through the collaboration of multiple departments at the University of Tennessee, Knoxville, each of which contributed through their shared knowledge, resources, or facilities. The Department of Wildlife and Fisheries provided critical instrumentation, and Professor Hayes' lab in the Department of Biosystems Engineering enabled the generation of microplastic particles. I am equally grateful to the Department of Earth, Environment, and Planetary Sciences for offering the space necessary to conduct my experiments and prepare my samples. Lastly, I must thank the support staff who help the department run smoothly on a daily basis. This includes Angela Collins, Michael Del Valle, Bob Freeman, Robby Hutcherson, Chris Gallop, Jennifer Twachtman, Chris Ulrey, Drew Bryant, Joel Rummage, John Michael Cassidy, Jordan Diamond, Sonia Calvin, Stephen Ward, Terry McConnell, and many others. Without the assistance and cooperation of these individuals, I would not have been able to complete this thesis. For that, I am forever grateful.

Abstract:

This study investigates the viability of using visible, near-infrared (VNIR), and short-wave infrared spectroscopy, specifically the PSR+ spectroradiometer, for the identification and quantification of microplastic pollution across various environmental matrices. Partial Least Squares Regression (PLSR) models were developed using Tennessee red clay soil combined with known concentrations of four plastic polymers: low-density polyethylene (LDPE), polyvinyl chloride (PVC), polystyrene (PS), and polypropylene (PP). The models yielded strong predictive performance with R^2 values of 0.83 (LDPE), 0.91 (PVC), 0.946 (PS), and 0.98 (PP). Environmental samples were collected from a semi-urban agricultural site in Blount County, Tennessee, and included dry atmospheric deposition, precipitation, groundwater, surface water, and soil. A total of 1,799 microplastic particles were confirmed through microscopic analysis, with fibers being the most abundant type, followed by fragments, films, pellets, microbeads, and foams. Spectral analysis identified LDPE, PVC, nylon, polystyrene, and polypropylene in the environmental samples, with the highest detection rates occurring in soil and surface water. This research demonstrates that the PSR+ spectroradiometer, when paired with properly constructed PLSR models and standardized sample processing, can serve as an effective, non-destructive tool for detecting and characterizing microplastics in terrestrial and aquatic environments.

Table of Contents:

Chapter 1. Introduction 1
1.1 History of Microplastics Study 1
1.2 What are Microplastics? 1
1.2.1 Primary Microplastics 2
1.2.2 Secondary Microplastics 2
1.2.3 The effects of Microplastic Pollution 3
1.3 Microplastics Detection Methods 5
1.3.1 Dry Atmospheric Microplastic Contamination 5
1.3.2 Wet atmospheric deposition 6
1.3.3 Hydrological Microplastic Contamination 7
1.3.4 Soil Microplastic Contamination 8
1.4 Microplastic Quantification and Identification 8
1.4.1 Destructive Detection 8
1.4.2 Non-Destructive Detection 9
1.5 Research Question and Approaches 11
Chapter 2. Methods 13
2.1 Pre-Sampling 13
2.2 Study area and Sample Size 14
2.2.1 Soil Samples 14
2.2.2 Precipitation Samples 16
2.2.3 Freshwater Samples 16
2.2.4 Groundwater Samples 16
2.2.5 Dry Atmospheric Deposition 17
2.2.6 Microscopic Analysis 17
2.3 Model Generation from Spectral Data 17
2.3.1 Partial Least Square Regression Modeling 17
2.3.2 Sample Generation and Methodology Validation 18
2.3.3 Spectral Data Analysis 19
2.3.4 Microplastic Counts Data Analysis 20
Chapter 3. Results 25

3.1 Microplastic Counts 25
3.2 Dry Atmospheric Results 25
3.3 Wet Atmospheric Results 28
3.4 Groundwater 31
3.5 Surface Water results 33
3.6 Soil Results 36
3.7 Spectra Results Overview 39
3.8 Model Results 44
Chapter 4. Discussion 54
4.1 Propylene Model 54
4.2 Polystyrene Model 56
4.3 PVC Model 57
4.4 LDPE Model 57
4.5 Consistent Margins of Error 58
4.6 Soil Variation 59
4.7 Contamination 60
4.8 Influences on Dry Atmospheric Microplastic Contamination 60
4.9 Particle Characteristics 61
4.10 Proximity to Urban and Industrial Sources 62
4.11. Topographical and Vegetation Effects 63
4.12 Human-induced Activities 64
4.13 Sources of Wet Atmospheric Microplastic Pollution 66
4.14 Proximity to Sources of Pollution and Land Use Effects 67
4.15 Determinants of Hydrological Microplastic Contamination 67
4.16 Properties of Microplastics and Their Impact on Transportation 68
4.17 Biological Uptake and Trophic Transfer in Pond Ecosystems 70
4.18 Microplastic Contamination of Groundwater 71
4.19 Microplastic Contamination of Soil 74
Chapter 5. Summary, Limitations and Conclusions 76
5.1 Notable Observations: Purple Microplastics and Color Distribution 77
5.2 Chemical Composition 77

5.3 Limitations 78
5.4 Conclusions.....79
References 82
Vita 92

List of Figures:

Figure 1: Satelite Image of the Sample Site.....15
Figure 2: Polyethylene Standard Spectra.....21
Figure 3: Polyvinyl Chlorine Standard Spectra.....21
Figure 4: Polypropylene Standard Spectra.....22
Figure 5: Polystyrene Standard Spectra 22
Figure 6: Nylon 12 Standard Spectra 23
Figure 7: Glass Fiber Filter Paper Spectra.....23
Figure 8: Glass Fiber and Boronsilicate Glass Spectra.....24
Figure 9: TN Red Clay Soil Spectra.....24
Figure 10: Distribution of Microplastic Types.....26
Figure 11: Microplastics Composition in Dry Atmospheric Deposition.....27
Figure 12: Microplastic Color Distribution in Dry Atmospheric Deposition.....29
Figure 13: Microplastic in Hurricane Helene 30
Figure 14: Microplastic Color Distribution in Hurricane Helene.....32
Figure 15: Microplastic Composition in Groundwater.....34
Figure 16: Microplastic Color Distribution in Groundwater.....35
Figure 17: Microplastic Composition in Surface Water 37
Figure 18: Microplastic Color Distribution in Surface Water.....38
Figure 19: Microplastic Composition in Soil.....40
Figure 20: Microplastic Color Distribution in Soil 41
Figure 21: Microplastic Detection Summary Across Enviroments.....42
Figure 22: Breakdown of Detected Plastic Types Across Enviroments.....42
Figure 23: Distribution of Detected Plastic Types Across Enviroments.....43
Figure 24: Plastic Dection Rates Per Enviromental Media.....45
Figure 25: PSLR Polypropylene Model Line Graph.....46
Figure 26: PSLR Polyprolene Model Bar Graph 47
Figure 27: PSLR Polystyrene Model Line Graph.....48
Figure 28: PSLR Polystyrene Model Bar Graph.....49
Figure 29: PSLR PVC Model Line Graph.....50
Figure 30: PSLR PVC Model Bar Graph.....51

Figure 31: PSLR LDPE Model Line Graph.....52
Figure 30: PSLR PVC Model Bar Graph.....53
Figure 33: Mechanical Grinder.....55

Chapter 1. Introduction

1.1 History of Microplastics Study

Plastic production began in the early 1900s resulting in polypropylene, polyethylene, and polystyrene becoming widespread in several aspects of society (Geyer et al, 2017). By the early 1960's a growing environmental concern began to grow in the marine sciences due to the large accumulation of plastic debris in the world's oceans and shorelines (Law, et al, 2011). Thus, oceanographers, marine biologists, and scientists working in similar fields began to investigate the effects of plastic pollution on the marine ecosystem. Gradually other fields began to investigate plastic pollution and its corresponding effects on terrestrial systems. Eventually, microplastics research exploded in quantity and quality in the 2000's (Thompson et al, 2024). Microplastics studies have changed in scopefrom numerical counts and observations to plastic pollution identification and tracing. The goal of the majority of microplastic investigations is to comprehend microplastic formation, origin, identification, and quantification. (Hale et al, 2020).

1.2 What are Microplastics?

Microplastics are small particles that are less than five millimeters in size and any form of plastic pollution exceeding 5 millimeters can be categorized as a mesoplastics and macroplastics if they exceed 20 mm in size (Duis et al 2016). Microplastics can be observed in the following forms beads, pellets, fibers, fragments, and films. These different types of microplastics are observed in every aspect of nature in both abiotic and biotic environmental reservoirs. The most observed microplastic type is fibers commonly found in all natural reservoirs but are largely concentrated in the atmosphere and hydrosphere. Microplastic fibers are small rod shaped microplastic that vary greatly in length anywhere from nanometers to several millimeters in scale. Microplastic fibers are generated through the production and maintenance of clothing, human activities, industrial processing, and textile industry (Habibet al 1998). The washing of clothes that contain synthetic material such as nylon or polyester will result in the formation of plastic fibers that are released primarily into the hydrosphere and atmosphere (De Falco et al, 2019). The sheer number of plastic fibers and their low resistance to movement has made microplastic fibers the most abundant and observed form of microplastic contamination.

The second most abundant microplastics are fragments, small irregular shaped plastic particles that are generated from the chemical or physical breakdown of larger plastics (Pfohl et al, 2022). Microplastic fragments are most observed in water and soil samples. Another orign of

microplastic contamination originates from the destruction and wear and tear of automobile tires generating plastic fragments. The reason for the variation comes from their increased mass and size that hinders the movement of the particle. Microplastics films are also observable in atmospheric and water mediums. Microplastic films are two-dimensional plastic particulates that range in color and size due to their formation from the photodegradation of large plastic particles such as mulch films or grocery store shopping bags (Kalogerakis et al 2017). Furthermore, films can be formed through mechanical and biodegradation pathways of larger plastic materials. These films are easily transported by abiotic or biotic factors and thus can be found in several locations but tend to be concentrated in atmospheric and hydrological samples.

Microplastic beads are three-dimensional plastic particles that range in size but are nearly spherical. Microplastic beads tend to be less than 1 millimeter in size and are generated in industrial processes (Singh et al, 2023). Similarly, microplastic pellets are three-dimensional plastic particles, but they vary much more in size. Microplastic pellets are primarily used in plastic manufacturing. Due to the variation of plastic manufacturing the observed size and color of the resulting microplastic pollution directly correspond to the application of manufacturing.

1.2.1 Primary Microplastics

Primary microplastics are plastic particles that are intentionally generated, manufactured or formed as a byproduct of specific processes (Singh et al, 2023). A majority of primary microplastics are much smaller than 5 millimeters in size. For example, the beads used in industrial processes or in bodywash are smaller than 1 mm in length. Furthermore, primary microplastics tend to have a pure composition that has not been altered by environmental factors when initially formed. The application of primary microplastics tends to be in cosmetics and skincare products; these products include facial scrubs and toothpastes (Singh et al, 2023. The application of primary microplastics in the formation of plastic manufacturing tends to lean towards resin pellets for raw materials. As a result, the majority of plastic particles observed in the environment that are identified as primary microplastics come in the form of plastic pellets and microbeads (Song, et al, 2024).

1.2.2 Secondary Microplastics

The most commonly observed microplastics in all studies are secondary microplastic particles. Secondary microplastics originate from the physical or chemical degradation of macroplastic or mesoplastics. Through repetitive exposure to wind, water, waves or other physical pneumonia in nature plastic pollution is slowly weathered down into microplastics

(Song, et al, 2024). Plastic pollution exposed to large periods of UV radiation may undergo photodegradation. Photodegradation is the process in which polymers absorb energy from sunlight resulting in the formation of free radicals. In the presence of oxygen photooxidation may occur resulting in a more rapid decomposition of the plastic polymers (Yousif, et al 2013). During this process free radicals or additives that are trapped within the polymers chemical structure are released into the environment. The released chemicals could affect biota by lower biological fitness and due to this it's important to be able to locate microplastic origins. The ultimate goal of the project is to determine if the application of portable spectroscopy can be utilized to determine microplastics chemical composition and possible concentration (Yousif, et al 2013).

1.2.3 The Effects of Microplastic Pollution

Environmental microplastic contamination has the potential to substantially alter biogeochemical cycles and hinder biological processes. Microplastic exposure in the environment is documented in freshwater hydrological systems, groundwater, marine systems, and soil ecosystems. Plastic pollution in marine systems alters food webs and the fitness of several organisms due to biomagnification (Miller et al, 2020). Groundwater contamination by microplastics is a great concern due to the human use of groundwater resources beginning to increase for agricultural or personal use. Freshwater systems are containment with plastic pollution from nearby terrestrial systems. Microplastic contamination in soil systems can lead to the destruction of soil ecosystems.

Microplastic pollution in marine environments presents a serious and growing threat to ocean health. These particles, originating from degraded plastic debris, synthetic textiles, fishing gear, and industrial waste, are now ubiquitous throughout the world’s oceans—from coastal regions to deep-sea sediments (Harsha et al, 2024). Once introduced into marine systems, microplastics can be ingested by a wide range of organisms, including plankton, fish, mollusks, and marine mammals. This ingestion leads to both physical and chemical harm, including internal blockages, inflammation, and the transfer of toxic compounds such as persistent organic pollutants (POPs) that adhere to plastic surfaces (Bhuyan, 2022). Furthermore, microplastics can bioaccumulate and biomagnify throughout the marine food web, meaning predators—often including humans—are exposed to higher concentrations of these contaminants (Miller et al, 2020). Disruptions in reproductive fitness, behavioral changes, and altered growth rates have all been observed in marine organisms due to microplastic exposure. As such, the persistence and

mobility of microplastics threatens not only biodiversity but also the stability of marine ecosystems and the sustainability of global fisheries.

In freshwater environments, such as rivers, lakes, and streams, microplastic pollution poses equally alarming risks. These systems serve as both transport routes and reservoirs for plastic waste originating from urban runoff, industrial discharge, agricultural activities, and atmospheric deposition (Raza et al, 2022). Microplastics can settle into sediments or remain suspended in the water column, making them accessible to a variety of aquatic organisms. Studies have shown that microplastics are ingested by freshwater invertebrates, fish, and amphibians, leading to internal injuries, reduced feeding efficiency, and energy depletion (Bhuyan, 2022). Additionally, freshwater systems are often sources of drinking water for human populations and play a critical role in irrigation, amplifying the concern for public health and food security. The interactions between microplastics and other contaminants, such as heavy metals and pesticides, may also enhance the toxicological risks to organisms. Moreover, these particles can alter microbial communities and interfere with key ecosystem services, including nutrient cycling and organic matter breakdown (Liu et al, 2021). As freshwater ecosystems are often the interface between terrestrial and marine systems, they serve as critical chokepoints in understanding and mitigating microplastic transport and transformation.

Microplastic contamination in soil environments has emerged as an urgent and underexamined issue with far-reaching ecological consequences. Sources of microplastics in soils include agricultural inputs like sewage sludge and plastic mulch films, atmospheric deposition, landfill leakage, contaminated bodies of water, and runoff from urban areas (Raza et al, 2022). Once in the soil, microplastics can affect key physical and chemical properties of the soil matrix, such as porosity, water retention, and aggregation (Lozano et al, 2021). These changes can significantly alter soil health and its capacity to support plant growth. More importantly, microplastics interfere with the activities of essential soil organisms, including earthworms, nematodes, and microbial communities, which are responsible for nutrient cycling, organic matter decomposition, and maintaining soil structure. Ingested microplastics can cause gut damage and reproductive harm in soil fauna, ultimately leading to a decline in biodiversity and ecosystem function (Schopfer, et al 2020). Additionally, microplastics may serve as vectors for harmful chemicals or pathogens, further destabilizing soil ecosystems. Considering that soil is the foundation of terrestrial food production and ecosystem resilience, the growing burden of microplastic contamination poses a critical threat to agricultural productivity and environmental

sustainability.

1.3 Microplastic Detection Methods

1.3.1 Dry Atmospheric Microplastic Contamination

Atmospheric pollution in totality is one of the largest threats to human populations and at the current moment millions of deaths occur every year (Manisalidis 2020). To properly understand plastic contamination of the atmosphere it is imperative to understand the fallout of microplastics without a precipitation event. To accomplish this, scientists begin to investigate dust accumulation to get an understanding of background contamination in labs or in the environment. The study conducted by Li, J et al. found that microplastic composition and type vary between dry and wet atmospheric deposition (2023). Furthermore, the study conducted by Yumei et al. found similar results, noticing significant differences in atmospheric dry deposition to wet deposition in regard to microplastic color, types, and chemical composition (2021). The main reason for the varied differences between microplastics observed in wet and dry atmospheric samples is the role that microplastics characteristics play in their transport in the environment.

Atmospheric microplastic particles can vary greatly in shape, size, chemical properties, surface roughness and surface area. These differences can control the transport potential of the particle. For example, rod shaped low density microplastics such as fibers would have more transport potential than microplastic fragments that have a greater surface area with an increased density or mass. Han et. al found that microplastics are heavily influenced by both anthropogenic and natural factors (2024). As a result of this finding, the methods for atmospheric dry deposition must take into consideration both potential natural factors and human factors that can affect the collection of microplastics. The two different avenues for microplastic collection include both passive and active collection.

The main way to collect dry samples is through passive collection but active collection has increased. The simplest collection method is through the active collection of dust through the application of open deposition devices. Dris et al. (2019) used shallow glass or metal dishes placed in open areas to collect dust and deposited microplastic particles (2016). The main way that open deposition dishes work is that they act as a vessel for dust collection and once an adequate amount of time has passed the material is rinsed and the water is filtered for microplastic count and identification. Furthermore, the study conducted by Allen et al. (2019) used stainless steel buckets with some modifications for dust collection to study microplastic

contamination in the Pyrenees mountains. The second form of passive atmospheric deposition collection is through the use of adhesive or sticky surfaces to collect microplastic particles that are naturally deposited from the atmosphere. The standard adhesive used for microplastic collection comes in the following forms: petroleum jelly, adhesive films, and synthetic resins. Studies focused on atmospheric deposition of microplastics in the Western portion of the United States used adhesive slides with an adhesive edge for microplastic collection (Brahney et al. 2021).

Active collection samplers use airflow to capture microplastics and tend to be the most efficient in controlled studies. High- volume air samples pull liters of air through filters composed of either glass fiber or quartz to collect the microplastic in the air. An example of HVAS, high volume active sampler, in use can be seen in the study, "Atmospheric transport is a major pathway of microplastics to remote regions" in which the HVAS was used to collect microplastic out of the air in several remote regions. Cascade impactors use multiple stages of size selective filters to separate microplastics based on the aerodynamic diameter. Abbasi et al. (2019) applied cascade impactors to actively collect microplastics from the air in Iran. A cheaper and more common way to actively collect microplastics through the creation and application of an electrostatic sampler. The latter is a device that generates an electromagnetic field on a charged plate that will attract or pull microplastic from the nearby air to be collected on the sampler. Huang et al. used electrostatic samples or airborne microplastic in both indoor and outdoor environments (2024).

1.3.2 Wet atmospheric deposition

Wet atmospheric deposition plays a critical role in the movement of microplastics from the atmosphere to terrestrial and aquatic environments. Precipitation includes the following: rain, snow, fog, and dew. These water molecules act as a natural collector of airborne plastic particles and deposit them onto terrestrial surfaces. The collection process influences the distribution and accumulation of microplastics in ecosystems, affecting their potential environmental and human health impacts. Understanding precipitations as a vector for microplastic deposition is essential for assessing the extent of atmospheric microplastic contamination and identifying key factors that control their removal from the atmosphere. The primary categories for wet atmospheric collection directly correlates to dry atmospheric collection in passive and active collection methods.

Passive wet deposition samplers gather precipitation without any mechanical or electrical

energy needed. The most common method is to use open glass, stainless steel, or other non-plastic material that acts as a catching device. For example, Dris et al. (2016) collected rainwater in Paris using glass containers primarily petri dishes. However, these open containers also collect dry atmospheric deposition and are being replaced by wet-only precipitation samplers. Passive samplers that only collect precipitation tend to be constructed based on a funnel system that opens only during precipitation events. A study that used wet only precipitation samplers was Zhang J et al. (2022) which applied automated wet only samplers to study microplastic fallout in Beijing from the atmosphere. Another collection device is a snow sampler that consists of sterile glass or metal containers with an open top, that catches snow precipitation. To study microplastic contamination in arctic snow Bergmann et al. (2019) used stainless steel to capture arctic snow.

Active collection methods tend to control the precipitation flow or volume being measured at one particular time. Automated rain samplers collect rainwater in a sealed, contamination free container that only opens once precipitation is detected. The previously stated methodology was used by Liu et al. (2019) in a study focused on collecting microplastic contamination in Shanghai China. The second active collection method is very similar to the first but on a much larger scale. High-volume precipitation collectors are industrial rain samplers designed to collect large quantities of rain for environmental analysis. Scientists have used this method to greatly affect collecting high volumes of precipitation in both urban and rural areas (Hale et al, 2020). Some studies introduce a filtration system incorporated inside the precipitation device that allows for microplastics to be separated from the sample before the scholars collected the sample. Active samplers are more effective and common in modern research and can be found in several other fields of microplastic research.

1.3.3 Hydrological Microplastic Contamination

Surface water includes oceans, rivers, lakes, and reservoirs. Groundwater systems refer to groundwater and its respective groundwater reservoirs. One of the most common ways to measure surface water in larger bodies of water is to use a Manta Trawl. A manta trawl is a net with a rectangular mouth towed behind a boat on the surface of the water. The net is utilized for collecting microplastics and macroplastic particles for further examination of just the plastics without the water (Eriksen et al. 2014). Besides manta trawls, plankton nets can be used for the collection of suspended microplastics. This methodology was proved to be accurate for large scale collection in calm water (Barrows, 2017). The most common method for surface water collection is bulk water sampling. Bulk water sampling is directly capturing the water in glass

containers (Mintenig et al, 2019). To study moving waters in rivers and creeks the most effective and growing method is a continuous flow methodology. Continuous flow methodology uses a pump and inline filtration to continuously sample microplastic contamination.

When examining microplastic groundwater contamination several studies tend to investigate the entire water system in a local area (Lee et al, 2024). The reason for this stems from the continental nature of the surface water and groundwater systems in the area. As a result of this the majority of methods from surface water examinations carry over to groundwater examinations. For example, the most common method for microplastic examination is direct well sampling. The study by Pivokonsky et al. (2018) collected groundwater samples from municipal wells by extracting the water using a bailer or pump. Continuous flow was also utilized for groundwater studies; the water was passed through several filters to extract the microplastics before being deposited back into the well. A few other methods are being investigated but direct collection and filtration are the main avenues for collection.

1.3.4 Soil Microplastic Contamination

Soil microplastics contamination is an emerging environmental concern, driven by inputs from agricultural activities, wastewater irrigation, atmospheric deposition, and plastic waste degradation. Once in the soil, microplastics can alter soil structure, affect microbial communities, and potentially enter the food chain or humans (Yang et a. 2024). Understanding the extent and distribution of microplastics in soil requires robust sampling methods that account for both surface and subsurface contamination. Surface collection consists of grab sampling and quadrat sampling, which measures microplastic accumulation via direct deposition. However, more complex methods such as vacuum based sampling are useful for retrieving finer particles. Soil coring and auger sampling allow for increased understanding of vertical distribution and potential transport through soil layers, and depth profiles to be generated. Furthermore, techniques like lysimetry help evaluate MP mobility through the measurement of leaching, while density separation and electrostatic separation enhance MP recovery from complex soil matrices. Through the utilization of these methods, researchers can gain a comprehensive understanding of soil microplastic contamination, its sources, and potential environmental effects.

1.4 Microplastic Quantification and Identification

1.4.1 Destructive Detection

If the method of analysis for the sample results in the sample no longer able to be

measured by other means, e.g., from it is categorized as a destructive methodology. The majority of microplastic quantification and identification methodology can be categorized as destructive. Destructive techniques involve altering or breaking down microplastic samples during analysis often through thermal, chemical, or spectroscopic techniques. The results of the analysis provide insights into polymer composition and concentration but prevent sample reuse or further experimentation.

One of the most common methods for microplastic particle identification is through combustion. An example of this is Pyrolysis-Gas Chromatography and Mass Spectrometry (Py-GC/MS) during the use of this device the plastics are destroyed and analysed by a mass spectrometer. The study by Primpke et al (2020) used Py-GC/MS to analyze microplastic particles in a comparison study. The study found that in correct circumstances destruction of plastic material could result in quick plastic identification. A second thermal method is thermal extraction desorption-gas chromatography- mass spectrometry (TED-GC/MS) in which the sample, the filter, and water are treated in a furnace and incarnated as a whole (Dümichen et al., 2015).

Thermogravimetric analysis (TGA) is a less than often used method for polymer identification. However, the literature review and investigation by Rola Mansa (2021) found that thermogravimetric analysis of microplastics is underutilized even though TGA is a rapid and painless method. Furthermore, TGA has been utilized in both laboratory and environmental samples. However, the main conditional requirements for TGA identification and quantification of microplastics is that the polymeric constituents must not share overlapping melting peaks. Nevertheless, TGA must be coupled with other instrumentation, such as, differential scanning calorimetry; coupled with Fourier transform infrared (FTIR) spectroscopy, mass spectrometry, and thermal extraction desorption-gas chromatography-mass-spectrometry (Mansa 2021). Regardless of additional instrumentation, TGA can be applied for plastics identification as long as the plastic polymers exhibit unique thermal peaks. Unfortunately, TGA results in the destruction of the sample and does not allow for sample reuse or remeasurement. Likewise, this makes temporal studies difficult where destructive methods could allow for the formation of a plastic database.

1.4.2 Non-Destructive Detection

Nondestructive methods for microplastic identification and quantification are growing in demand and interests. The reason for the increased demand is for their ability to preserve the

physical and chemical integrity of microplastic particles. Nondestructive techniques allow researchers to characterize microplastics in the environmental matrices without altering their morphology or chemical composition; the preservation of the plastic particles enables further analysis by researchers of different destructive or nondestructive identification and quantification methodology.

Raman and Fourier Transform Infrared Spectroscopy are the most commonly used nondestructive methods for microplastic identification and quantification. Both Raman and FTIR spectroscopy provide detailed chemical information that allows for microplastic identification. Raman spectroscopy uses the application of laser generated light to measure inelastic scattering. FTIR uses infrared light and measures the absorption of a material. A similar nondestructive technique is Near Infrared spectroscopy which provides the chemical absorption features of the plastic particles. Furthermore, a more recent methodology for microplastic identification and quantification is the application of full range reflectance spectroscopy.

Full range spectroscopy is the application of spectroradiometry that captures reflectivity percentage and expresses absorption. In the beginning reflectance spectroscopy did not use all available segments of light but instead tended to focus on visual and near infrared for plastic identification. One of the first studies that investigated the application of portable spectroradiometry was by the scholar Fabio Corradini. Corradini et al. (2019) developed a method for quantification and identification of microplastic contamination in soil using a portable spectroradiometer with a contact probe, a device that is physically placed on the sample for spectrographic measurements. In the study the spectra gathered were used to train a model for microplastic analysis in soils, and they successfully quantified and identified terrestrial LDPE, PET, and PVC (Corradini, 2019). Now the Corradini study used an instrument that only measured the visual and near infrared wavelengths for microplastic identification and quantification in the 350-2500 nm range. Due to the Corradini results, scholars have begun to investigate this methodology for refinement and application in environmental samples.

Pieniazek et al. (2024) expanded on Corradini’s work on microplastic identification and quantification in soils but used a spectrometer. that measured visual, near infrared, and ultraviolet light and had a significantly higher resolution. The increased resolution allowed for the detection of new absorption features that were not present in standard resolution. Furthermore, the Pieniazek study developed a method to process and generate a more natural homogeneous mixture of microplastics and soil. However, the Pienazek study used a pure

substrate consisting of 100 percent vermiculite as soil and used a benchtop probe rather than the contact probe in the portable spectroradiometer. The application of the benchtop probe and a higher resolution seems to have improved the overall accuracy of microplastic identification and quantification when compared to the Corradini investigation. However, the Corradini methods are more realistic and applicable methods for field application.

Nondestructive methodologies for microplastic identification and quantification are crucial for the field of microplastic analysis. The ability to preserve samples for future investigation and the ability of applying multiple methods for identification and quantification of microplastic pollution could be crucial in studying environmental samples. Furthermore, by preserving samples true temporal studies can be conducted in different areas or regions across the globe. At the current moment the majority of microplastic investigations or studies only provide a snapshot into microplastic contamination, and larger studies need to be conducted that investigate temporal trends of numerical counts, types, and chemical composition of the plastic polymers.

1.5 Research Question and Approaches

I aimed to investigate the methods developed by Pieniazek and Corradini (2024, 2019) and develop a new methodology for microplastic identification and quantification. For this study we hoped to bridge the gap between laboratory and field analyses. The goal of this study was to evaluate the ability to use portable UV-Vis-NIR spectroscopy for microplastic identification and quantification. The question we wanted to answer was the following: Can a portable spectrometer and radiometer be used for microplastic identification and quantification in laboratory and environmental settings? To accomplish this a model set of calibration samples were generated for soil analysis such as the one generated in Corradini and Pieniazek; (2024, 2019) but, the investigation was also continued by examining the following TN soil, precipitation, atmospheric deposition, surface and groundwater.

The spectroradiometer that is being used to investigate microplastic contamination is a PSR+ spectroradiometer. The PSR+ is a standard resolution spectrometer that measures several different wavelengths of light.: visible ranging from 350-700 nm, Near-Infrared 700-1000 nm, and Shortwave Infrared from 1000-2500 nm. The resolution of the device does not measure UV and has a lower resolution than the device used in the Pieniazek study. However, the PSR+ does have the advantage of a slightly higher resolution than the device used in the Cordinal paper with the addition of shortwave infrared measurements. The PSR+ is a device primarily used in field-

based studies. Our goal is to test the limitations of this device for field and laboratory sample analysis of microplastics due to it being very similar to devices found in several science departments across the globe. If the device can be utilized for microplastic identification and quantification, then thousands of departments or labs can begin investigations without spending a dollar for new scientific equipment.

Chapter 2. Experimental Methods Used in this Thesis

The various methods used in this study span from model generation to environmental sample collection of the following mediums: soil, dry atmospheric deposition, precipitation, groundwater, and freshwater. Each of the environmental samples will undergo a vacuum filtration and additional methods to remove the microplastic material from the environmental matrix if needed for plastic particulate isolation. Prior to sample collection or model generation a site needed to be located that offered a semi pristine environment that was not located in close proximity to urban or industrial processes. Furthermore, soil will be collected at the site for use in the samples to train the PLSR model. The model will be generated in R studio and will be tested against a testing sample set.

2.1 Pre- Sampling

In June of 2024 the search for a site that met the following criteria was chosen: close proximity to the University of Tennessee Knoxville, surface water present, groundwater wells present, flat terrain present for atmospheric measurements, and distant from the industrial and urban processes for atmospheric measurements not to be contaminated from a point source. An area located in Blount County TN, near Maryville. The area surrounding Maryville and Seymour TN is experiencing urbanization but did not have any active construction projects occurring on or near the property. The average air temperature for this location is 17.4 degrees Celsius, and the average soil temperature is 12.78 degrees Celsius. The average rainfall on location is 129.54 cm. Furthermore, the area is a low traffic area surrounded by dairy farms; thus, it was relatively rural.

Before sample collection could occur the groundwater, surface water, and soil were investigated to get a proper understanding of the area and possible sources of microplastic contamination. The groundwater well on site was initially drilled 45 years ago at a depth of 300 ft.For all bodies of water present on location the total dissolved solids and the potential of hydrogen were measured. The groundwater was found to have a PH of 8.1 and a TDS value of 357 mg/L. For all three ponds the PH leans slightly alkaline with a PH of 7.6 in all three locations. However, the TDS of all three ponds varied greatly: pond 1 has a TDS of 150 mg/L, pond 2 has a TDS of 233 mg/L, and pond 3 has a TDS of 345 mg/L.

Due to the nature of the study, background mineralogical investigation needs to be conducted before model generation. The soil below 12.7 cm exhibits a red color and is enriched in clays. Furthermore, the PH of the soil was found to be acidic with a PH of 4.7. Soil was collected from the site and was grounded in an agate mortar and pestle and was ground by hand

for 1 hour and 30 minutes to generate a fine powder. The soil was then moved into a XRD machine for measurements on a tilted mount. The mineralogy of the soils exhibits similar characteristics in physical and chemical properties to that of an Ultrasol based on PH, appearance, and XRD results. The examination of the soil under XRD showed a high presence of iron rich minerals such as hematite and a higher percentage of clay minerals when examined underneath a petrographic microscope.

2.2 Study area and Sample Size

The study area was a small semi urbanized set of farmlands located in Blount County TN. The area can be seen in **Figure 1**. The area was monitored for microplastics contamination due to the unique circumstances of a groundwater well being installed on the property along with several freshwater ponds within a couple hundred yards. The area was also selected due to its distance from industrial and urban activities thus allowing for a more natural representation of rural property and its relationship with microplastics. Due to the presence of freshwater, groundwater, and rural land the area provides an unique opportunity to study the interactions and difference between groundwater, freshwater, soil, and atmospheric microplastic contamination.

2.2.1 Soil Samples

Soil samples were collected using an Okaland soil sampler at a depth of 38.1 cm. However, the topsoil was discarded due to its enrichment of organic matter and contamination from atmospheric deposition. The soil that was collected to generate the soil samples for Partial Least Square Regression (PLSR) model along with the soil samples for density separation analysis of microplastic contamination originated from a range of 5 to 15 inches below the surface. The locations of the soil samples were collected can be seen in green on **Figure 1**. To ascertain the microplastic contamination of the soil a density separation needed to occur.

To remove microplastics from the soil, it was passed through a secondary sieve to ensure organic material and larger pieces of sediment were removed from the sample. Then the soil was partitioned into 5-gram samples inside of a 2000 ml borosilicate glass beaker. Once in the beaker the sample was mixed with a sodium iodine solution that has a density of 1.8 g/cm^3 with a volume of 30 milliliters. The mixture of soil and sodium iodide was stirred for 3 minutes to allow for complete separation between the microplastics and the soil. Once settled the solution was removed using a borosilicate glass pipette, then the solution and transfer it into a vacuum filtration. Inside the vacuum filtration the solution passes through a 0.45-micron glass fiber filter that collects the microplastic particles for observation. Ten milliliters of the solution was passed



Figure 1: The figure above shows the location of the sampling site near Maryville TN, the different colored dots represent the environmental samples that were collected. The atmospheric location sites are expressed by yellow dots. The ponds are labeled with red dots. The precipitation site is expressed in a lime green dot. The soil location site is located in a dark green dot. The groundwater well is annotated by a pink dot.

through the filtration setup at a time, to generate one sample. The filter membrane is then collected and transferred into a borosilicate glass petri dish for storage. After a sample runs through the filtration setup, it is taken apart and rinsed with ultra purified water. In total 30 soil samples were taken for microscopic analysis under a dissecting light microscope with 40 x magnification. The data was recorded in a csv. file before being moved into R studio for further analysis.

2.2.2 Precipitation Samples

Precipitation collection took place in the months of September, October and early November. The location of the rain gauges can be observed in lime green in Figure 1. To accurately collect precipitation glass rain gauges were installed on the property at least ten meters away from any building or roads. Collection of the precipitation occurred primarily during the large rainfall and flooding event caused by Hurricane Helene. In total 925 milliliters of water were collected by three rain gauges. The water was transferred from rain gauges to borosilicate 1 liter glass containers for storage. Due to the expected low occurrence in microplastic contamination a total of 75 ml of precipitation was filtered per sample. In total 37 samples were successfully created from the precipitation sample. Some water was discarded due to contamination or accidents occurring during the vacuum filtration. The collected glass fibers filter papers were placed into petri dishes before being observed under a microscope.

2.2.3 Freshwater Samples

A total of nine liters of freshwater was collected at three different ponds in Blount County TN. The ponds can be seen in red in Figure 1. At each pond a water collector waded out into the pond until the water was around waist level or 1.42 meters deep and collected a sample of water by placing a glass cylinder under the water and filling it. This occurred on three separate collections that spanned from August, September, and October. The freshwater samples were filtered in a measurement of 100 ml per sample resulting in a total of ninety samples for each collection and a total of 270 samples for the freshwater measurements. To ascertain the extent of the microplastic contamination the samples were passed through a vacuum filtration with a glass fiber filter paper. Post filtrations of each sample were measured with a contact probe from the PSR+ to see if microplastics could be identified and quantified.

2.2.4 Groundwater Samples

Groundwater was collected from a well with a depth of 300 ft, but the exact depth in which the water originated varied due to the groundwater level fluctuating due to environmental

factors affecting recharge rate and extraction rate as well. A total of 13 liters of groundwater was extracted from the well and transferred in borosilicate glass containers on three separate occasions in August, September, and October. The samples were filtered in 100 ml samples through a vacuum filtration. In total 137 samples were generated and passed through a vacuum filtration with a glass fiber filter paper. The samples were then processed by taking measurements of a contact probe on the PSR+ instrument.

2.2.5 Dry Atmospheric Deposition

The dry atmospheric samples or dust samples were collected on site by collecting dust. To collect dust on location several galvanized steel buckets were placed three feet above the ground. It took around three days for an adequate amount of dust to form inside the bucket. Thus, once three days had passed ultra purified water was used to turn the dust into a liquid and transferred to a borosilicate glass container for transport back to the lab. One liter was used for each bucket resulting in a total of three (L) used. It was determined that 50 milliliters of water should be filtered per sample. In total 60 samples were generated for filtration through a vacuum filter with a glass fiber filter paper.

2.2.6 Microscopic Analysis

For each sample that passed through a vacuum filtration were examined under a dissection microscope made by AmScope SM-2 Series Zoom Binocular Stereo Microscope with a range of 7X-90X magnification. The samples underwent examination a total of three times. Each time a plastic particulate was found a hot needle was used to ascertain if the expected plastic particle was indeed plastic. If a particle completely disintegrated, it was determined that the material was organic in origin. If the hot needle caused the particulate to undergo zero change it was categorized as an abiotic material such as a mineral or a piece of sediment. The particle was only categorized as a plastic particle if the particulate was found to undergo partial melting or movement caused by the heat but not disintegration it was categorized as a plastic. To ensure count accuracy the samples were counted a total of three times and if significant difference was not found then the sample was marked as complete and measured by the PSR+ instrument.

2.3 Model Generation from Spectral Data

2.3.1 Partial Least Square Regression Modeling

PLSR models are a multivariate statistical method that is widely used for modeling relationships between a set of predictor variables and response variables. PLSR modeling

applications are suitable when the predictors are highly collinear or when the number of predictors exceeds the number of observations in this thesis. The fields that commonly use the PLSR modeling typically involve chemometrics, environmental sciences, and spectral analysis. For example, the foundation of this work builds off the work conducted by Penizac et al, (2024). PLSR modeling simultaneously extracts components from predictors that maximize their covariance with the response variable. The reason PLSR modeling is used for predictive based modeling is due to its efficiency for maximizing the covariance between the predictor and dependent variables.

2.3.2 Sample Generation and Methodology Validation

The generation of a PLSR model requires data that follows a specific standardization process to ensure the accuracy of the model. Thus, every sample used to train and calibrate the model needs to follow the same treatment and protocol. In total 400 artificially plastic pollution samples were generated using TN red clay soil and a microplastic material. The first step was to gather the TN red clay soil from 5 inches below the surface in Blount County TN. The soil was then passed through multiple metal sieves to get the particle size down to around 300-250 microns. The soil was then transferred into mason jars in the lab.

To generate a spectral library of data that can be used to train a linear model a large concise sample set is required. The total mass of each sample is the equivalent of 15 grams with variations of microplastics contamination from 1% by mass to 10% by mass, which means the 10% samples contained 1.5 grams of plastic and the 1% samples contained 0.15 grams of plastic. For each percentage ten unique soil samples were generated. Once the soil and microplastics were mixed together they were placed in a ceramic mortar and pestle. Each individual sample was then grounded for a total of five minutes each to generate a homogeneous mixture. The mixture was then weighed, to ensure no significant mass was lost from the grinding process; the mortar and pestle was scraped clean with a metal spatula. The soil and plastics removed from the mortar and pestle was then added to the soil samples.

The portable PSR+ near infrared spectrometer was used to take five measurements of each sample. The attachment used to take the measurements was a contact probe. The contact probe is the primary application for direct contact analysis of samples in both field and laboratory settings. Nevertheless, the contact probe was designed by spectral evolutions to be utilized in a field-based setting. To ensure consistency in between each measurement the sample was stirred using a glass stir rod for 60 seconds. Furthermore, the contact probe was then blown

dried using an electric dust cleaner and then wiped down through the use of a microfiber cloth. This process was followed for each 100 samples for all the following plastics: isotactic polypropylene, polyethylene, polyvinyl chlorine, and polystyrene.

To ensure the accuracy of the soil sample models several new samples were created as a model validation set. Twenty samples were generated for each plastic. The validation sample consisted of a mixture of plastic concentrations to ensure the accuracy of the model. In the case of this study two samples were made for each plastic concentration for each individual plastic. The result was 80 new samples in the validation set that were compared to the model outcomes to generate a comparison between actual microplastic concentrations and the observed.

2.3.3 Spectral Data Analysis

All spectral data was collected and stored using the software Darwinsp, a spectral data collection software that is paired with the PSR+ spectrometer. Darwinsp is made by Spectral Evolution, located in Haverhill Massachusetts. Whenever a measurement is taken the data is saved and presented in Darwin but is also saved as a csv file. The absorption features along with the wavelength and reflectivity values were examined before determining if the measurement was deemed accurate. Each value and feature were compared to a standard generated inside the lab to ensure proper identification in environmental samples. Once approved the file was saved and ported into R for analysis and model generation.

To ensure proper identification and quantification of microplastic particles the samples need to be compared to a standard. The generation of plastic spectral standards require a pure plastic polymer material that has not been affected by any dyes or industrial processes. Pure plastic polymer standards were acquired and milled if required from plastic beads to generate primary microplastic particles. The next step was the measurements of each pure plastic polymer, the filter paper, TN red clay soil, and the borosilicate glassware used in this experiment. **Figure 2** below expresses the absorption features detected by the PSR+ spectrometer when measuring pure LDPE. The absorption features of pure PVC can be examined in **Figure 3**. Polypropylene exhibits three different absorption features and they can be observed in **Figure 4**. The polystyrene standard exhibited several different absorption features, and all of these can be expressed in **Figure 5**. Nylon 12 shows unique absorption characteristics in the form of doublets and these can be seen in **Figure 6**.

Now that the absorption features of all the plastic polymers are identifiable, the absorption features of the glass fiber filter papers, TN red clay, and borosilicate glass that was

used to store the glass fiber filter post filtration. Glass fiber filters absorption features lie within the range of 119 to 102 reflectance percentage and 3 separate absorption features can be observed on **Figure 7**. The environmental samples were passed through a vacuum filtration, and the glass fiber filter paper was deposited into borosilicate petri dishes for storage. **Figure 8** shows the absorption feature that represents the combined spectra of the glass fiber filters and borosilicate glass. The spectral signature of the red clay soil exhibits a reflectivity percentage ranging from 0 to 38 percent, and the spectra exhibits 4 unique absorption features and this can be examined in **Figure 9**.

Figure 2-9 acts as a baseline for the environmental sampling spectra analysis and these spectra help determine which absorption features can be used for PLSR model generation. Furthermore, these standards and methods can be utilized to distinguish between noise in the spectral data. The spectral signal acts as a pseudo dichotomous key that allows for microplastic polymer identification.

2.3.4 Microplastic Counts Data Analysis

To avoid overcounts and misinterpretation or misidentification of microplastic particles a strict method was enforced along with guidelines to ensure data accuracy. Overcounting or undercounting can lead to severe misinterpretations of data to prevent this for each sample not only underwent three separate counts but was examined by three different individuals. Furthermore, all samples were compared to the blanks ran with each batch of samples. If the samples match the blanks in the following ways, it will be discarded and marked as contaminated: microplastic number, types, and color needed to match without a significant difference. Furthermore, to ensure all data was recorded in the correct way all examiners recorded data with the following categories: microplastic number, size, types, shape, and color. To determine color all microplastic particles were initially counted with a naked eye then reviewed by using a standard in the lab. By following all of these procedures the data ensures accurate microplastic counts for statistical analysis and interpretation.

The methodology of the thesis has been described for each environmental medium and the means in which the data will be processed. The methods also illustrated the means in which the PLSR models were made and validated. Data storage process and data validation were also discussed. The guidelines and the tools in which this study was conducted can be followed for ease of replication.

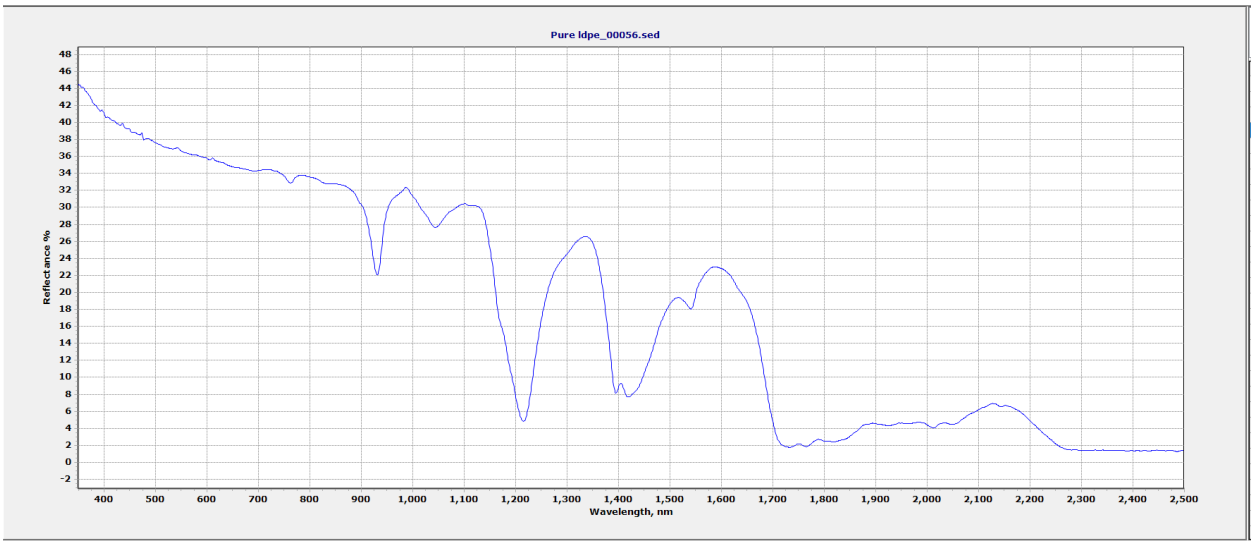


Figure 2: The spectra signal of a pure low density polyethylene standard. The most prominent absorption features can be observed at 930 nm, 1216 nm, 1385 nm, 1414 nm and 1730nm. However, smaller absorption features are present at 1768 nm, 2013 nm, and 2147 nm.

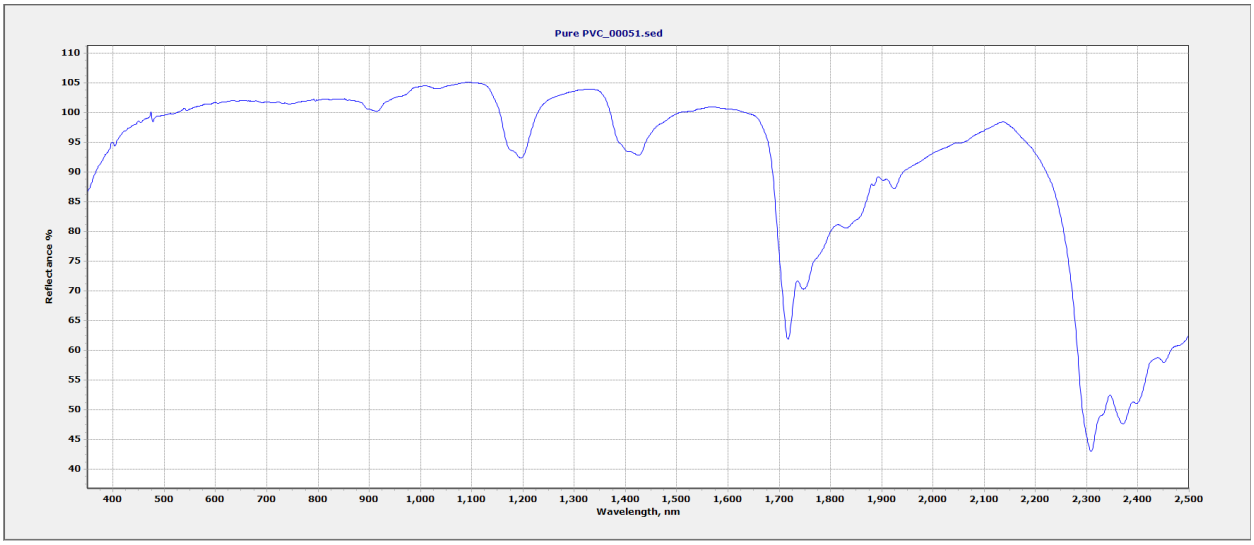


Figure 3: The spectra signal of a pure polyvinyl chlorine standard. The most prominent absorption features can be observed at 900 nm, 1200 nm, 1385 nm, 1428 nm and 1719nm. However, smaller absorption features are present at 1924 nm, 2309 nm, 2400 nm, and 2453 nm.

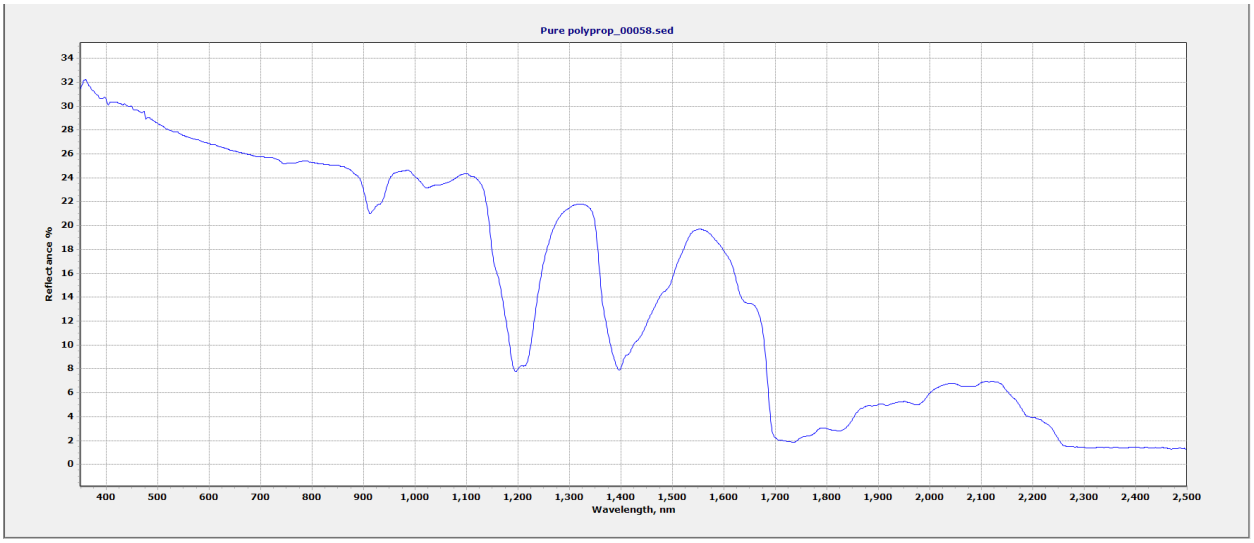


Figure 4: The spectra signal of a pure polypropylene standard. The most prominent absorption features can be observed at 912 nm, 1196 nm, 1385 nm, 1399 nm and 1700nm. However, smaller absorption features are present at 1831 nm, 1985 nm, and 2077 nm.

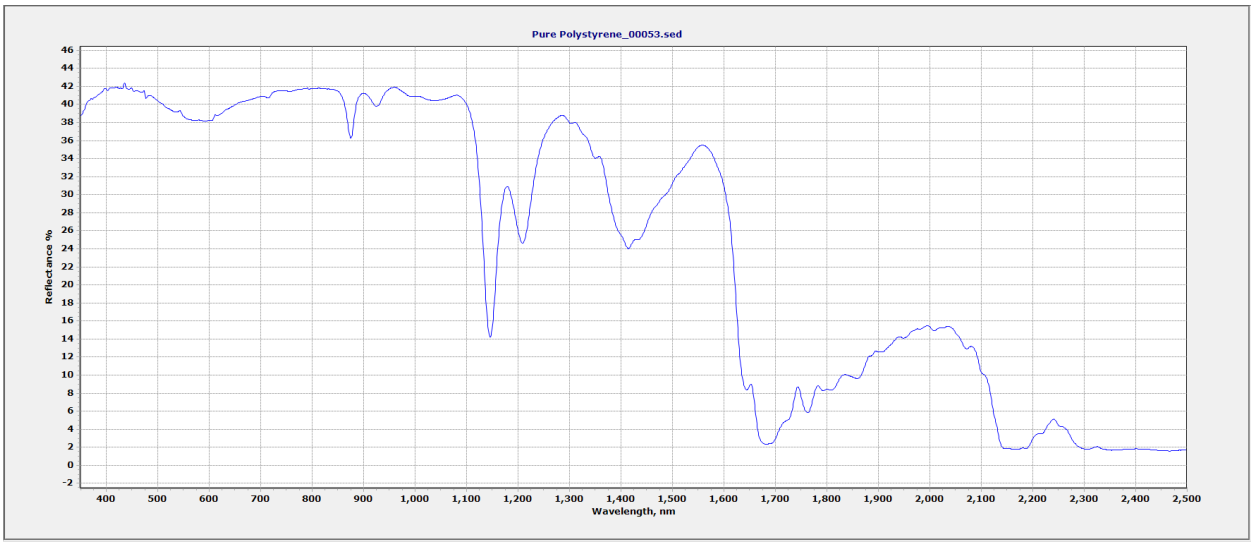


Figure 5: The spectra signal of a pure polystyrene standard. The most prominent absorption features can be observed at 875 nm, 928 nm, 1147 nm, 1213 nm, 1414 nm, and 1685 nm. However, smaller absorption features are present at 1766 nm, and 1864 nm.

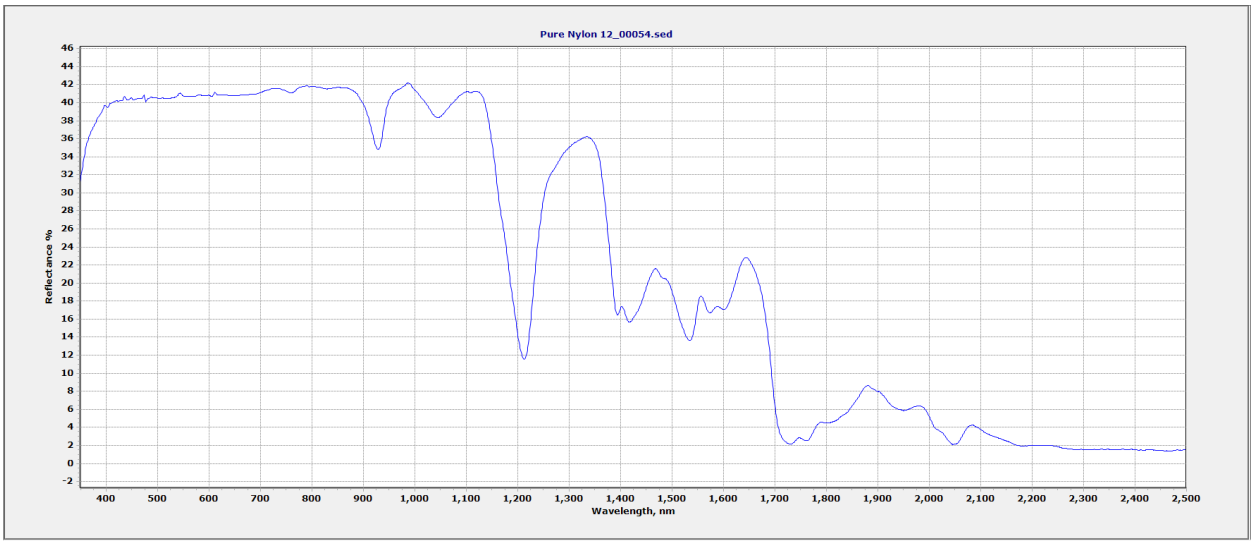


Figure 6: The spectra signal of a pure nylon 12 standard. The most prominent absorption features can be observed at 925 nm, 1040 nm, 1212 nm, 1213 nm, 1395 nm, 1420 nm, 1532 nm, and 2052 nm. However, smaller absorption features are present at 1572 nm, and 1605 nm. Another cluster of smaller features can be observed in 1731 and 1768.

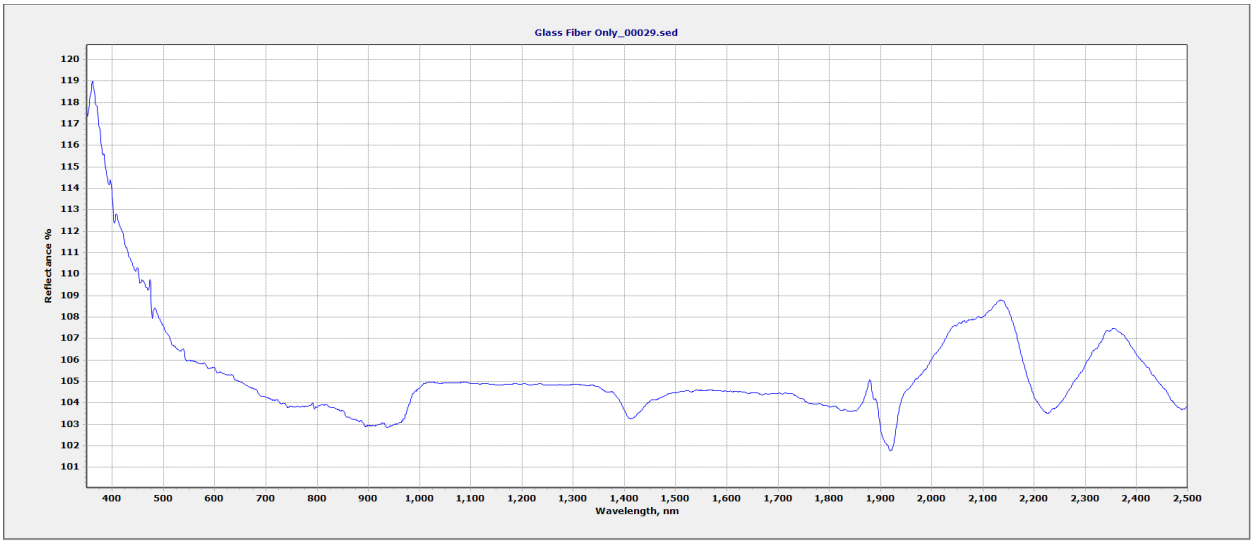


Figure 7: The spectra signal of a glass fiber filter paper. The most prominent absorption features can be observed at 1413 nm, 1920 nm, and 2229 nm. Furthermore, the lowest reflectivity can be observed at 102 percentage.

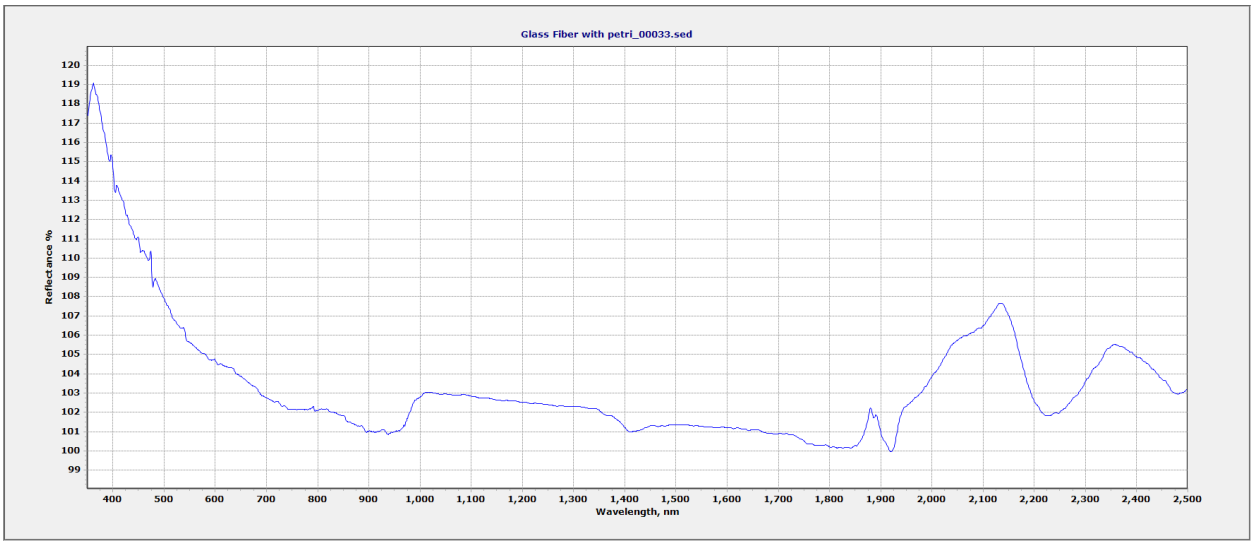


Figure 8: The spectra signal of a glass fiber filter paper inside a boron silicate petri dish. The most prominent absorption features can be observed at 1920 nm, and 2233 nm. Furthermore, the lowest reflectivity can be observed at 100 percentage.

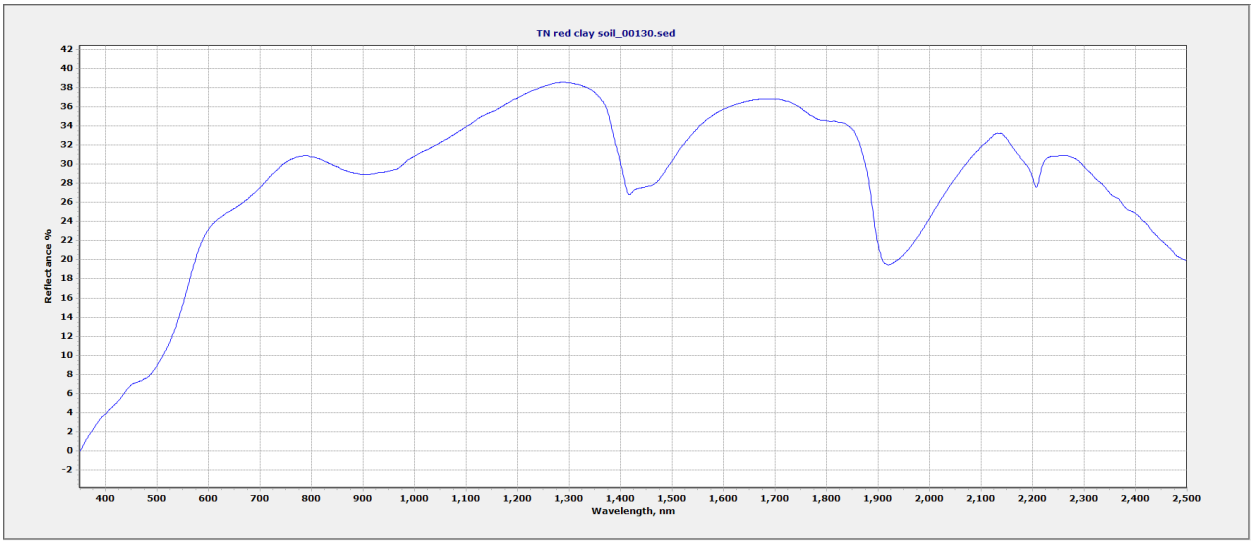


Figure 9: The spectra signal of TN red clay soil. The most prominent absorption features can be observed at 1418 nm, 1917 nm, and 2208 nm. Furthermore, the lowest reflectivity can be observed at 0 percentage.

Chapter 3 Results

The thesis results can be seen in the following paragraphs. First, we will discuss the numerical values of the microplastic particles detected in every environmental medium. Followed by the detection of plastic signatures in the differing environmental mediums consisting of the following presence absences: PVC, LDPE, Nylon, Polystyrene, and Polypropylene. Each individual PLSR model generated is given its own section and evaluated individually before being compared to the other PLSR models.

3.1 Microplastic Counts

By examining all the samples under microscopic analysis a total of 2183 plastic particles were observed. However, after testing the plastic particulates and removing any plastic particles that correspond to the background contamination found in the lab a total of 1799 plastic particles were determined to not originate from background contamination. Dry atmospheric deposition or dust examination samples yield 347 plastic particles. The precipitation samples from Hurricane Helene yielded 317 microplastic particles. Groundwater samples yield 379 plastic particles post filtration. The surface water was collected from three separate ponds for a total of 546 plastic particles. The TN red clay soil yields the smallest amount of plastic contamination with 188 microplastics particles observed. **Figure 10** shows the distribution of microplastic types visually.

3.2 Dry Atmospheric Results

The microplastics observed in the dust collection primarily consist of fibers with a small number of fragments. On average 10 microplastic particles were observed in 100 ml of water. In total 328 of observed plastic particles in dust collection were categorized as microplastic fibers. Microplastic fragments made up 10 plastic particles in the dust collection. The remaining 9 consist of films. A visual distribution can be seen in **Figure 11**. Atmospheric site 1 observed in Figure 1 has an average of 21 plastic particles per sample. Among the three different dust collection sites atmospheric site 2 contains the fewest amount of microplastic, a total of 50 microplastic particles. The samples from atmospheric site 2 average 5 microplastic particles per sample. Atmospheric site 3 was found to have the second highest concentration of microplastic contamination with 86 plastic particles with each sample averaging 8.6 plastic particles per sample.

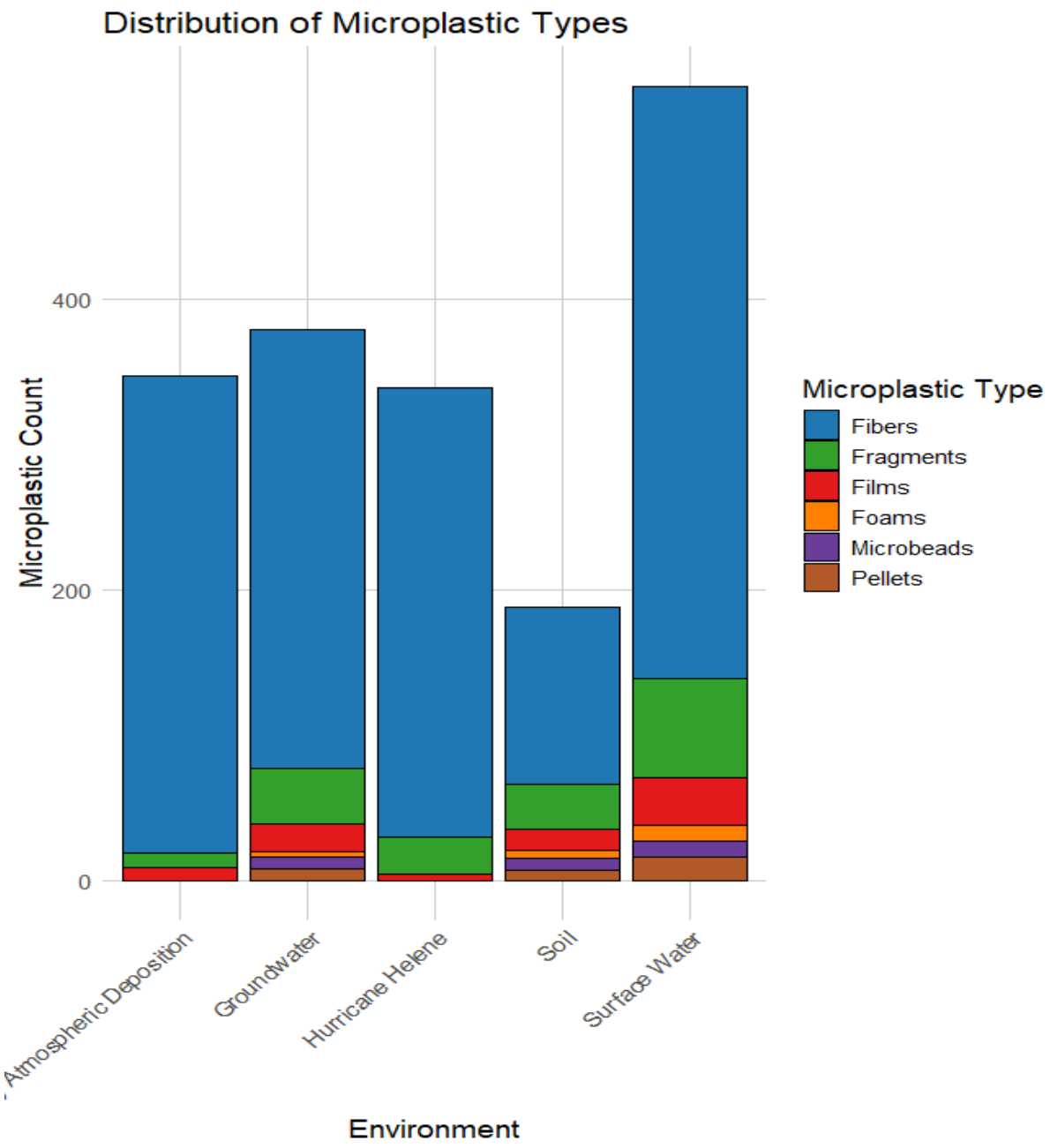


Figure 10: The stacked bar chart illustrates the relative abundance of six microplastic types (fibers, fragments, films, foams, microbeads, and pellets) in dry atmospheric deposition, groundwater, Hurricane Helene, soil, and surface water. Fibers were the dominant microplastic type across all environments, with the highest concentration observed in surface water. Fragments, films, and other microplastic forms were present in smaller quantities, with soil and surface water exhibiting a more diverse distribution of microplastic types.

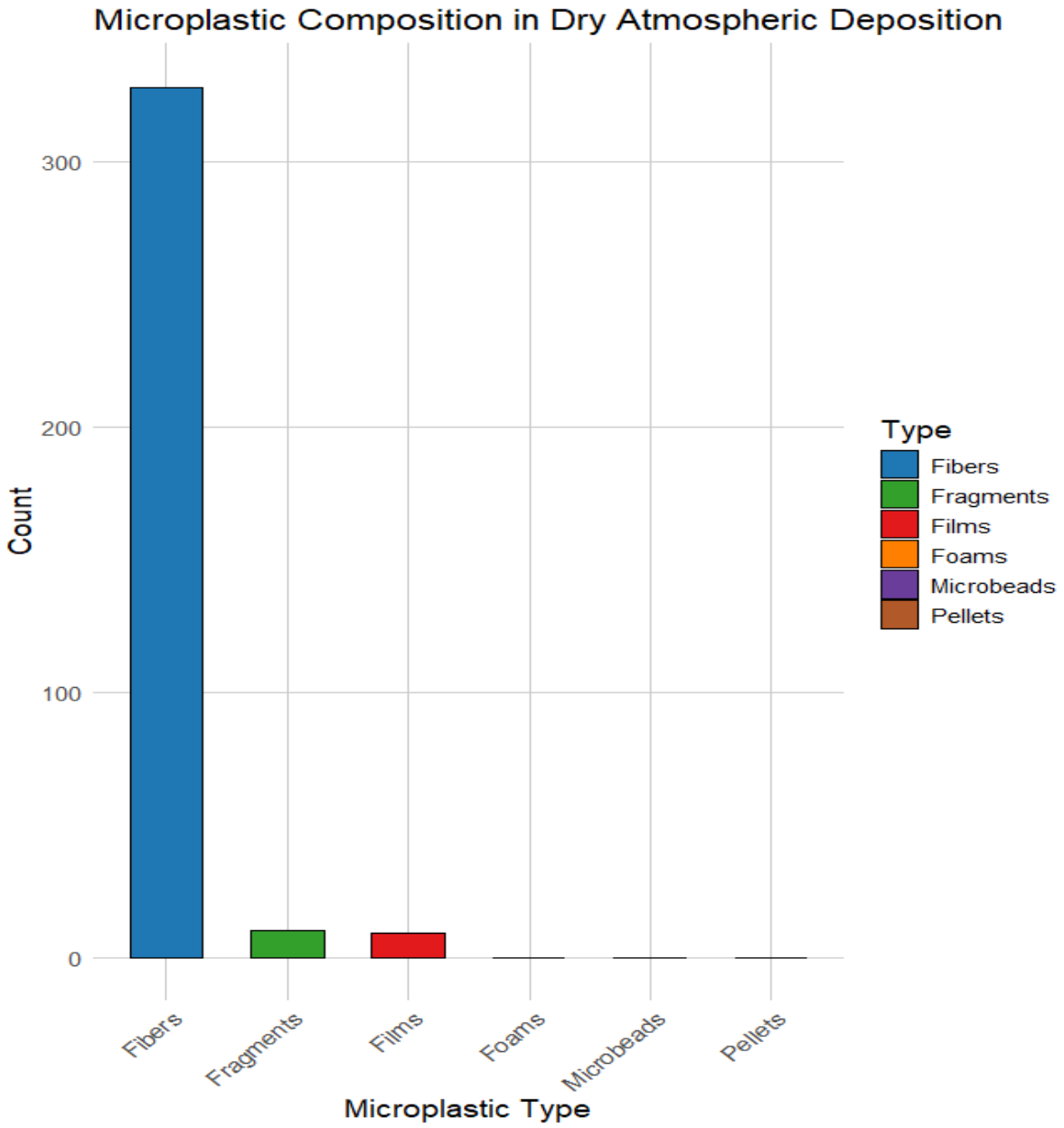


Figure 11: The bar chart illustrates the distribution of different microplastic types, including fibers, fragments, films, foams, microbeads, and pellets. Fibers were the most abundant, with 328 recorded particles, followed by fragments (10) and films (9). No foams, microbeads, or pellets were detected in the analyzed samples. The results highlight the dominance of fibrous microplastics in atmospheric deposition,

The color and size distribution of the microplastics in the dust accumulation was fairly homogeneous in regard to size, but heterogenous in regard to color. All non-fibrous particles at all atmospheric sites were less than 1 mm in length. Furthermore, the fragments and films in the samples exhibited pointed edges and were categorized as angular. Observed microplastic fibers ranged from less than 1 mm in length to the largest at 5 mm in length. The heterogeneity of the color variation of the microplastic particles exists in the fiber portion. All plastic films observed were categorized as clear due to their transparency. The plastic fragments predominately were categorized as clear with a few exceptions of grey and purple. The microplastic fibers had the most diversity of color ranging from 10 different colors. The distribution of all these colors can be observed in **Figure 12**.

In the 150 measurements taken with the PSR+ spectroradiometer no significant absorption features were observed with samples that exhibited a large domination of small microplastic fibers. However, in 20 measurements a possible plastic signature was detected in samples that had a more heterogeneous microplastic type makeup. Samples that contained fibers along with other types of microplastic such as fragments or films seemed to exhibit stronger absorption features. The most common abortion feature observed was at the 1400 nm wavelength, but this corresponds to several different materials including non-plastic material. The second most common absorption feature was at 1720-1740 wavelength with a reflectivity percentage near 4% and generally corresponding to polypropylene plastics. The third most common absorption feature observed corresponded to Nylon with a reflectivity of 1510-1530 with a reflectance percentage of 18- 20%. The samples did not exhibit any absorption features that corresponded to polystyrene, polyvinyl chloride, acrylic, or low-density polyethylene.

3.3 Wet Atmospheric Results

The wet atmospheric samples originated from the large precipitation event from September 26, 2024, to September 28, 2024, in which 11 inches of rain was deposited on the study site. The collected precipitation yielded a total of 346 microplastic particles. Only three types of microplastic were observed in the samples: microplastic fibers, films, and fragments. In total 289 plastic particles found in rainwater were identified as microplastics fibers. The remaining 28 percent of microplastics were identified as microplastic fragments and film; with plastic fragments accounting for 25 of the observed. This can be observed in **Figure 13**. No significant difference was found between the different rain gauges. However, one thing that became apparent as filtration and microscopic measurements began was that the majority of the

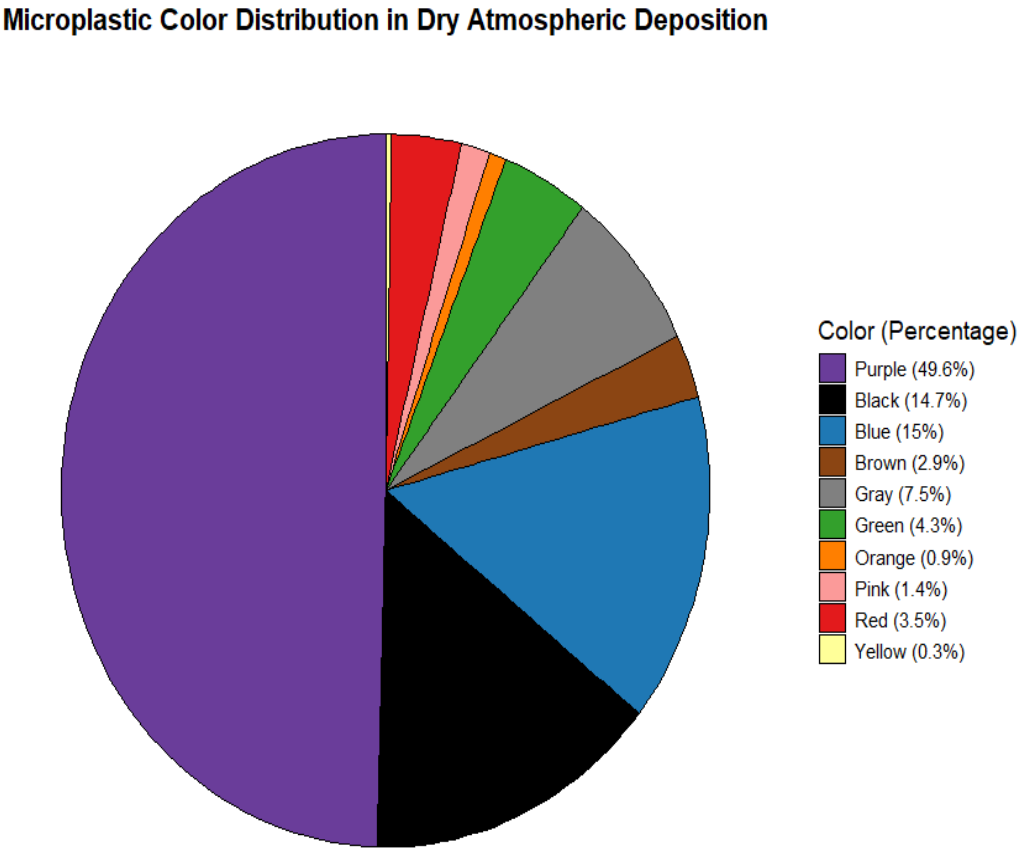


Figure 12: The pie chart illustrates the relative abundance of different microplastic colors, with percentages indicated in the legend. Purple was the most dominant color, accounting for 49.6% of the total microplastic particles, followed by blue (15%) and black (14.7%). Other colors, including gray, green, red, brown, pink, orange, and yellow, were present in smaller proportions. These results highlight the variability in microplastic color composition within atmospheric deposition, which may reflect differences in sources, transport processes, or degradation pathways.

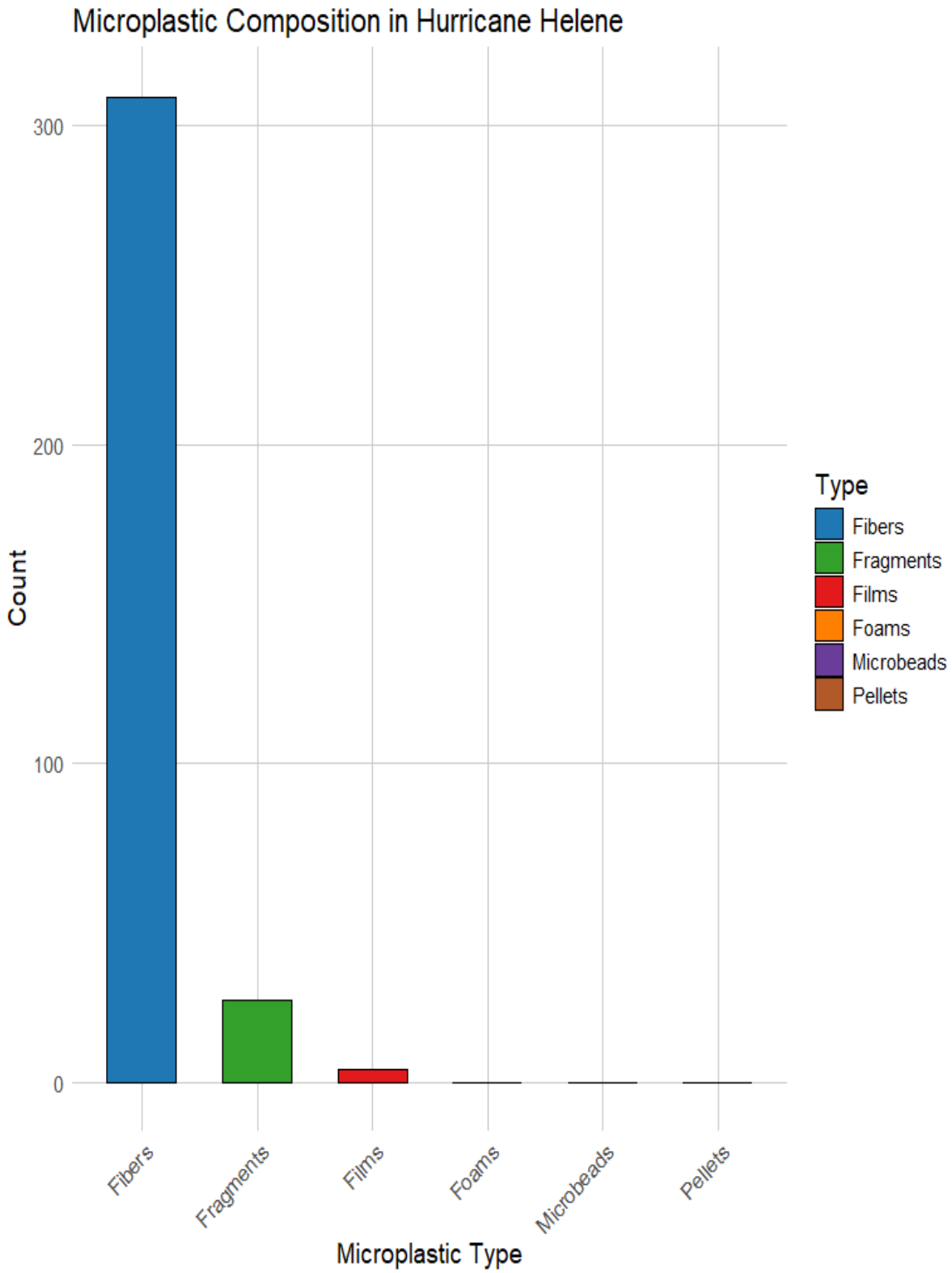


Figure 13: The bar chart represents the distribution of microplastic types identified, with fibers being the most abundant at 309 particles, followed by fragments (26 particles) and films (4 particles). No foams, microbeads, or pellets were detected in the samples.

microplastic were observed in the first three samples filtered from each rain gauge. As the filtration went on the amount of observed microplastic decreased significantly. For example, the first three samples from each liter resulted in a microplastic count that exceeds 27 microplastics per sample. However, towards the end of the filtration the samples averaged two microplastics per sample.

Microscopic analysis of the samples exhibits a mostly homogenous data set. All The microplastic fibers ranged in size from less than 1 mm in length to over 8 mm in length. The norm was that microplastics fibers were measured to be less than 1 mm, but a few outliers exist that exceed 1mm. A total of nine different colors of microplastic fibers were observed including the following from greatest concentration to least: purple, blue, grey, clear, light grey, light grey, light purple, green, brown, and black. The combined observations of purple, black, and blue microplastics were equal to 281 of the microplastic observed. The remaining colors were divided evenly but these samples exhibited a high concentration of purple, black, and blue microplastic fibers. The microplastics fragments were all less than 1 mm in length and exhibited angular characteristics. All microplastics fragments were identified as grey. The color distribution can be visually seen in **Figure 14**. The homogenous results continued into the spectrographic measurements.

Of the 37 samples 185 spectrographic measurements were taken with a contact probe and yielded no definitive microplastic detection. However possible signals for Nylon and Low-Density Polyethylene were found in the spectrographic measurements, but their reflectivity percentages did not meet the minimum threshold for identification. The samples did not exhibit any absorption features for any other plastics in our database.

3.4 Groundwater

The microscopic examination of the groundwater samples showed a fairly heterogeneous mixture of microplastic types. The most common microplastic observed was fibers in total 377 of plastic particles counted were found to be fibrous particles with varied length from less than 1 mm to over 2 mm. Fragments were the second most common plastic observed with a total of 26 microplastic particles that arranged from angular to subangular in shape. Regardless, 17 of the fragments were identified as rounded or sub rounded particles. The third most common microplastic particle was film; a total of 8 were observed. None of the films exceeded 2 mm in length. A total of 6 pellets were observed in samples. All pellets were less

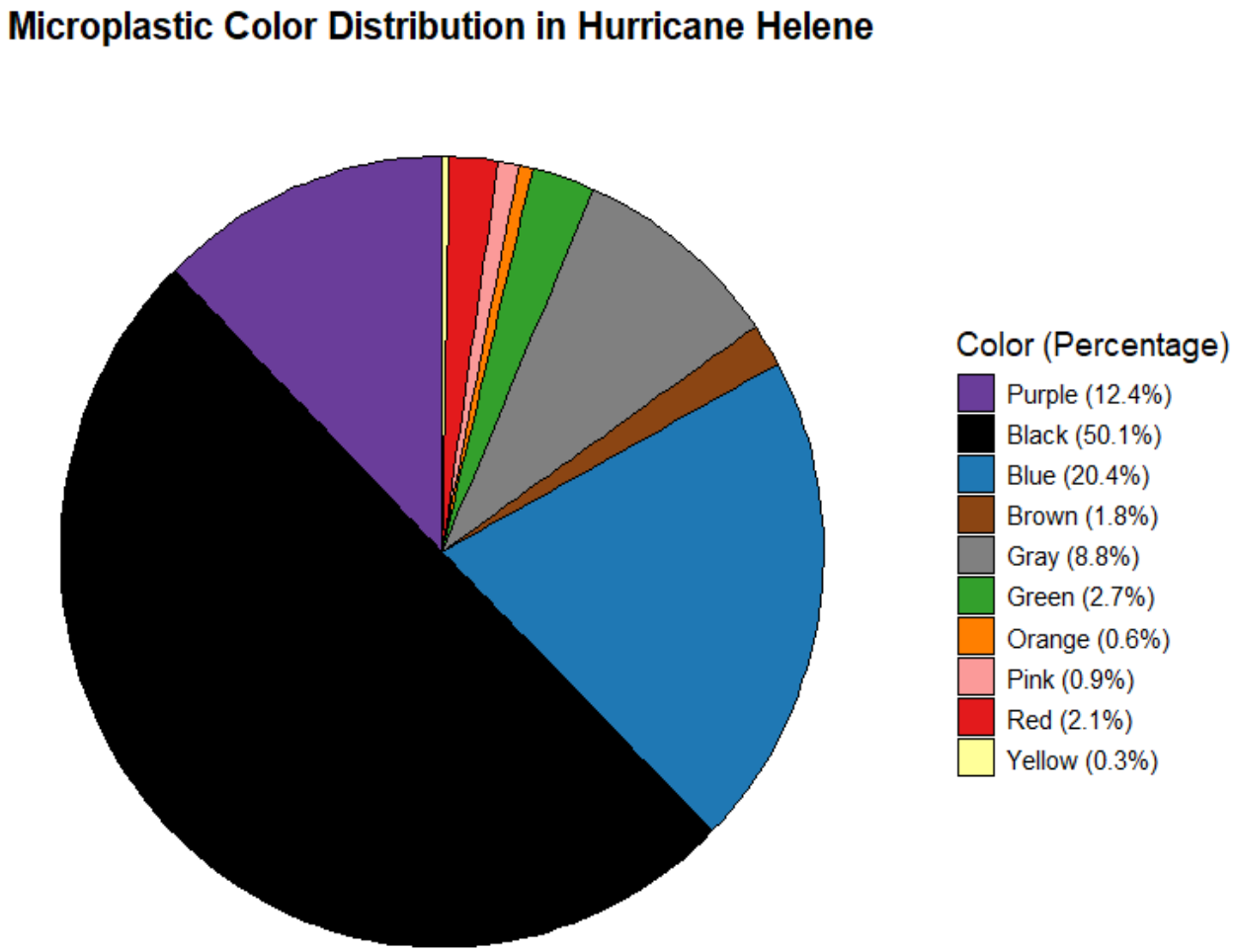


Figure 14: The pie chart illustrates the relative abundance of different microplastic colors, with percentages indicated in the legend. Black was the most dominant color, accounting for 50.1% of the total microplastic particles, followed by blue (20.4%) and purple (12.4%). Other colors, including gray, green, red, brown, pink, orange, and yellow, were present in smaller proportions.

than 1mm in length. The least common microplastic observed were microbeads and foams which had the following counts respectfully, 3 and 2. The distribution of microplastic type can be visually seen in **Figure 15**. Overall, the microplastic types were not concentrated samples and as result each sample was fairly the same in regard to type distribution.

Ten different colors were observed in the groundwater samples. Out of the 422 microplastic particles over half of the observed microplastics fell under 5 colors. The most common color of microplastic was black followed by the following from greatest to least: purple, blue, clear, and red. Brown, grey and green made up 42 microplastic particles in groundwater samples. The rest of the observed colors did not exceed a microplastic count above seven. The color distribution can be visually seen in **Figure 16**.

Of the 13 liters of water filtered a total of 130 groundwater samples were generated. And for each of these samples five spectrographic measurements were taken for a total of 650 measurements. Among these 650 microplastic contamination was identified, in total 100 scans potentially expressed signals that correspond to a possible plastic contamination. However, these measurements were narrowed down to 2 scans having a prominent plastic absorption feature. In this case the two plastics that were observed were PVC and LDPE due to the prominent signals found. Furthermore, potential polystyrene signals were observed but they fell below the minimum threshold for identification.

3.5 Surface Water results

The surface water results expressed a high concentration of microplastic contamination when compared to the other reservoirs. In total 446 microplastic particles were confirmed in nine liters of pond water. The highest concentration of microplastic contamination originated from the third pond. The second highest contamination was found in pond 2 and the lowest contamination was observed in pond 1. Nevertheless, the types or colors of the microplastic observed in each of these ponds did not have a significant difference.

The most common microplastic type observed in all three ponds was fibers, in total 407 microplastic fibers were observed in all three ponds. These fibrous particles have a size range from less than 1 mm to the largest microplastic fiber 10 mm. The second most common microplastic type observed was microplastic fragments with a total of 68 being observed in all pond samples. The relative size of the microplastic fragments ranged from less than 1 mm in length to the maxim of 3 mm in length. A total of 33 microplastic films were observed with all of these films not exceeding 3 mm in length. Microplastic pellets were observed with the next

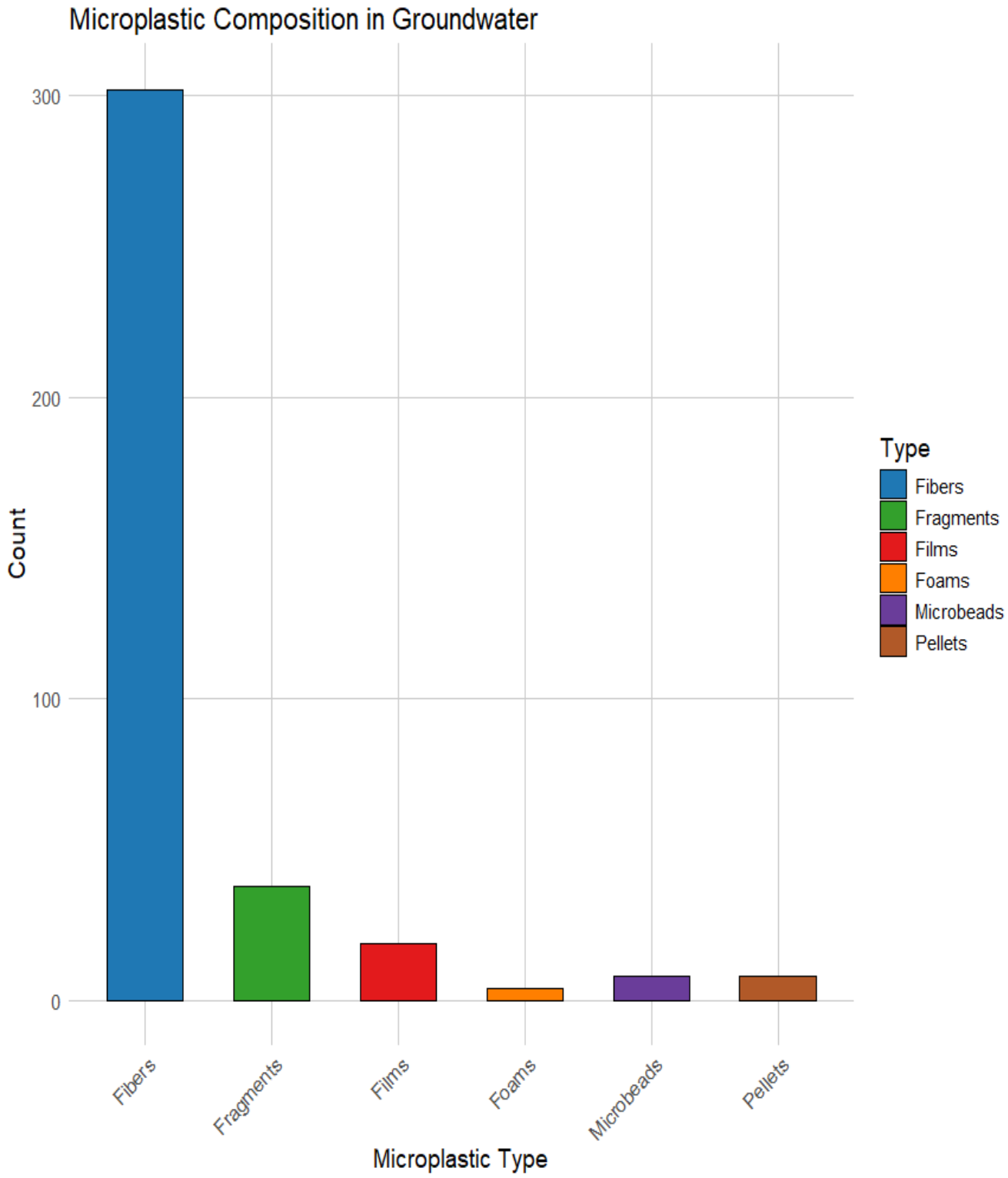


Figure 15: The bar chart represents the distribution of different microplastic types detected in groundwater samples. Fibers were the most abundant, accounting for 302 particles, followed by fragments (38 particles) and films (19 particles). Smaller quantities of foams (4 particles), microbeads (8 particles), and pellets (8 particles) were also identified.

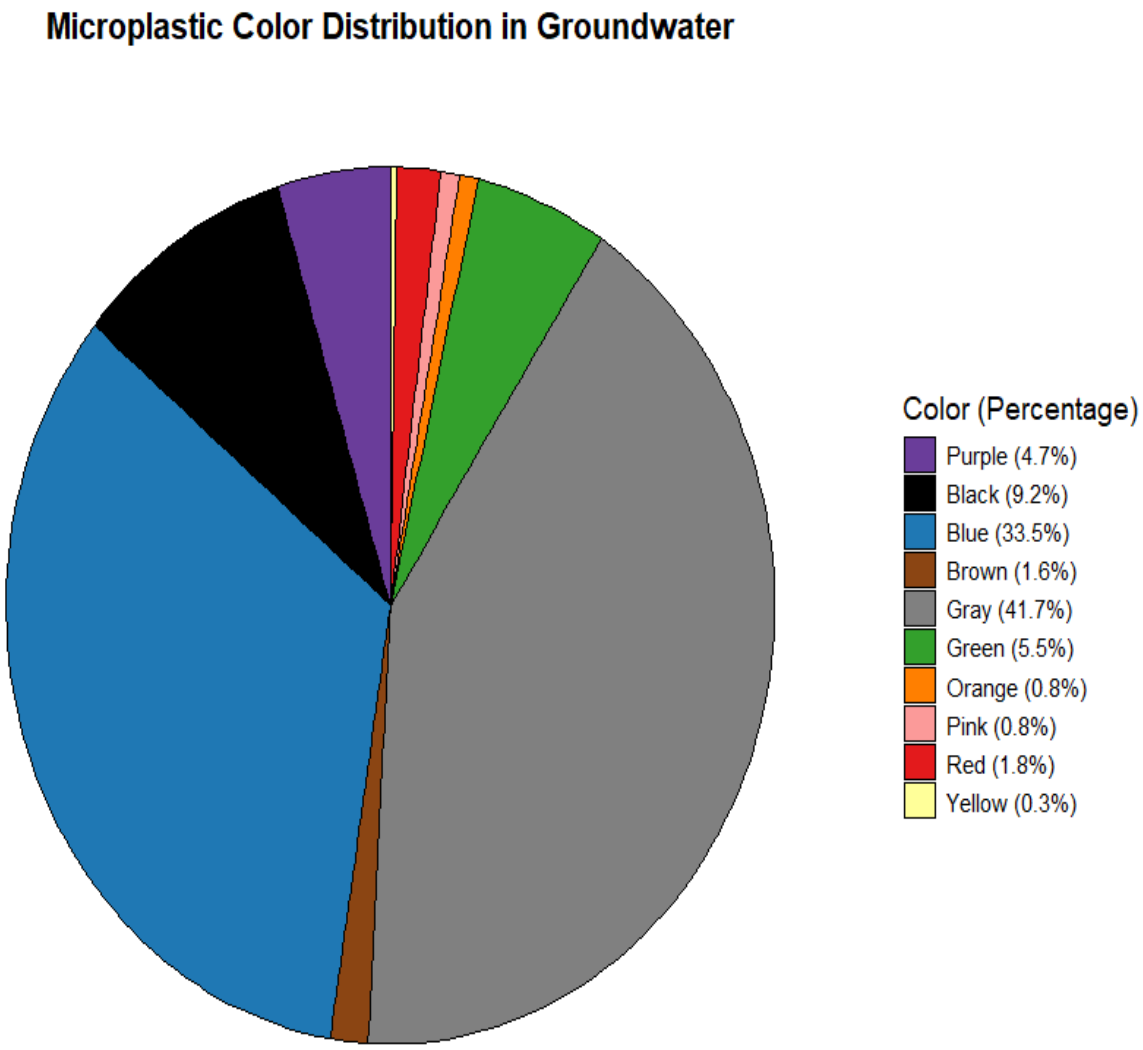


Figure 16: The pie chart illustrates the relative abundance of different microplastic colors, with percentages displayed in the legend. Gray was the most dominant color, accounting for 41.7% of the total microplastic particles, followed by blue (33.5%) and black (9.2%). Other colors, including green, purple, red, brown, pink, orange, and yellow, were present in smaller proportions.

higher concentration with a total of 16 particles observed. The microplastic pellets did not exceed 1 mm in length and were all fairly rounded in shape. Foams and microbeads both have an equal concentration of microplastic particles of 11. The size of the microplastic particles did not exceed 1 mm in length for both foams and beads. The heterogeneity of the microplastic types observed continues to the diverse colors observed in all the freshwater samples. A visual distribution of microplastic type can be seen in **Figure 17**.

A total of 546 microplastic particles were identified in the surface water samples, categorized into ten primary color groups. Green microplastics were the most abundant, with 200 particles recorded. Purple microplastics were the second most prevalent, accounting for 164 particles, followed by orange with 101 particles. Black and gray microplastics were observed in moderate quantities, with 32 and 20 particles, respectively. Blue microplastics were less common, with 19 particles identified. Brown, red, and pink microplastics were present in lower concentrations, with 4, 4, and 2 particles, respectively. Yellow microplastics were not detected in the analyzed samples. The color distribution can be visually seen in **Figure 18** below.

In the 9 liters of water filtered resulting in the formation of 30 samples from each pond with a total of 90 samples. The 90 samples were measured a total of five times each resulting in 270 scans. Among these scans six different scans yielded positive results of microplastic particles. Two of the scans exhibited absorption features that correlate to polyvinyl chlorine. Furthermore, two scans showed absorption features of LDPE. The remaining two scans exhibited characteristics of Nylon contamination. However, several other scans showed partial signs of microplastic contamination, but the absorption features were not strong enough or varied slightly thus they could not be counted.

3.6 Soil Results

The soil reservoir exhibited the lowest amount of microplastic contamination with a total of 188 microplastic particles. The most prominent microplastic type was microplastic fibers with a total of 122. Fibers ranged in size from less than 1 mm to greater than 3 mm. Thirty-three microplastic fragments were observed. All fragments were less than 1 mm in length and were predominantly angular. The third most common was microplastic films consisting of 14 microplastic particles. The length of the plastic films varied greatly; the majority of the films exceeded 1 mm in length while the largest was 3 mm. A total of 8 microbeads were observed in the samples. All of the microbeads did not exceed 1 mm in length. Furthermore, all of the microbeads were smooth or rounded. The total number of pellets observed was 7, and they did

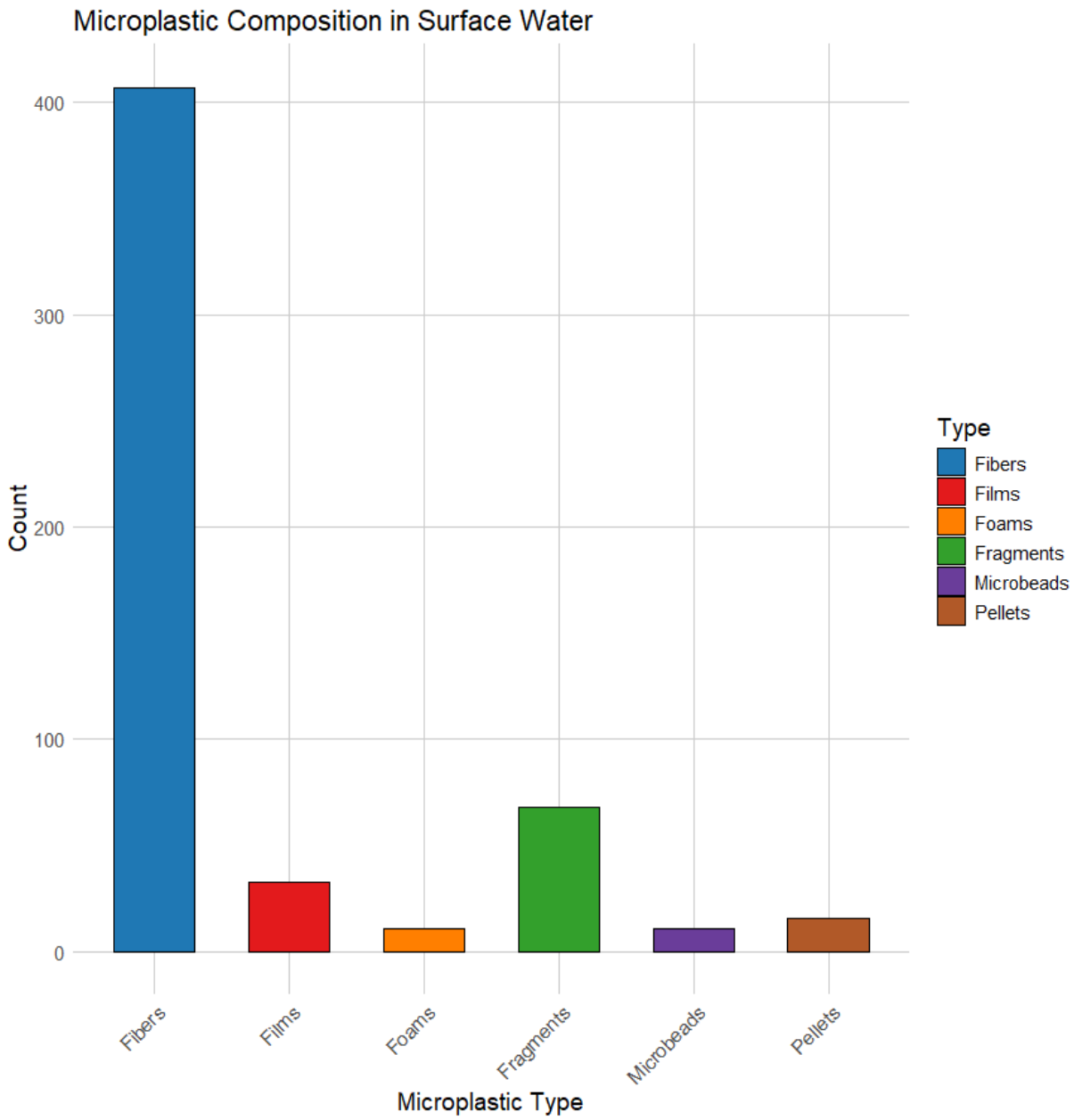


Figure 17: The bar chart represents the distribution of different microplastic types detected in surface water samples. Fibers were the most abundant, accounting for 407 particles, followed by fragments (68 particles) and films (33 particles). Smaller quantities of foams (11 particles), microbeads (11 particles), and pellets (16 particles) were also identified.

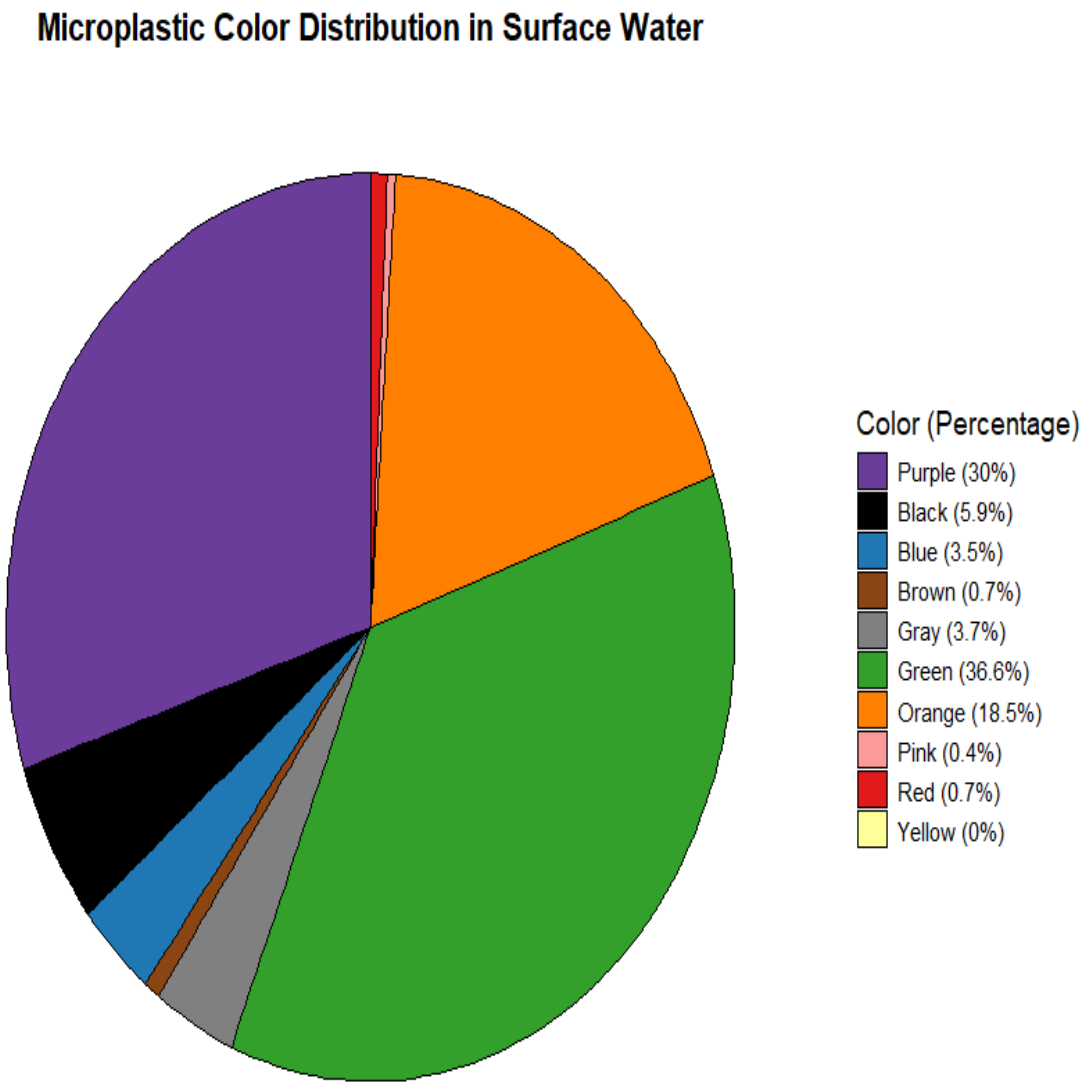


Figure 18: The pie chart illustrates the relative abundance of different microplastic colors, with percentages displayed in the legend. Green was the most dominant color, accounting for 36.6% of the total microplastic particles, followed by purple (30%) and orange (18.5%). Other colors, including black, blue, gray, brown, red, and pink, were present in smaller proportions, while yellow was not detected.

not exceed 1 mm in length. The least common microplastic type observed was foams which consisted of 6 microplastic particles. All of the foams were less than 1 mm in length. A visual representation of the microplastic type distribution can be seen in **Figure 19**.

A total of 188 microplastic particles were identified in the soil samples, categorized into ten primary color groups. Green microplastics were the most abundant, comprising 55 particles. Black and gray microplastics were also prevalent, with 36 and 35 particles, respectively. Blue and purple microplastics were observed in equal quantities, each accounting for 20 particles. Orange and brown microplastics were present in lower concentrations, with 10 and 6 particles, respectively. The least abundant microplastic colors were pink (2) and red (4), while yellow microplastics were not detected in the analyzed samples. The color distribution can be visually seen in **Figure 20**.

A total of 30 soil samples were analyzed, resulting in 150 scans. Of these, 20 scans yielded positive identifications of specific polymer types. Six scans exhibited absorption features corresponding to low-density polyethylene (LDPE), while another six scans identified polyvinyl chloride (PVC). Additionally, four scans correlated with polystyrene, and four with polypropylene. These results provide a quantitative assessment of polymer presence within the analyzed soil samples, highlighting the distribution of different plastic types.

3.7 Spectra Results Overview

Each of the environmental media that was measured had a prominent plastic signature. A prominent signature refers to an absorption feature being present at a specific wavelength and with a specific reflectivity range that corresponds to one of the following plastics: PVC, LDPE, Nylon 12, PS, and PP. In total 56 plastic scans were detected in the environmental samples and the distribution can be observed in **Figure 21**. Furthermore, the numerical counts of the plastic polymers that were successfully identified can be viewed in **Figure 22**. Plastic was most readily identified in soils samples and freshwater samples. In total 42 or roughly 75 percent of the prominent plastic signatures of our study were found in freshwater and soil samples. For Hurricane Helene precipitation samples, 8 prominent plastic signatures were found. Dry atmospheric deposition a total of five distinct plastic signatures. The groundwater samples exhibited a total of two positive plastic signatures. Nevertheless, the plastic composition identification did vary between environmental media and this can be observed in **Figure 23**. The distribution of plastic types is largely dependent on the environmental medium being observed. For example, the surface water shows a mixture of PVC, Nylon, and LDPE.

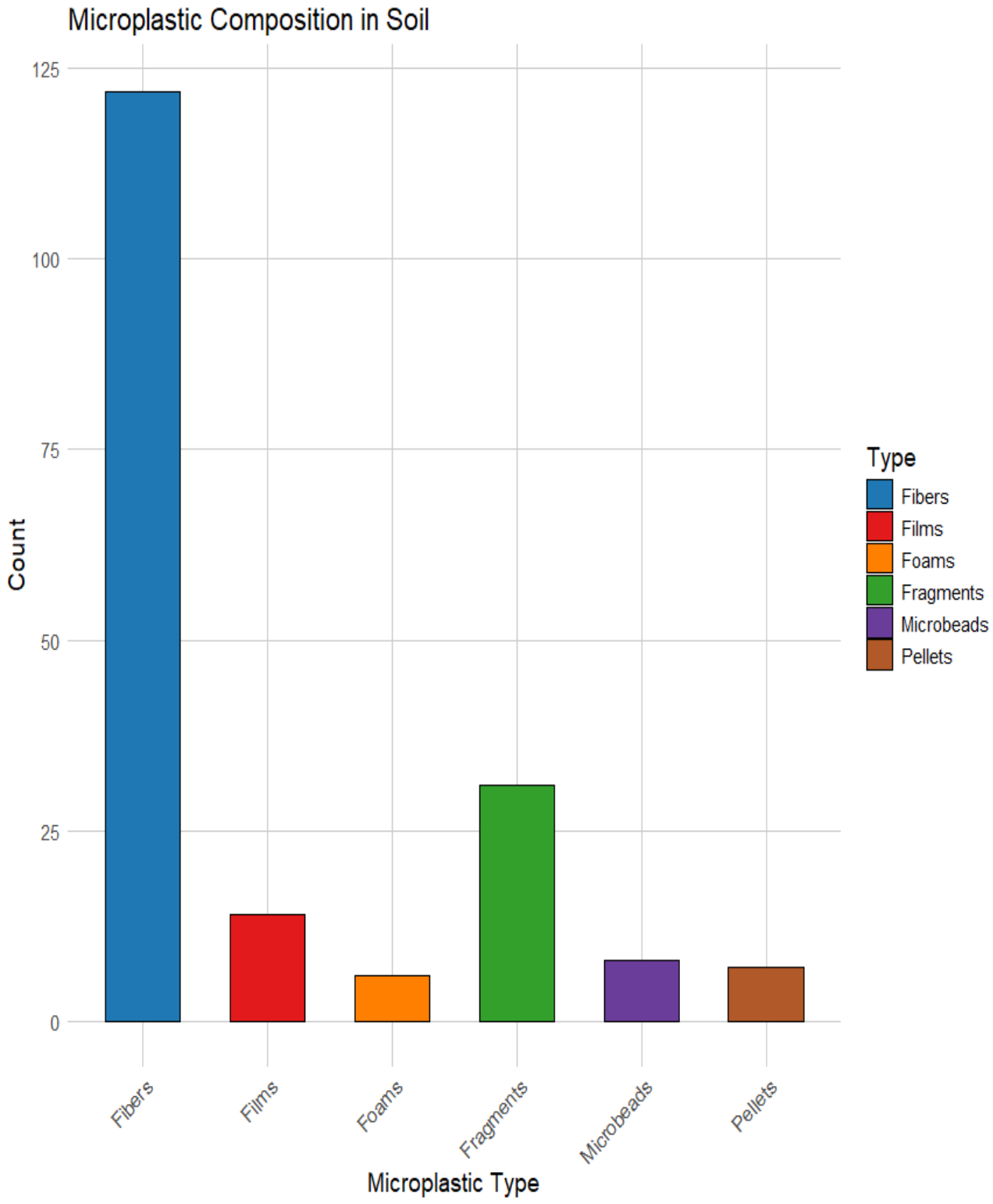


Figure 19: The bar chart represents the distribution of different microplastic types detected in soil samples. Fibers were the most abundant, accounting for 122 particles, followed by fragments (31 particles) and films (14 particles). Smaller quantities of foams (6 particles), microbeads (8 particles), and pellets (7 particles) were also identified.

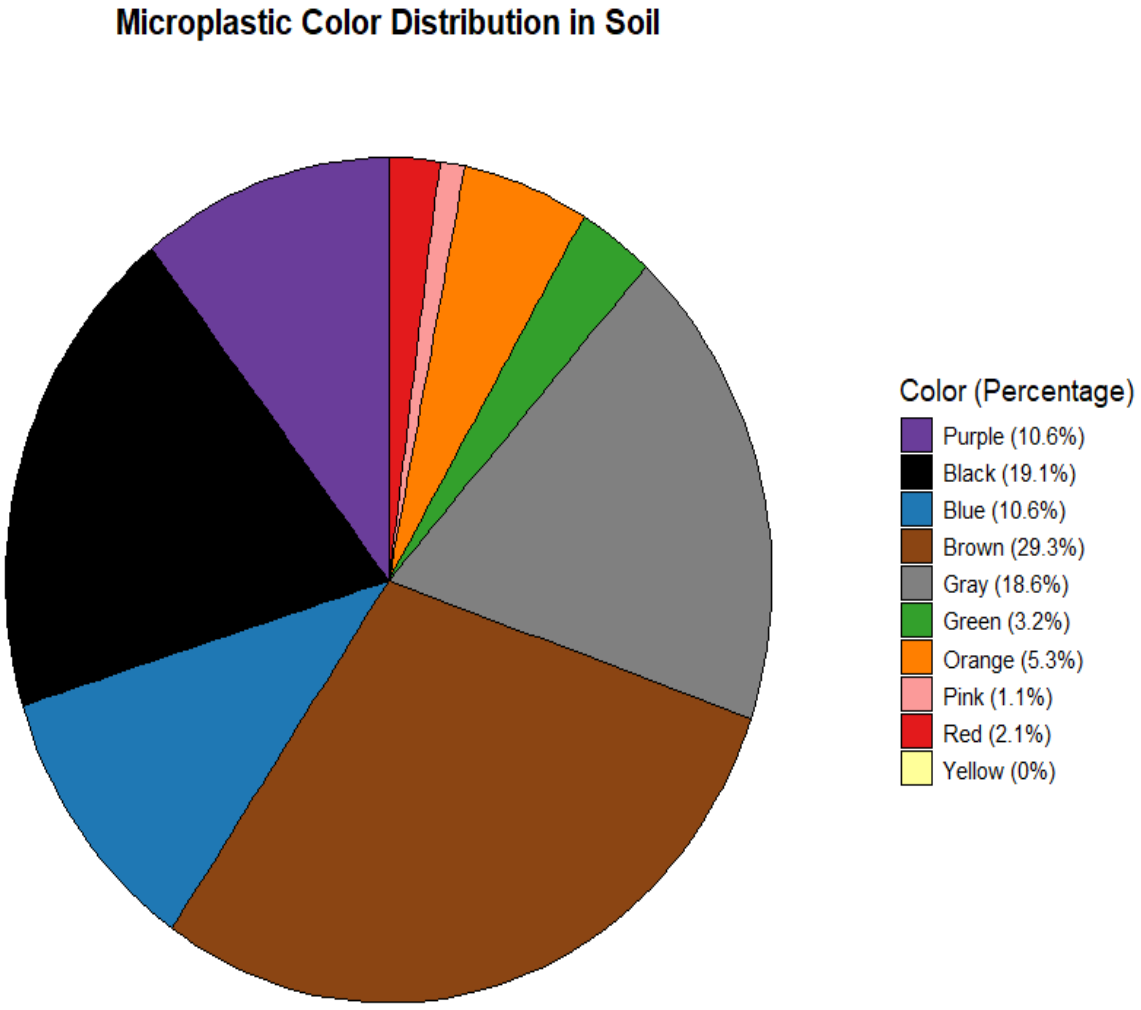


Figure 20: The pie chart illustrates the relative abundance of different microplastic colors, with percentages displayed in the legend. Brown was the most dominant color, accounting for 29.3% of the total microplastic particles, followed by black (19.1%) and gray (18.6%). Other colors, including purple, blue, green, orange, red, and pink, were present in smaller proportions, while yellow was not detected.

Table 1: Microplastic Detection Summary Across Environments

Environment	Samples	Scans	Plastic_Signatures
Freshwater	270	1350	18
Groundwater	137	685	15
Dry Atmospheric Deposition	60	300	5
Hurricane Helene Precipitation	37	185	8
Soil	30	150	20

Figure 21: The table presents the number of samples collected, total scans conducted, and detected plastic signatures across various environments, including freshwater, groundwater, dry atmospheric deposition, Hurricane Helene precipitation, and soil. This data provide insights into the distribution of microplastics across different environmental compartments.

Table 1: Breakdown of Detected Plastic Types Across Environments

Environment	PVC	Nylon	LDPE	Polypropylene	Polystyrene	Nylon_LDPE
Surface Water	2	14	2	0	0	0
Groundwater	1	0	1	0	0	0
Soil	6	0	6	4	4	0
Dry Atmospheric Deposition	0	4	1	0	0	0
Precipitation	0	3	5	0	0	3

Figure 22: The table summarizes the occurrence of different plastic types, including PVC, Nylon, LDPE, Polypropylene, Polystyrene, and Nylon_LDPE, detected in various environmental compartments such as surface water, groundwater, soil, dry atmospheric deposition, and precipitation. The Nylon_LDPE column shows a potential detection of a Nylon and LDPE microplastic mixture. This data provides insight into the distribution and prevalence of plastic polymers in different environmental contexts.

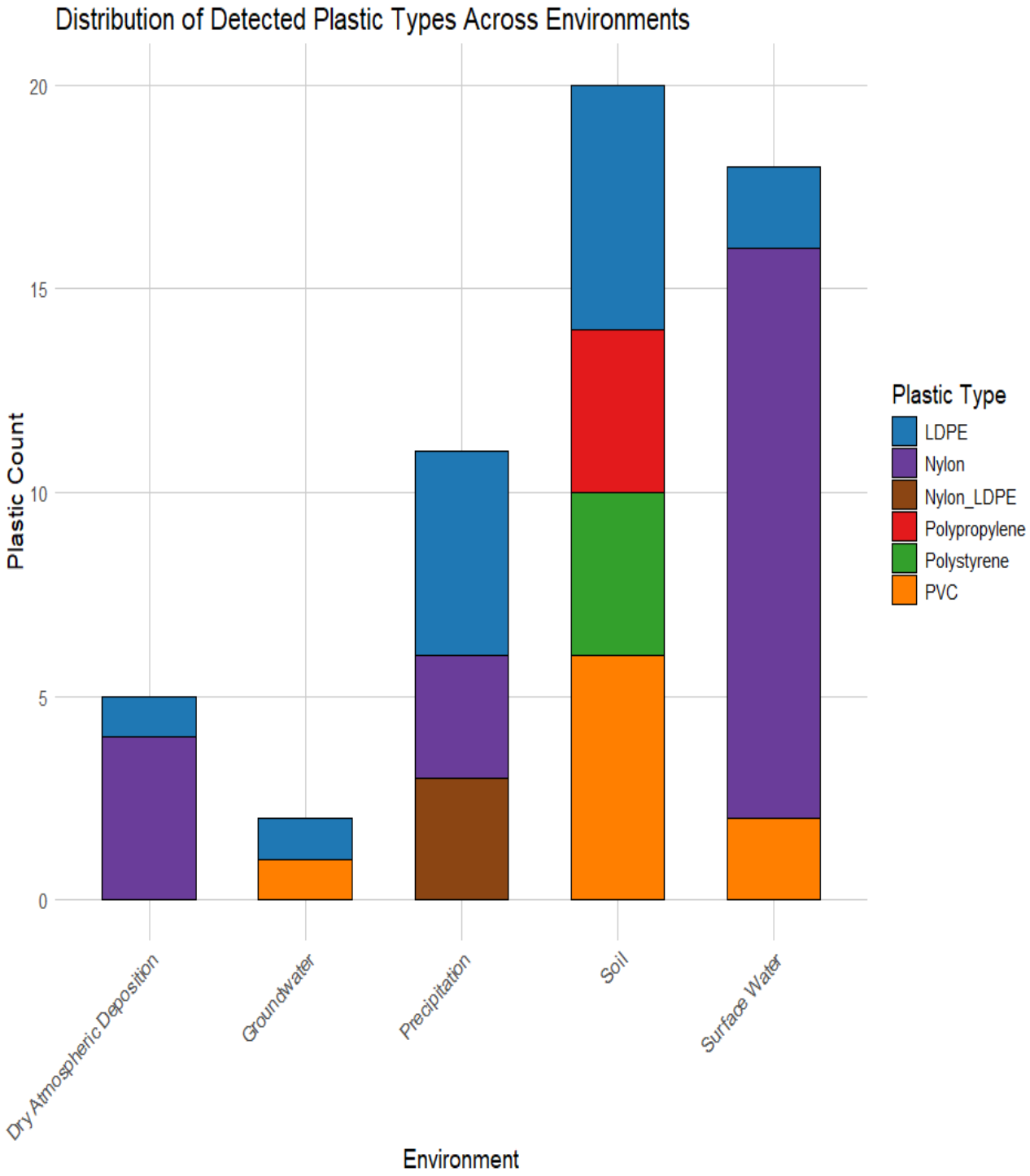


Figure 23: The bar chart illustrates the occurrence of various plastic types, including LDPE, Nylon, Nylon_LDPE, Polypropylene, Polystyrene, and PVC, across different environmental compartments: surface water, groundwater, soil, dry atmospheric deposition, and precipitation. The height of each stacked bar represents the total plastic count within each environment, highlighting variations in plastic type distribution among matrices.

Furthermore, polypropylene and polystyrene were only detected in soil matrices. Interestingly the scan to detection ratio was also the most prominent in soils compared to other environmental mediums. The number of scans did not directly correlate to plastic detection rate. Evidence of this can be seen in **Figure 21** and **Figure 24** that shows with 270 samples and 1350 scans only 18 plastic signals were identified, which is a much larger sample set than the soil samples which numbered 30 and had a total of 150 scans. The difference in plastic detection also correlates to the difference in microplastic types.

3.8 Model Results

The PLSR models were validated by generating a key of numerical values that represent the actual concentrations of the plastic polymers inside the soil samples ranging from 1 percent to 10 percent in concentration. To test the model's accuracy a new sample set was generated and the resulting information was fed into the PLSR model providing a numerical outcome that corresponds to concentration in the sample and the type. The accuracy and the subsequent R squared value of each model varied with each plastic chemical composition.

The PLSR model for polypropylene was found to have an R squared value of .98. This can be viewed in **Figure 25**. Furthermore, in **Figure 26** a more accurate comparison can be seen. The second most accurate model was found to be correlated to polystyrene plastic with an R squared value of .946. This can be viewed in **Figure 27**. The variation between the measured set and the calculated set can be viewed easily in **Figure 28**. The PVC model held an R squared value of .91 which can be seen in **Figure 29**. The variation between the data sets becomes more apparent in **Figure 30**. The least accurate model belongs to LDPE with an R squared value of .83 which can be viewed in **Figure 31**. The large numerical inconsistencies between the testing data set and the calculated set can be seen in **Figure 32**.

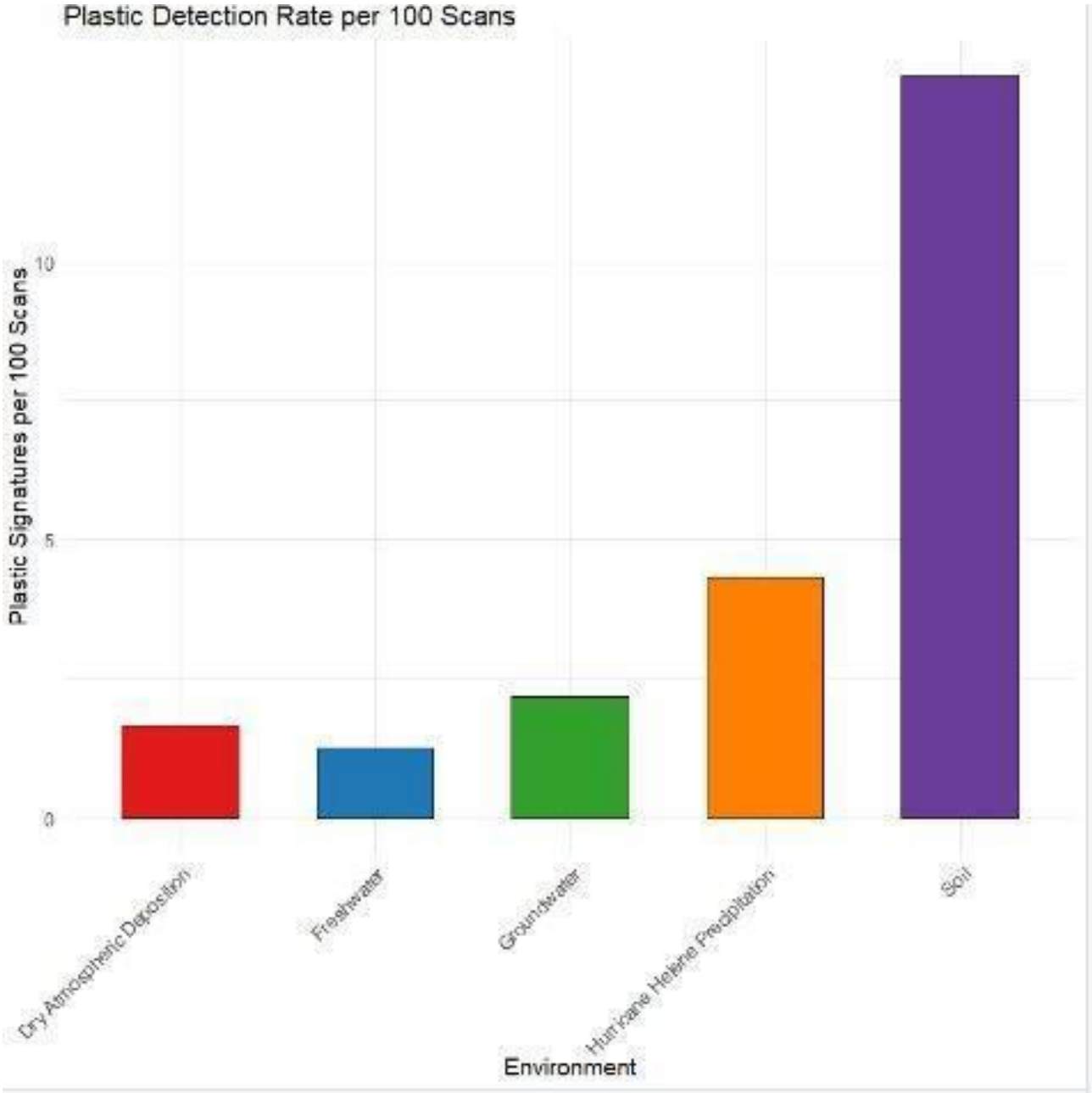


Figure 24: The bar chart displays the rate of detected plastic signatures per 100 scans in different environmental compartments, including dry atmospheric deposition, freshwater, groundwater, Hurricane Helene precipitation, and soil. The results indicate variability in plastic detection rates, with soil exhibiting the highest detection rate, suggesting a greater accumulation of microplastics in this environment.

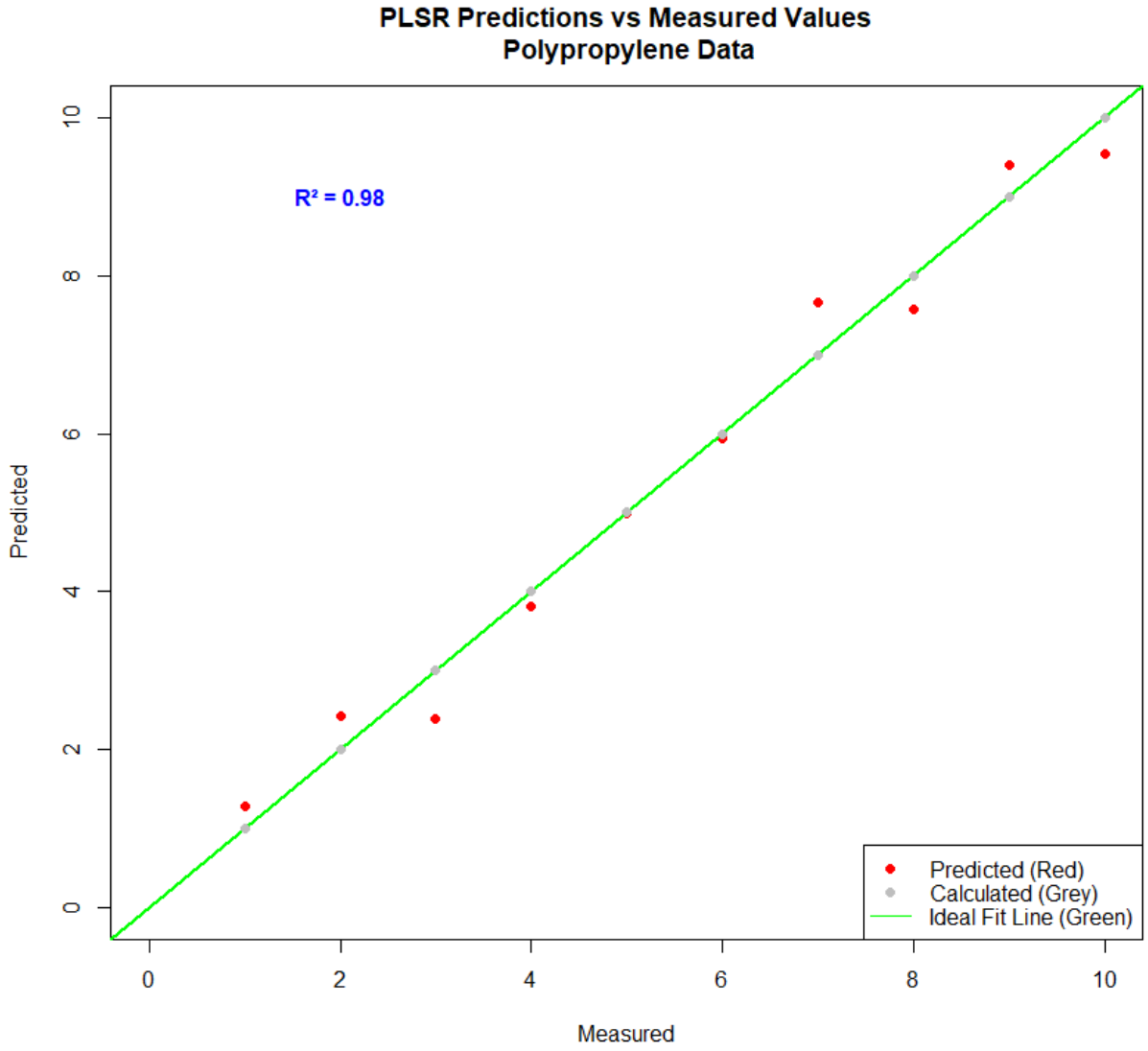


Figure 25: The scatter plot compares predicted values (red) with measured values for polypropylene, using Partial Least Squares Regression (PLSR). The green line represents the ideal 1:1 fit, and the strong correlation ($R^2 = 0.98$) indicates excellent predictive performance of the model.

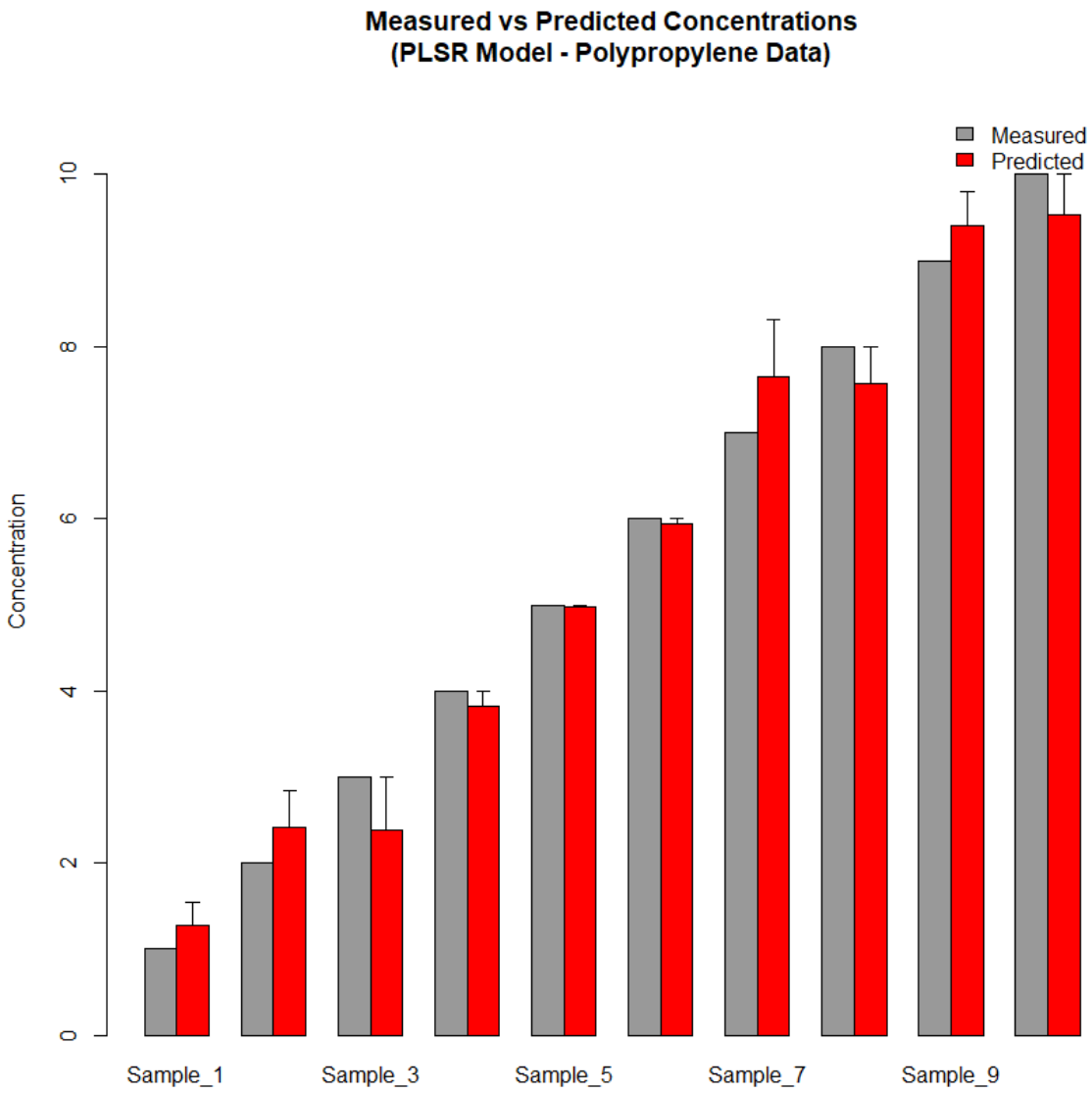


Figure 26: This bar plot compares measured (gray) and predicted (red) concentrations for ten Polypropylene samples based on a Partial Least Squares Regression (PLSR) model. Error bars represent the absolute difference between predicted and measured values, serving as indicators of prediction accuracy. The PLSR model demonstrates strong agreement with actual values, especially at higher concentrations, with minimal deviations observed across most samples.

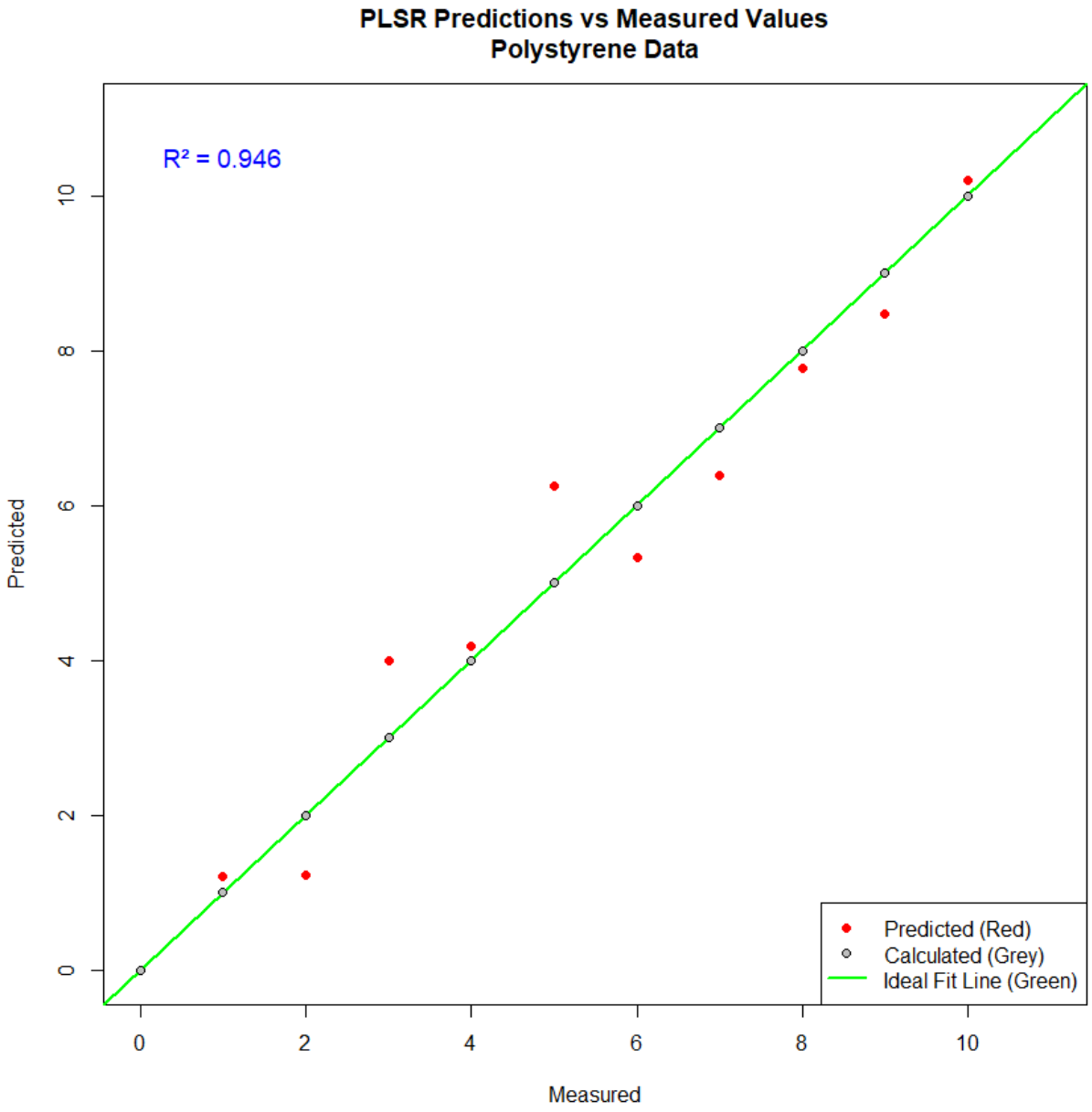


Figure 27: The scatter plot compares predicted values (red) with measured concentrations of polystyrene using a Partial Least Squares Regression (PLSR) model. Grey points represent calculated values along the ideal 1:1 fit line (green). The high coefficient of determination (R^2 = 0.946) indicates strong model performance in predicting polystyrene concentrations.

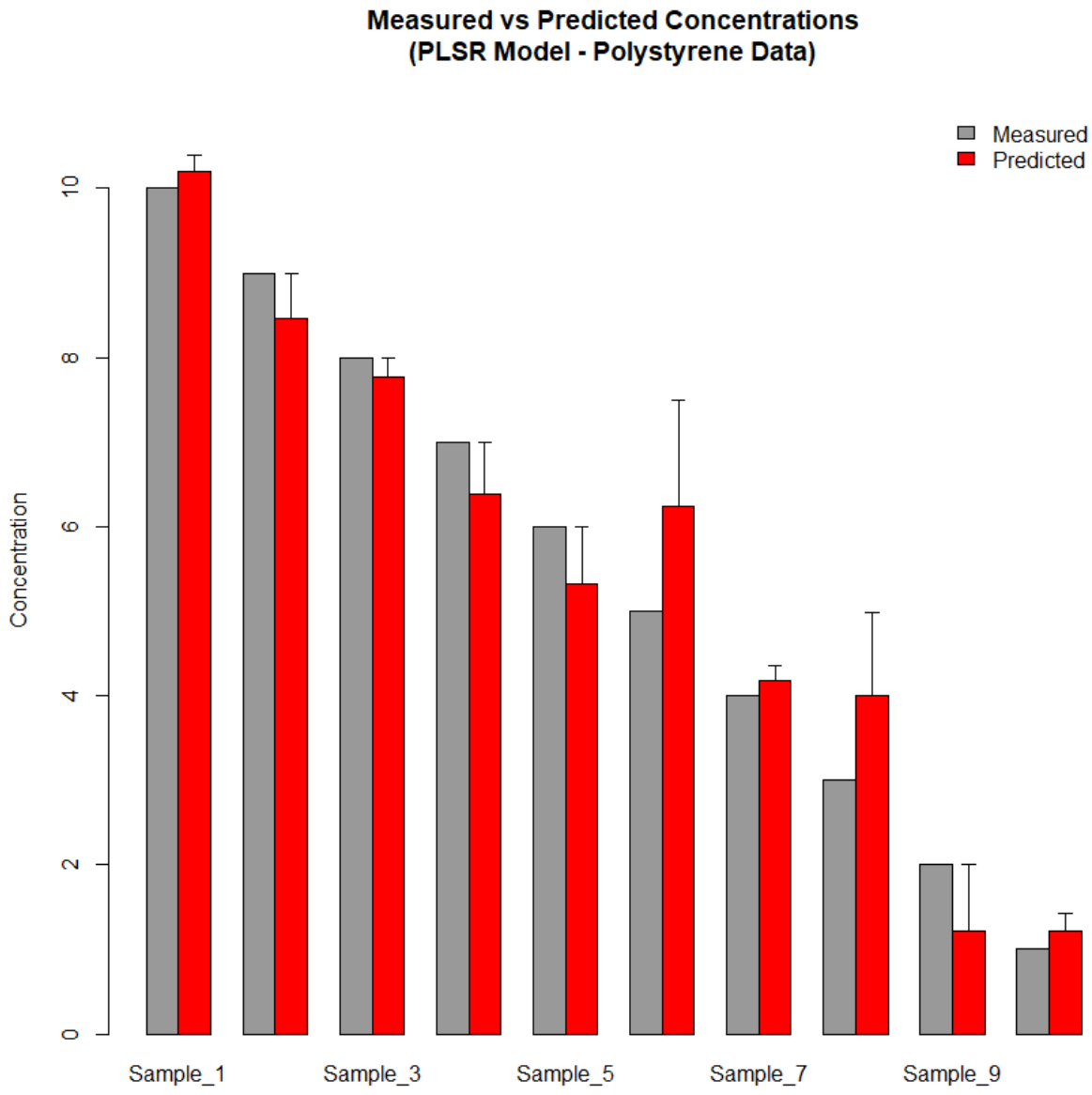


Figure 28: The bar plot displays measured (gray) and predicted (red) concentrations for ten samples using a Partial Least Squares Regression (PLSR) model trained on Polystyrene spectral data. Error bars represent the absolute differences between predicted and measured values, providing a visual assessment of model accuracy. The model demonstrates strong performance across most samples, particularly at higher concentrations, with deviations becoming more pronounced in mid-to-lower concentration ranges.

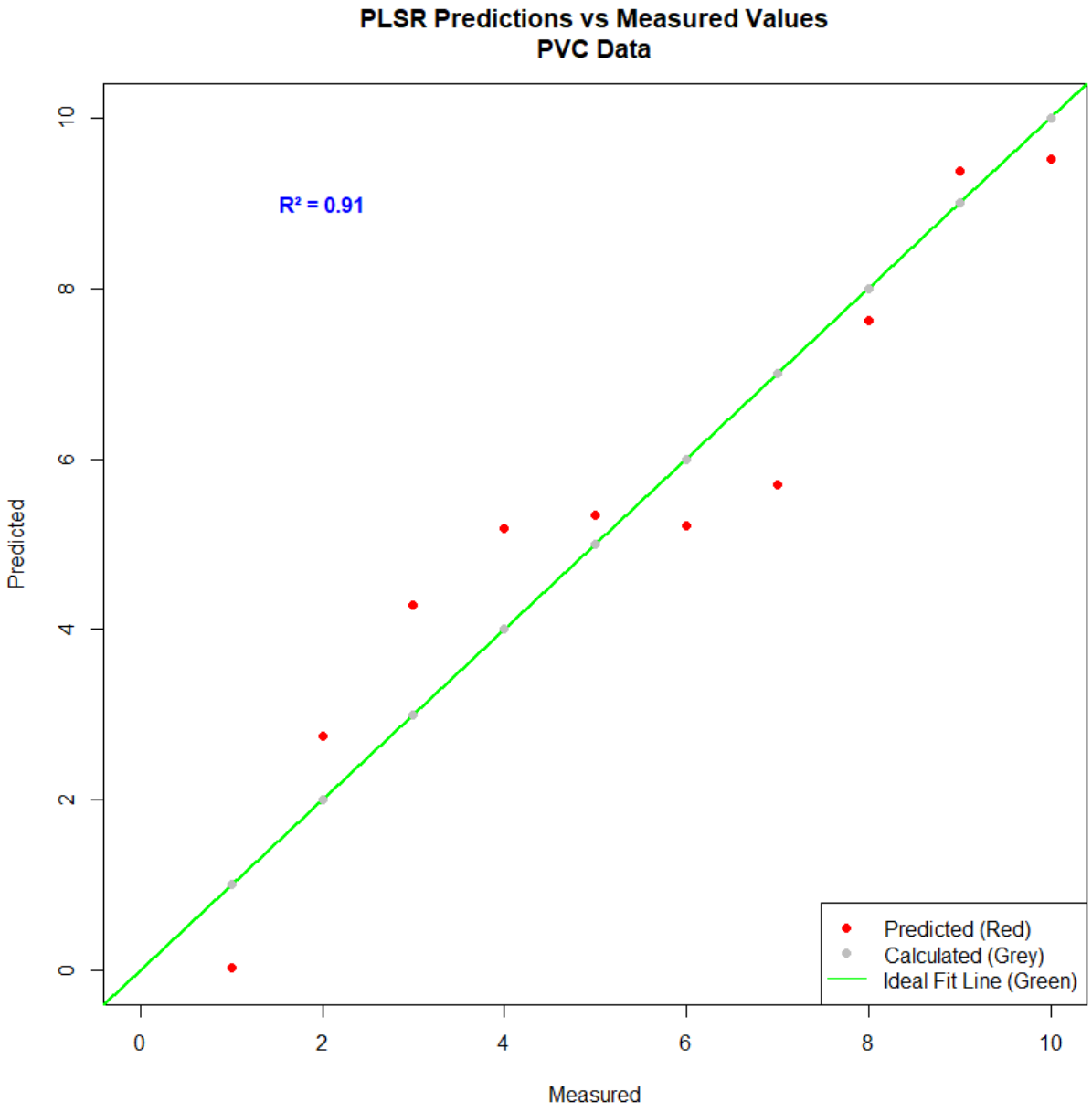


Figure 29: This plot compares predicted (red) and measured concentrations of PVC using a Partial Least Squares Regression (PLSR) model. Grey points represent calculated values along the ideal 1:1 fit line (green). The coefficient of determination ($R^2 = 0.91$) indicates strong model accuracy in predicting PVC concentrations.

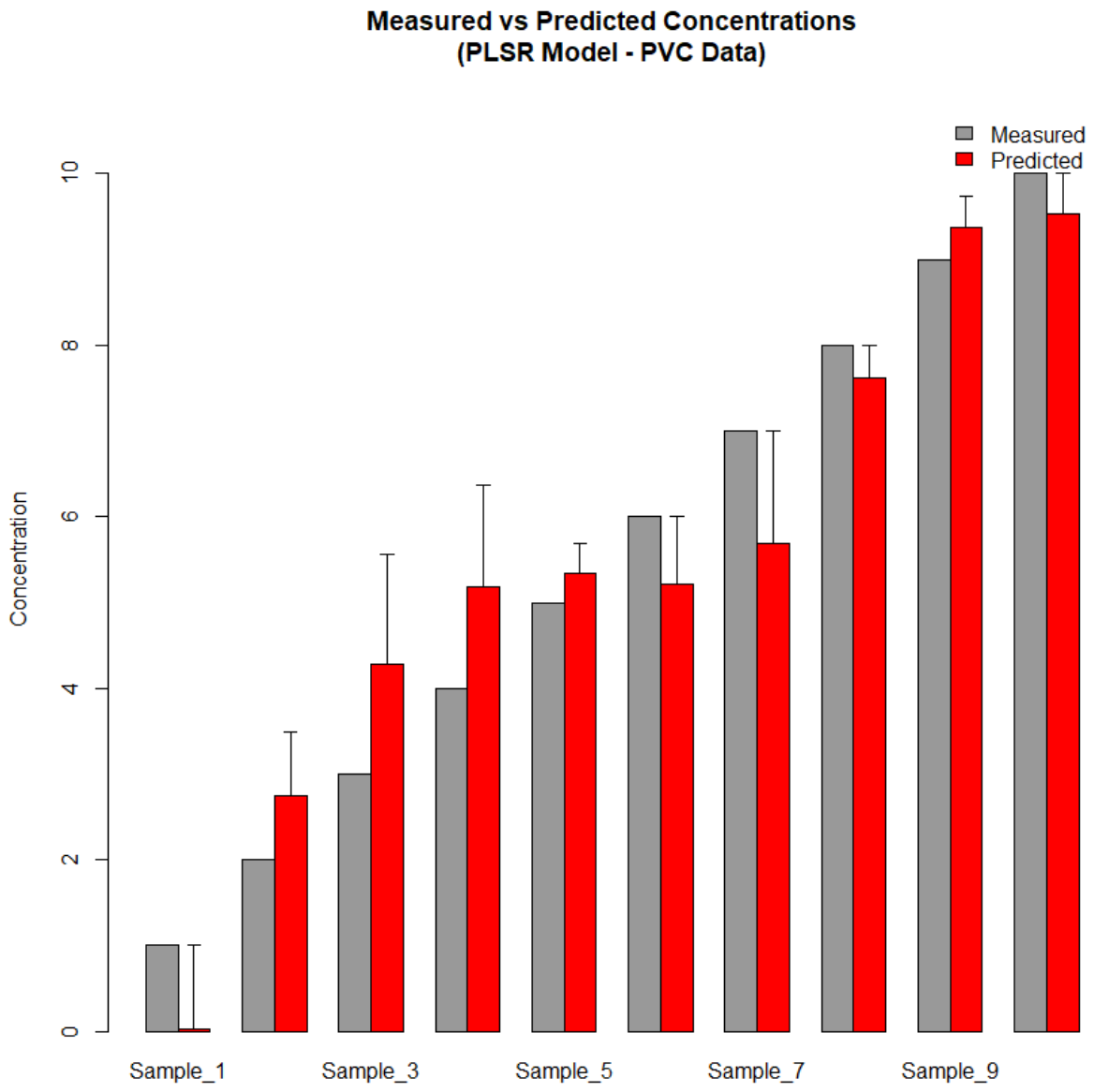


Figure 30: The bar plot presents a side-by-side comparison of measured (gray) and predicted (red) concentrations for ten PVC samples using a Partial Least Squares Regression (PLSR) model. Error bars indicate the absolute deviation between predicted and measured values, providing a visual representation of model performance across samples. Overall, the PLSR model demonstrates strong predictive accuracy, particularly in higher concentration ranges, with relatively small errors observed in most samples.

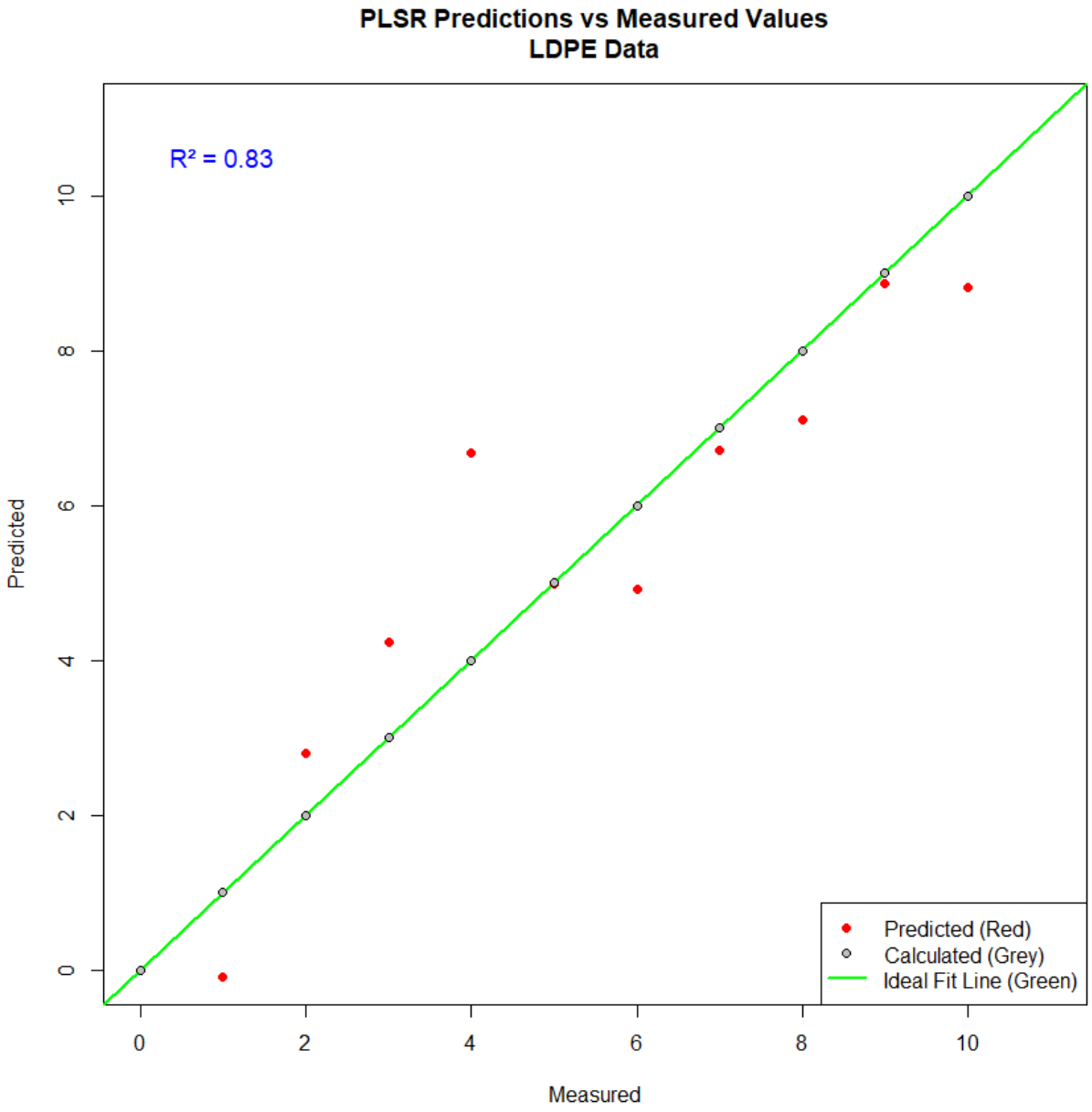


Figure 31: The scatter plot compares predicted concentrations (red) with measured concentrations for LDPE using a Partial Least Squares Regression (PLSR) model. Grey points along the green diagonal line represent ideal calculated values. The coefficient of determination ($R^2 = 0.83$) indicates strong predictive accuracy for LDPE concentration using the latent variable model.

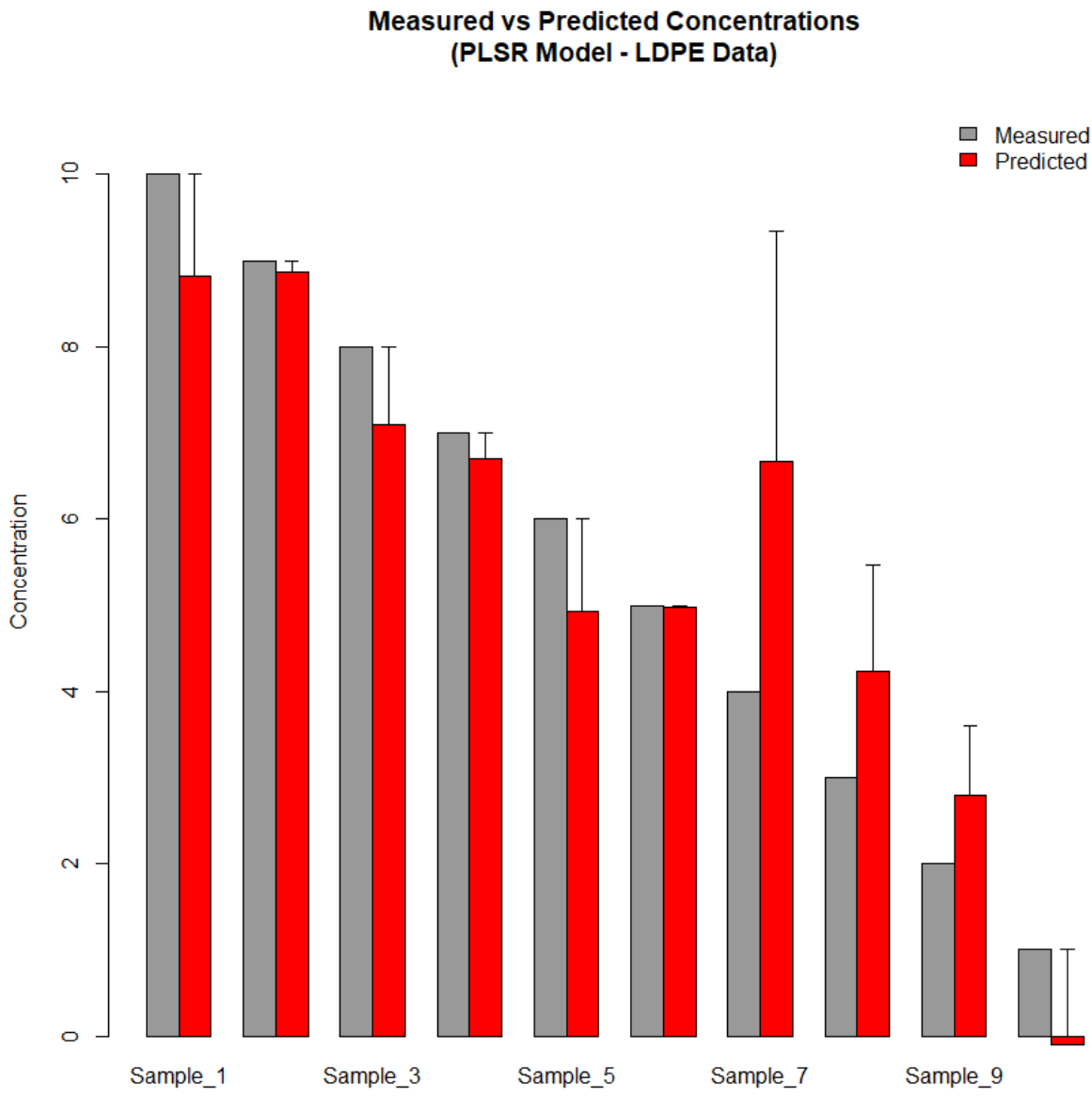


Figure 32: The bar plot illustrates measured concentrations (gray) and PLSR model-predicted concentrations (red) for ten LDPE samples. Error bars represent the absolute deviation between measured and predicted values, providing a visual indication of prediction accuracy. Samples with taller error bars indicate greater discrepancies, suggesting lower predictive performance for those cases. Overall, the model demonstrates reasonable agreement across most samples, with increased error observed at lower concentration levels.

Chapter 4 Discussion

The goal of this investigation is to test the limitation of PSR+ spectroradiometer for microplastic identification and quantification. To accomplish this, we set out to develop PSLR models for propylene, polystyrene, polyvinyl chloride, and low-density polyethylene in a native Tennessee soil. Then to further test the capabilities of the PSR+; the device was implemented in the traditional methods for environmental microplastic examination. By testing the PSR+ in these two different ways we will lay the foundation for future scientific work on the different approaches for microplastic identification.

4.1 Propylene Model

The R squared value of the PLSR model for polypropylene was 0.98. The plastic standard for polypropylene arrived from the manufacture in small plastic beads that ranged in size from 1 mm- 2.5 mm. Due to the size of the plastic beads they needed to be milled through a mill generated in Professor Hayes Lab that uses a fisher scientific motor, which can be seen in **Figure 33**. The plastic beads were milled down to 250-845 microns to be the same size as the other plastic standards. The R squared value for this model exceeded the other PLSR models by a significant margin. The reason for this could stem from the unique physical and chemical properties of polypropylene. For example, the process of generating primary microplastics from the standard varies greatly in time and the resulting form of the microplastic particle varies greatly due to the physical and chemical properties of the polymer. In this case milling of the polypropylene beads resulted in the formation of small plastic particle fragments that varied slightly in size but remained within the 250–845-micron range.

The polypropylene sample set was generated over the course of one week in which the samples were processed and measured with the PSR+ spectroradiometer within a seven-day period. The duration of sample creation to measurement is vital due to the increased chance of contamination occurring within the sample set the longer the samples are exposed from atmospheric plastic fallout.

During the data analysis and data cleaning portion of the model building it was very apparent that the polypropylene outliers were more easily recognizable due to the presence or absence of plastic signatures at the following wavelengths: 900, 1200, 1400, and 1700 nm. Furthermore, the mixture of soil and plastic will result in the formation of a mixture that has its own reflectivity that values that could be higher or lower. Polypropylene mixtures start at 0 reflectivity and end around 65 percent reflectivity with the highest reflectivity around 83.5%



Figure 33: The image above shows the grinder used for the physical breakdown of plastic standards. The plastic standards are grinded into the desired particle measurement and passed through a metal sieve before the plastic particles are collected inside a glass container for transport.

reflectivity at 2100 nm wavelength. Any measurements that did not match these patterns more than likely was a result of human error with measurement with the contact probe or a mismeasurement and could be removed from the data for model creation. The relative quickness in sample creation and measurement coincided with chemical and physical properties of polypropylene resulting in the formation of the high R squared value.

4.2 Polystyrene Model

The r squared value of the polystyrene model was the second highest of all the models with a value of 0.946. The polystyrene standard arrived in the form of large fragments that ranged in size from 1-4 mm in length. As a result of their large size these fragments needed to be broken down into a powder substance within the 250–845-micron range. However, the majority of the fragments seemed to be smaller or equal to 250 microns. The R squared value for the PLSR model was acceptable and comparable to the results obtained by the PVC data which was also a powder material. Nevertheless, the reason for the good results stems from the unique chemical structure of the polymer. Polystyrene is made from styrene monomers, each containing a phenyl group ($–C_6H_5$) attached to its carbon backbone. Polystyrene has unique absorption features compared to other plastic polymers and especially chemical or mineralogical compounds in nature which makes it very easy to characterize and identify.

The polystyrene sample set was generated over the course of 12 days. The PSR+ measurements took place 3 days after sample generation, thus each sample set was exposed to atmospheric fallout for a duration of 15 days for the oldest samples. The increased exposure of microplastic fallout did not seem to have a direct impact on the model outcomes.

The data analysis and data cleaning portion it was fairly easy to remove any outliers to ensure proper data acquisition. The reason for this is due to the unique reflectance percentage and absorption feature of polystyrene. Pure polystyrene has a reflectivity starting within the range of 30-48% percent reflectivity while the mixture of polystyrene has a reflectivity percentage starting at 0 percent reflectivity and peaks at 75 percent reflectivity and ends within the range of 30-56 percent reflectivity. The large variation in reflectivity percentages in the polystyrene mixtures did make some outliers difficult to measure; however, since we can use a mixture of reflectivity and absorption features to determine if polystyrene can be detected these outliers can be removed and the data can be properly utilized. In the case of polystyrene, the absorption features can be observed at the following wavelengths 871, 1137, 1204, 1408, 1673, and 1759 nm. The polystyrene model resulted in adequate results due to the relatively short

exposure to atmospheric fallout inside the lab and the unique chemical composition of polystyrene.

4.3 PVC Model

The R-squared value of the PVC model was the third highest among all the models in this study, with a value of 0.910. The PVC standard arrived as a fine powder, with particle sizes ranging from 250 to 845 microns; however, the powder generally favored the 250-micron size range. Because the material was already in powdered form, no additional milling was required. This R-squared value falls within the anticipated range for PVC, although the PVC model in the Panzac paper reported an even higher value. One major contributor to our model's strong performance is the distinct chemical and physical properties of polyvinyl chloride. PVC does not exhibit overlapping absorption patterns with the soil used in this study, which made it relatively easy to differentiate its spectral features from those of the surrounding matrix.

The PVC sample set was generated over a two-week period and measured across another two weeks using the PSR+ spectroradiometer. Consequently, the samples were exposed to atmospheric fallout for approximately 14 days. Fortunately, this exposure did not noticeably impact the model’s accuracy. Data cleaning and analysis were relatively straightforward due to PVC's unique absorption features. Pure polyvinyl chloride generally exhibits reflectance between 60% and 85%, with consistent absorption bands. When mixed with Tennessee red clay soil, however, reflectance varied significantly, ranging from nearly 0% to 80%. Although this range introduced outliers, the model still effectively distinguished PVC due to its characteristic absorption features at 913, 1168, 1412, 1715, and 2315 nanometers. Despite its success, the model's performance could be improved. One limitation may be related to PVC arriving as a powder, in contrast to polystyrene and polypropylene, which were in pellet or glass-like form. While the polystyrene model also used a powdered form and achieved high performance, the visual and physical properties of polystyrene differ substantially from PVC, potentially affecting results. Still, the R-squared value of 0.91 demonstrates the PSR+ is effective in identifying PVC in soil mixtures.

4.4 LDPE Model

The PLSR model for low-density polyethylene (LDPE) yielded the lowest R-squared value among all models, at 0.830. This underperformance may be attributed to either chemical or physical properties of the polymer. Like polystyrene and polypropylene, LDPE arrived as 1 to 2 mm plastic pellets, requiring milling down to 250 to 845 microns. Overlapping absorption

features between LDPE and Tennessee red clay soil, along with other compounding factors, likely contributed to the lower accuracy.

The LDPE samples were prepared over three weeks and measured over two weeks, resulting in a 35-day period of potential exposure to atmospheric fallout. This prolonged exposure might have introduced microplastic contamination, as some scans revealed features inconsistent with both LDPE and soil. These unidentified features may result from fibers or microplastic fragments deposited during storage. Furthermore, the LDPE sample set was the last generated, and a second soil batch, taken just a foot from the original site, may have introduced subtle mineralogical differences.

LDPE's spectral overlap with soil complicated data cleaning. For example, the prominent plastic absorption feature near 1400 nm is also strongly present in the soil, rendering it unusable for model building. The 930 nm feature was absent in mixture scans, while the 1215 nm feature became unreliable at lower concentrations. This could result from interactions with the soil matrix or contamination. As a fallback, the 1700 nm region was used despite some overlap with the soil. Reflectance for pure LDPE ranged from 35% to 45%, eventually declining to around 0% at 2500 nm. Mixture samples showed greater variability, from 0–10% up to 66% reflectance. These inconsistencies made LDPE particularly difficult to model accurately. Although the R-squared value of 0.83 is adequate for some applications, improved methodology or different instrumentation may be needed for more precise results. Using a different LDPE source, such as a powder or glass-like plastic, could enhance future model performance.

4.5 Consistent Margins of Error

When examining all four models collectively, a clear pattern emerges: model accuracy declines as plastic concentration decreases. This is a direct consequence of the methodology, which uses a contact probe with a limited detection window. In mixtures of 15 grams of soil and plastic, reducing the amount of plastic results in a proportionally greater influence from the soil's spectral signature, making plastic signals harder to detect. Another factor that could directly hinder the outcomes of the PLSR model could include impurities or possible contamination of the plastic standard. Due to the nature of our methodology contamination during the grinding process or sample measurement could potentially hinder or skew results.

In the highest-performing model (polypropylene), the greatest errors occurred in samples with less than 5% plastic concentration. Notably, a 7% sample consistently measured as 7.5%, while the 9% sample was slightly underestimated. In the polystyrene model, the greatest

deviations occurred in samples below 4% concentration. Similarly, the PVC model showed significant discrepancies below 5% and failed to reliably detect concentrations as low as 1%. While 2% to 5% PVC samples were detected, the margin of error was substantial. LDPE, however, showed the highest variation across all low-concentration samples. For instance, the 4% LDPE sample had the largest error across all models, and the 1% sample failed to register altogether. The LDPE model proved especially unreliable, below 5% due to erratic detection rates, making it the least predictable. Despite these challenges, the LDPE model performed reasonably well at concentrations of 5% or more, even outperforming the PVC model in some cases.

The following different variables could play a significant role in the model formation: soil heterogeneity, contamination, physical microplastic characteristics, chemical microplastic characteristics, and human error. The soil in the study was collected at one location during a singular collection event to minimize soil variation. However, the amount of soil needed for this experiment was several kilograms which means small variations in mineralogy or soil characteristic could affect the spectral imaging. The entirety of the sample correction and measurement took place in a laboratory that has an open airflow and frequent movement of individuals thus plastic particles could have contaminated the sample. The plastic standards that were used to generate the microplastics needed to develop the samples were not in the same size or shape upon arrival from the manufacturing and thus certain plastics needed to be milled to the size needed. Lastly, human error could have played a role in the r squared value in all four of the models.

4.6 Soil Variation

Another factor influencing model outcomes is the variation in soil chemistry and mineralogy. Although all soil used in this study originated from the same site, it is possible that individual batches contained slight differences in organic matter or mineral content. The composition and form of the organic matter can play a significant role in the outgoing spectra formed during reflectance spectroscopy (Ben-Dor, 1997). Furthermore, the form of the organic matter could play a more significant role due to the organic matter being in the form of an insatiable or stable formation. An example of this could be in minerally associated organic matter that could have a different spectral signature than dissolved organic matter (Hansen et al., 2016). The mineral composition of the soil plays a significant role in the spectral signature, and in this case upwards of 90% of the samples in the PLSR model are composed of soil with the

remainder being the selected plastic. For instance, research has demonstrated that soil mineral composition directly affects the turnover of soil organic matter, which indicates that the mineral content can influence soil reflectance (Dóra Zacháry et al., 2022). These variations can cause minor differences in reflectance or introduce or obscure certain absorption features.

The Tennessee red clay soil used in this study is classified as a heavily weathered ultisol, known for its low pH, low nutrient content, and reddish hue, which is associated with a high concentration of iron oxides. X-ray diffraction (XRD) analysis confirmed high levels of iron-rich minerals and minimal kaolinite content. However, since the XRD was conducted on only one subsample, variations in mineralogy across batches may have influenced spectroscopic measurements. Despite this, the steps taken to standardize soil usage were largely effective. Nevertheless, it should be mentioned that the physical and chemical alteration during sample preparation can directly affect the reflectance of the soil (McGuirk et al., 2024). The PVC, polystyrene, and polypropylene models all met or exceeded expectations based on comparable studies.

4.7 Contamination

Contamination is a common issue in microplastic research, often originating from laboratory environments (Jones et al., 2024). In our study, the most frequent contaminants were translucent or white plastic fibers, typically 1–2 mm in length. These were suspected to be cotton-polyester blends likely originating from lab coats or the building's ventilation system. All petri dishes placed throughout the lab for monitoring airborne microplastics showed similar fibers, indicating widespread, unavoidable contamination. The presence of microplastic contamination is often discussed in several other studies that include not only atmospheric contamination but from water or consumables (Jones et al., 2024). To help fight the contamination we followed the protocols highlighted in Prata et al. (2024) but amended a few protocols to fit within the context of our study and lab.

Although these contaminants did not significantly affect the PVC, polystyrene, or polypropylene models, they may have influenced the LDPE model due to its prolonged exposure period. To mitigate contamination, samples were stored in airtight cabinets, but fibers were still introduced during handling. This underscores the importance of developing new methodologies to prevent laboratory-introduced plastic contamination in future environmental microplastic studies.

4.8 Influences on Dry atmospheric Microplastic Contamination

The processes that govern the deposition of atmospheric microplastics are primarily driven by meteorological factors, which regulate the transport, suspension, and ultimate deposition of the particles. Wind speed and direction are key factors that dictate the movement of microplastic particles (Sarmite Kernchen et al., 2024). High wind speeds have the capacity to carry lightweight synthetic fibers and small fragments over long distances prior to their deposition (Sarmite Kernchen et al., 2024). The direction of such winds dictates the source of incoming particulates, meaning that locations that are downwind from major urban areas, industrial clusters, and transportation hubs are more prone to having elevated levels of plastic pollution in the air (Sarmite Kernchen et al., 2024). Also, wind turbulence can promote resuspension, where microplastics that have already settled are lifted again into the air, thus prolonging the length of time they stay airborne.

Microplastic aerodynamics are predominantly controlled by humidity and temperature (Liu et al., 2024). The increasing temperature can, in turn, also alter the physical structure of the plastics, with some polymers becoming more pliable and, in some instances, more buoyant in the air. Changes in temperature may also result in fragmentation, wherein plastic fragments deteriorate further under thermal expansion and contraction, making them disintegrate into smaller microplastics that suspend themselves more easily in the air (Liu et al., 2024). Humidity levels affect how these particles interact with atmospheric water. Hydrophilic plastics may absorb water from the air when it is humid, making them heavier and sinking more quickly, while hydrophobic plastics may remain suspended longer since they are resistant to moisture (Liu et al., 2024). Furthermore, humidity has the potential to enhance the electrostatic activity of microplastics, which will cause them to adhere to surfaces or clump together in the air.

A key consideration is the absence of precipitation, which affects the pathways by which microplastics are removed from the atmosphere through wet or dry deposition mechanisms (Sarmite Kernchen et al., 2024). Wet deposition occurs when rain or snowfall efficiently removes airborne microplastics from the atmosphere, leading to their deposition in aquatic environments or soil on land. On the other hand, dry deposition takes place without rain, wherein microplastics slowly descend through the action of gravity, atmospheric turbulence, and electrostatic attraction to surfaces (Sarmite Kernchen et al., 2024). In the absence of rain, microplastics remain airborne for longer durations, allowing them to cover greater distances and expand more widely prior to deposition.

4.9 Particle Characteristics

Physical characteristics of microplastic particles, such as size and density, determine their atmospheric lifetime and final deposition locations. Smaller and lighter microplastics, such as synthetic fibers originating from apparel, can remain suspended for extended periods because they have a lower settling velocity (Tatsii et al., 2023). Driven by meteorological conditions, such fibers can be transported hundreds to thousands of kilometers before deposition. In comparison, more dense and heavier plastic debris, microplastic beads, and pellets are more likely to settle in a rush under the influence of gravity (Tatsii et al., 2023). More dense particles tend to accumulate in regions close to their source of emission points, thereby rendering their deposition patterns more localized.

The polymer type that makes up microplastics also affects their atmospheric behavior and deposition rates. Plastics vary in whether they are hydrophobic or hydrophilic, meaning how they react to atmospheric water. Hydrophobic polymers, such as polyethylene and polypropylene, repel water and can stay suspended longer, while hydrophilic polymers, such as certain types of nylon and polyester, can absorb water, become denser, and deposit rapidly (Prajapati et al., 2022). The environmental results in this thesis are directly correlated to microplastics characteristics. For example, the environmental results that were observed in the atmospheric deposition, wet or dry, freshwater, groundwater, and soil are dependent on what microplastic particles were present in the environmental media when the collection takes place. As a result in environmental media like soil, denser and larger microplastic material would accumulate due to their lower mobility. Environmental media such as water in a pond would have less dense microplastics due to heavier microplastic that enter a body of water will slowly sink into the water column and settle on the soil until responded by biotic or abiotic factors. These statements are promoted by our results. Also, the state of degradation of microplastic particles influences their persistence in the atmosphere; aged and fragmented plastics are more irregular in shape and surface, and this may influence their aerodynamic characteristics and deposition.

4.10. Proximity to Urban and Industrial Sources

The concentration and classification of atmospheric microplastics in an area are significantly determined by the closeness to urban and industrial sources. Urban and industrial areas are significant sources of airborne microplastic pollution, resulting from a myriad of human activities (Evangeliou et al., 2020). Motor vehicle emissions, for instance, such as tire wear particles and plastic debris from roads, are some of the highest contributors to urban airborne microplastics (Evangeliou et al., 2020). Because automobiles travel on asphalt, microplastic

particles are continuously being generated and airborne, particularly on highways and main roads.

Among some of the most significant urban sources of airborne microplastics is the release of synthetic textile fibers from garments. Such everyday activities as walking, running, and normal wear and tear result in the release of minute fibers into the air (Ashkan Jahandari, 2023). Furthermore, synthetic fibers are shed during washing cycles, into wastewater systems, where they can become aerosolized during wastewater treatment operations. The other urban sources include construction activities, industrial emissions, and breakdown of plastic wastes, all of which are accountable for the presence of airborne plastics in densely populated regions.

The influence of urban and industrial sources does not terminate in metropolitan areas since it is possible for microplastics to extend through atmospheric processes to more distant locations (Li et al., 2023). Further, the availability of extensive road networks, shipping lanes, and air routes may contribute to high levels of deposition in predominantly rural or semi-rural settings. Regions downwind of factories are bound to receive more microplastic deposition, even though they are far from the initial source of pollution (Li et al., 2023).

The sample size for all our environmental microplastic examinations was a fair distance away from any industrial sites and Blount County Tennessee. However, the sample site was near a residential neighborhood by the factor of around 500 M through a forest and it was about 2.41 Km away from a prominent road that is used for transportation by several hundred vehicles a day. Thus, the influences of industrial and urban activities on microplastic contamination in the area could vary significantly depending on the amount of human activity occurring during the sampling. Furthermore, that means the type of microplastics being deserved and thus the colorization and physical properties of the microplastics in the environmental set could be dependent on the type of human activities occurring in close proximity.

An interesting finding in our results was the presence of purple microplastic particles being present in every environmental media. The blanks placed inside the lab only exhibited microplastic fibers that were categorized as clear microplastic fibers. The lack of purple microplastic material in any of the blanks is indicative that the purple microplastic material is localized to the sampling site. Purple microplastic material could originate from the possible photodegradation of other colored material or purple microplastic material might be generated by the physical breakdown of a larger plastic material.

4.11 Topographical and Vegetation Effects

Topography and vegetation in a region can significantly impact the pattern and rate of microplastic deposition. Forests, grasslands, and other vegetated areas act as natural air filters, capturing microplastics as they settle from the atmosphere. Leaves, twigs, and soil surfaces create physical barriers that trap these particles, preventing their further distribution. This interception effect means that vegetated areas are likely to accumulate more atmospheric microplastics compared to open-field settings, regardless of the distance from the pollution source. The site we studied can be described as a semi-urban environment with elevation variations of approximately 10 to 15 feet in most areas. However, around Pond 3, we observed a more substantial shift in elevation of about 100 feet between Pond 3 and Pond 1. Most of the areas where we collected samples were wide open spaces without tree cover, although several sites did have a significant amount of leaf and plant material, which could have contributed to the concentration of microplastics in these areas.

In addition, elevation and surface roughness have an effect on microplastic transport in the air. Mountainous or hilly terrain possesses localized winds, turbulence, and temperature inversions that impact deposition rates. Higher elevation areas should expect higher depositions of airborne plastics due to exposure to regular winds that undergo long-distance travel with microplastics in tow before finally being deposited. Alternatively, low-lying valleys may experience higher deposition due to stagnant air pockets, where airborne particles gradually settle. Whereas atmospheric deposition was located at a higher elevation sampling site than the ponds and as a result of that we could see higher influxes of certain types of plastic at that higher elevation versus at the lower elevation with the ponds (Thendo Mutshekwa et al., 2025). This could explain the differences of microplastic types being deserved in the surface water versus the atmospheric deposition samples in our study.

4.12 Human-induced Activities

Agricultural activities contribute to airborne microplastic pollution, particularly where plastic-based agricultural products are prevalent. Plastic mulch films, greenhouse covers, and irrigation pipes degrade over time, releasing microplastics into the air through wind erosion (Sa’adu & Farsang, 2023). Certain fertilizers and pesticides also contain microplastic carriers, which can become airborne during application or when the soil is disturbed. These agricultural plastic sources contribute to microplastic accumulation in both rural and urban environments, altering atmospheric deposition patterns in regions dominated by agriculture.

Waste management practices are another significant anthropogenic contributor to the

atmospheric dry deposition of microplastics. Open dumps, incineration facilities, and recycling centers—especially those with inadequate waste containment—are known to release microplastics into the air. The incineration of plastic waste can produce fine plastic particles that become airborne, while poorly managed recycling processes can lead to the release of microplastics during handling and transportation.

The site under investigation was chosen due to its distance from plastic waste management facilities. However, the site is situated near a road and a residential area, both of which could have played a crucial role in the local atmospheric deposition of microplastics, particularly in relation to the types and colors of microplastics detected in the samples. In regard to the overall historical plastic pollution at the sampling site, these ponds and the surrounding area have been heavily monitored and altered due to agricultural practices over the past 300 years. More recently, the land served as a cattle and horse farm, with a significant portion dedicated to growing corn and similar agricultural products. Throughout these agricultural practices, the application of plastics—along with fertilizers and other materials often stored in plastic containers—may have contributed to historical environmental microplastic contamination.

For example, several fields on the farm used biodegradable or plastic mulches to improve crop yield. Near Pond 3, a large fruit orchard was covered with plastic nets, typically composed of nylon and low-density polyethylene, to prevent animals from eating the cherries and other fruits. As a result, when examining the ponds and observing higher concentrations of nylon and green fibers (materials not found in atmospheric deposition samples), it is possible that much of this contamination originated from historical pollution linked to human activities at the sampling site.

In addition to the use of plastic materials in agriculture, microplastic contamination could stem from the creation of the ponds themselves. All the ponds on the property were artificially created in the past 60 years, and various plastic materials were employed during the construction. For instance, the irrigation systems connecting Pond 2 to Pond 3, and Pond 1 to Pond 2, are entirely made of PVC (polyvinyl chloride). This suggests that some of the PVC detected in our pond samples may have originated from the irrigation systems used in the construction of the ponds.

A significant source of microplastic contamination may also arise from nonpoint-source pollution linked to nearby homes and human populations. For example, during periods of

fluctuating water levels, tires and other litter have been observed in the ponds. Over time, these plastic materials slowly break down into microplastics, which means that some of the particles we detect in our samples may be the result of long-term historical pollution rather than more recent atmospheric or point-source contamination.

4.13 Sources of Wet Atmospheric Microplastic Pollution

Wet atmospheric deposition of microplastics is effectively dictated by atmospheric processes, with these influencing the interaction of atmospheric microplastics with rain and other sources of water in the atmosphere. The rate of loss of microplastics from the atmosphere is dependent on rainfall intensity and frequency. More intensive and frequent raindrops are more effective at scavenging aerial microplastics and delivering them to the Earth's surface.

The chemical makeup of precipitation also affects microplastic deposition. Rainwater holds different concentrations of dissolved gases, acids, and particulate material that can change the behavior of microplastic particles. Acidic rain, for instance, can gradually degrade some plastic polymers, potentially changing their surface charge and potential for interaction with water droplets. Wind dynamics during precipitation events can also potentially have a strong impact on deposition patterns. Heavy winds can distribute rain droplets across a larger surface area, affecting the final destination of microplastic deposition. In areas where slower wind speeds dominate, precipitation falls more perpendicularly, resulting in greater localized concentrations of deposited microplastics. Atmospheric turbulence, which is affected by storm systems, convection currents, and local weather fronts, also has the potential to change mixing of microplastics with rain droplets prior to surface arrival.

The weight, shape, and size of microplastics are important factors that govern their interaction with precipitation and their removal efficiency from the air. The bigger and heavier the plastic debris, including fragments and pellets, the greater the likelihood that they will settle rapidly and be intercepted more easily by raindrops (Zhang et al., 2020). On the other hand, fine fibers and low-density microplastics, particularly those constructed from polyethylene or polypropylene, have the capacity to remain airborne for extended durations and need several precipitation events prior to their complete elimination. Surface properties and polymer chemistry also play a role in the behavior of microplastics in wet deposition. Hydrophobic polymers are water-repelling and can withstand being incorporated into raindrops, leading to prolonged atmospheric suspension. Hydrophilic polymers, such as nylon, can absorb water and become more susceptible to deposition through rain. Additionally, microplastics that have rough

or irregular surfaces tend to agglomerate with other particles in the air and thereby increase their prospects of being scavenged by rain droplets. Agglomeration has the potential to impact the rate and efficiency of wet deposition (Zhang et al., 2020).

4.14 Proximity to Sources of Pollution and Land Use Effects

Regions situated near industrial hubs, busy highways, and urban centers tend to experience greater microplastic deposition, attributed to the dense presence of plastic particles in the air (Wright et al., 2020). For example, a study estimates that individual urban stormwater outfalls discharged between 1.9 million to 9.6 billion microplastics per rain event (Ross et al., 2023). Thus, rainfall events in these regions are more prone to leach out and scavenge microplastics from the atmosphere, thus resulting in elevated deposition compared to remote areas. Conversely, rural precipitation events will have a lower microplastic concentration, with the exception of those regions found downwind of urban sources of emission (Thendo Mutshekwa et al., 2025). For instance, agricultural ecosystems will more likely accumulate plastic film debris, synthetic fiber bits, and plastic-component fertilizers, owing to the utilization of plastic-covered crops and irrigation systems within agriculture.

Land use types have a profound impact on the storage and transport of deposited microplastics following precipitation. In urban areas, the availability of impervious surfaces like sidewalks and roads enhances rainwater runoff laden with microplastics into storm drains, thereby resulting in the accumulation of microplastics in aquatic ecosystems like rivers, lakes, and oceans (Cakaj et al., 2023). However, natural systems like grasslands and forests have the potential to serve as effective natural filters, entrapment deposited microplastics in soil, plant matter, and sedimentary layers.

4.15 Determinants of Hydrological Microplastic Contamination

In ponds lacking dam structures, natural hydrodynamic forces primarily dictate the transport, distribution, and deposition of microplastics. Compared to rivers and streams, where flowing water persistently carries microplastics downstream, ponds experience slower water flow, thereby enabling increased microplastic retention. Thus, ponds act as a body of water that will retain historical microplastic pollution. In the absence of a dam to manage water levels and outflow, ponds depend on surface currents induced by wind, precipitation, and seasonal patterns to affect water movement. That means the plastic pollution examined in ponds without dams like the ones on our location site are akin to landfills. Plastic pollution that is deposited into the water bodies will either settle into the water column until they settle onto the pond floor or they will be

resuspended and ejected from the water body. Thus, the microplastic material gathered and observed in our results are a mixture of microplastics that were recently deposited or were already inside the water column.

This implies that the less dense, more buoyant microplastics such as fibers have a tendency to stay close to the water surface, where they can readily be re-transported by wind and slight water motion. The denser microplastics such as polyvinyl chloride (PVC) or polyethylene terephthalate (PET) fragments or beads sink rapidly and become integrated into the sediments of the ponds (Ben Stride et al., 2024). Due to the lack of a dam the ponds do not undergo artificial water level changes, one parameter that can influence the resuspension of microplastics. Nonetheless, natural occurrences like intense rainfall or high winds can lead to localized turbulence, which can briefly suspend microplastics deposited into the water column. Likewise, the ponds are not enclosed, and birds and other organisms could cause distribution in the water causing microplastic resuspension. Seasonal changes, including differences in rates of evaporation and groundwater input, also influence the fate of microplastics in the pond ecosystem (Ben Stride et al., 2024).

4.16 Properties of Microplastics and Their Impact on Transportation

The morphology, mass density, and size of microplastic particles significantly influence their mobility in a pond ecosystem. Plastic fibers and thin films tend to be the most mobile due to their buoyant nature, which keeps them suspended in the water column for a long time. These microplastics are typically generated from the degradation of synthetic fabrics, breakdown of fishing line, or decomposition of plastic packaging. However, larger plastic debris such as beads, pellets, and fragments sink and settle in the sediments of the ponds, causing long-term plastic pollution of the benthic environment. These microplastics tend to be formed as a primary microplastic material in beauty supplies or industrial manufacturing.

Polymer hydrophobicity is a further factor in microplastic behavior. Hydrophobic plastics, including polypropylene and polyethylene, will not take on water and may potentially float on the surface, whereas hydrophilic polymers, such as certain types of nylon, will adsorb water and eventually sink. Over time, the formation of biofilm, the accumulation of microorganisms on plastic surfaces, can drag floating microplastics down with greater density and cause them to sink to the bottom of the pond (Kaiser et al., 2017). The ponds tend to have algae blooms periodically; these events in which algae cover a significant portion of the pond could act as an avenue in which microplastic become concentrated in the pond (Mendrik et al.,

2023). It is important to mention that biofilms are generated due to colonization of several different types of organisms such as bacteria, fungi, and other organisms. This process alters the time microplastics are suspended in the water column, and thus their ecological interactions. The potential growth of biofilms affecting older microplastic positions in the water column could indicate that the microplastics gathered on the surface of the pond are younger.

Ponds without dams are usually sited in agricultural, urban, or semi-natural environments, which implies that microplastic input is of varied sources (Huang et al., 2024). Among the major routes of entry of microplastics into ponds is through stormwater runoff, where rainfall facilitates the movement of synthetic fibers, tire wear particles, and plastic debris from roads and urban surfaces into the pond. In agricultural settings, plastic mulch films, irrigation pipes, and plastic-coated fertilizers contribute microplastic contaminants, particularly during heavy rainfall that results in surface runoff. Atmospheric deposit is another important source of pond pollution. The ponds being investigated are exposed to both the sources typically found in both urban and agricultural settings. However, it is important to note the area is not currently undergoing any agricultural activities and the horses and cattle are no longer directly interacting with the ponds. The potential of historical contamination originates from these agricultural activities. Airborne microplastics gradually settle on the water surface, particularly in regions surrounding roadways, industrial areas, or urban areas. Unlike rivers or lakes, which have high rates of inflow and outflow, ponds retain water for extended periods, leading to the gradual buildup of microplastics in the environment (Huang et al., 2024).

Microplastics in ponds have a distinct settlement and accumulation pattern due to their limited water movement (Liu, Vianello, et al., 2019). The smaller and less dense particles such as fibers will circulate for longer periods of time before settling, while the larger and heavier fragments quickly sink to the bottom of the sediment. Depth and pond bottom type dictate microplastic accumulation, where muddier substrates trap more particles than sandy or rocky substrates (Liu, Vianello, et al., 2019).

The vegetation in the pond can act as a natural filter that catches microplastics before they enter sediments (Leppänen et al., 2022). Aquatic plants and algae have a tendency to capture floating microplastics and suspend them for longer periods of time in the water or make them degrade slowly through microbial activity. Upon rotting of plants or disruption caused by fish mobility, the previously captured microplastics are released into the water, resulting in persistent contamination (Leppänen et al., 2022).

4.17 Biological Uptake and Trophic Transfer in Pond Ecosystems

Ponds provide habitats for numerous aquatic organisms, most of which interact with microplastics in various ways. Filter-feeder organisms like plankton, freshwater mussels, and small invertebrates are more vulnerable to the ingestion of microplastics, which is a consequence of their feeding mechanism (Kudla et al., 2024). Since these organisms employ water filtration as a means of obtaining nutrients, they end up ingesting microplastic fibers and particles, thus causing adverse health impacts like decreased digestive efficiency and inflammation.

Aquatic life in ponds can ingest microplastics either directly by mistaking them for food or indirectly through predation of contaminated organisms. This ingestion can lead to gastrointestinal blockages, reduced feeding activity, and the potential accumulation of toxic additives that leach from the plastics (Hale Tatlı et al., 2025). Amphibians, such as frogs and salamanders, are particularly vulnerable to microplastics, especially during their early developmental stages when they are highly dependent on aquatic environments for survival (Hale Tatlı et al., 2025).

One critical factor to consider when discussing biological influences on our results is that most of the ponds in this study are not naturally occurring, and as a result, the fish populations are stocked. However, the other organisms observed in the ponds are part of the natural flora and fauna, moving in and out of the environment. Regardless of whether the fauna is natural or introduced, the interactions between organisms and microplastics create a unique dispersion effect. The biological activities of these organisms can either concentrate or disperse microplastic material within the ecosystem. For example, certain fish and other aquatic organisms in the pond may disturb the bottom sediments, releasing microplastic particles that had previously settled, thus increasing the microplastic concentration in the water column above (Pukos et al., 2023).

In addition, waterbirds and bird species that rely on pond ecosystems can ingest microplastics through surface feeding or by consuming fish and invertebrates contaminated with plastic particles. This ingestion can lead to bioaccumulation and trophic transfer, where microplastics move up the food web, potentially affecting higher-level predators that feed on species found within these pond ecosystems (Bhatt & Chauhan, 2022). The movement of plastic material throughout the trophic system or food chain could serve as a direct mechanism for microplastics to persist in aquatic ecosystems for prolonged periods or contribute to the introduction of new plastic material into the system. In the case of the ponds and freshwater

systems observed in this study, several bird species, including migrating Canadian geese, swans, and various predatory birds, utilize these ponds as breeding grounds or seasonal habitats. Through their typical biological activities, these birds could either contribute to or disrupt microplastic contamination within the system by adding or removing plastic material (Athey et al., 2020).

4.18 Microplastic Contamination of Groundwater

Groundwater pollution with microplastics is an increasing concern, especially in karst aquifers, which are highly permeable limestone landscapes that facilitate the easy infiltration and passage of water (Panno et al., 2019). In East Tennessee, numerous undammed ponds exist in karst landscapes, where the surface water and groundwater systems are highly interconnected. Compared to confined aquifers, where there is sluggish flow of water through fine-grained sediments that can filter out impurities, karst aquifers are defined by their fractures, sinkholes, and subsurface drainage that provide rapid flow of water—and any possible pollutants—through the subsurface (Panno et al., 2019). Consequently, karst systems possess heightened susceptibility to surface microplastic pollution, which can enter the aquifer through direct infiltration of water, stormwater runoff, and wastewater effluents. Understanding how microplastics enter, flow through, and persist in karst groundwater is vital to the evaluation of their long-term ecological impacts, particularly in regions where groundwater is a primary source of drinking water (Balestra et al., 2024). Karst aquifers are found to be more susceptible to microplastic contamination because they have rapid recharge processes.

One of the primary routes for microplastic entry into groundwater in karst systems is via the infiltration of surface water. In karst areas, ponds are commonly hydrologically linked to groundwater via sinkholes, fractures, and solution channels, meaning that any microplastics in the pond water can freely move into the subsurface zone (Elvira Colmenarejo Calero et al., 2024). The operation of these connections is highly improved during periods of high rainfall, thereby promoting the downward movement of microplastics into the aquifer. One other significant route of contamination is via soil percolation, where microplastics deposited on the soil surface due to atmospheric deposition, agricultural runoff, or plastic waste degradation are transported downwards by rainwater percolating through the soil (Elvira Colmenarejo Calero et al., 2024). Unlike other aquifer types that depend on thick soil cover and permeable sediments to filter out contaminants, karst systems frequently lack or have limited soil cover, thus permitting the rapid movement of microplastics through natural filter systems and into the aquifer. The

ponds in this study do not have sealed bottoms and as a result have a direct connection to the water and table and the groundwater aquifer. Apart from the invasion process via pond water and percolation through soil, sinkholes and swallets are direct pathways for the karst groundwater to transport microplastics (Elvira Colmenarejo Calero et al., 2024).

The properties found within the limestone-prevailing landscape of East Tennessee serve as accelerated pathways for contamination through the conveyance of stormwater and surface runoff directly into underground streams. By bypassing the natural attenuation mechanisms that minimize contamination in non-karst aquifers, it provides an effective means for extensive underground water channel transport of microplastics. Two septic systems are located on the property near pond one and pond two. The septic tank for the larger house is closer to pond 2 while the septic tank for the smaller house is farther away. Leach fields with septic systems also pollute groundwater with microplastics since wastewater laden with synthetic fibers from laundry wastewater, plastic debris from personal care products, and microbeads from washing products enters the aquifer (Panno et al., 2019). In rural settings, where groundwater irrigation is frequent in agriculture, even polluted water from ponds or streams with microplastics can be pumped through irrigation wells and reintroduced plastic material into the subsurface system. In addition, excessive groundwater extraction can alter natural flow regimes and pull microplastics deeper into the aquifer. Microplastic transport in karst aquifers differs significantly from transport in traditional sedimentary aquifers due to the rapid movement of groundwater and the lack of natural filtration (Panno et al., 2019).

Instead of percolating slowly through permeable rock or sediment layers, karst groundwater moves through a network of subsurface conduits, caves, and fractures, allowing contaminants to move quickly and unpredictably. In the case of the study area the closest cave is located about one mile away. This produces fast and widespread microplastic transport, with contaminant concentrations fluctuating with precipitation events, recharge conditions, and seasonal water table fluctuations. Unlike traditional aquifers that offer natural filtration by clay and organic material, karst systems do not have these barriers. Therefore, microplastics can persist in groundwater for extended durations (Viaroli et al., 2022). Furthermore, the differences in aquifer geometry and dissolution characteristics cause the formation of stagnant water zones where microplastics settle, forming reservoirs of contamination that can be resuspended during storm events or when groundwater is withdrawn. Once microplastics have entered a karst aquifer, their fate is controlled by their size, density, surface properties, and chemical

composition (Viaroli et al., 2022).

Microplastics with lower density and greater buoyancy, such as polyethylene and polypropylene fibers, will persist suspended in the water column, moving quickly through the aquifer and appearing at springs or drinking water wells. More dense plastics particles, however, such as polyvinyl chloride (PVC), polyethylene terephthalate (PET) fragments, and microbeads, sink and are trapped in sedimentary pockets in caves, fractures, and underground lakes (Hoang et al., 2025). These microplastics can build up over time, remaining in the groundwater for long durations prior to being remobilized by water level fluctuations caused by seasons or intense rainfall. The microplastics observed in the groundwater show a very heterogeneous mixture on the different types of microplastics, the groundwater microplastic exhibited all types of microplastic particles similarly to the soil analyzed. The development of biofilms on the surfaces of plastics, where microorganisms colonize plastic particles, can also affect their transport. Plastics covered in biofilm can adhere to aquifer walls, become embedded in sediment beds, or encounter mineral deposits, which can possibly change microbial populations and groundwater quality (Hoang et al., 2025).

The intimate connection between groundwater and surface water in karst areas implies that microplastic pollution in ponds has a direct impact on groundwater quality. Under heavy rainfall conditions, the water level of ponds can rise rapidly, pumping dirty surface water into sinkholes and subsurface drainage networks, discharging large amounts of microplastics into the aquifer. Seasonal drying and groundwater pumping can further facilitate microplastic transport because, as the water level in ponds drops, microplastics become concentrated in the remaining water, and thus the potential infiltration is higher once recharge occurs again. Furthermore, spring flow in karst aquifers is a process of export, where groundwater emerges and subsequently introduces microplastics into surface water bodies such as streams, rivers, or wetlands, thereby establishing additional routes for plastic pollution in the larger ecosystem. Anthropogenic activities impose profound influences on the levels of microplastic pollution in karst groundwater.

In East Tennessee agricultural sectors, the utilization of plastic mulch film, irrigation pipes, and polymer-coated fertilizers contributes to the input of microplastic contaminants that leach into groundwater via sinkholes and soil erosion. Similarly, stormwater runoff from roads, parking lots, and industrial sites spreads tire wear particles, synthetic polymer dust, and plastic debris into karst units, providing them ready entry to groundwater with minimal filtering.

Leachate from septic systems, particularly in rural areas where wastewater treatment is decentralized, releases plastic fibers and other anthropogenic particles into the groundwater through percolation and exacerbates contaminant concentrations. Disposal of plastics in sinkholes, abandoned wells, or limestone outcrops through illegal dumping has the potential to directly pollute the groundwater because the plastics degrade slowly and release microplastic particles into the sub-surface.

Microplastic contamination of groundwater is a concern for safe drinking water, aquatic ecosystem health, and environmental sustainability in the long term (Hoang et al., 2025). Due to the susceptibility of karst aquifers to contamination, enhanced monitoring and mitigation measures need to be implemented to mitigate microplastic pollution and safeguard groundwater resources in these sensitive environments. The issue of microplastic pollution in terrestrial ecosystems is gaining increasing attention, especially in agricultural and natural habitats where plastic particulates are being deposited increasingly (Hoang et al., 2025).

4.19 Microplastic Contamination of Soil

In East Tennessee, most of the land surrounding freshwater ponds and karst groundwater recharge zones is red clay soil, which is famous for its fine texture, high iron content, and low permeability. Contrasting with loam or sandy soil, beneath which water penetrates easily and through which pollutants easily pass, the red clay type of soil has high water and pollutant retention properties, which influence deposition, transport, and eventually get release of microplastics to aquatic environments (Vijay Kumar Aralappanavar et al., 2024). The fate of microplastics in red clay soil is influenced by a combination of factors that include soil characteristics, external inputs, biotic interactions, and hydrological processes, which collectively regulate the environmental destiny of these contaminants (Vijay Kumar Aralappanavar et al., 2024). Red clay soil possesses a high capacity to adsorb and retain microplastics, which may be due to its minute particle size and compact nature, leading to low permeability and reduced water infiltration rates (Xie et al., 2023).

When deposited on the soil surface, microplastics tend to reside in the surface layers for longer durations, contrary to sandy soils where they enter deeper layers with ease. Red clay's coarseness facilitates widespread adsorption of microplastic particles and hence limits their mobility, enabling them to persist in the soil matrix. Furthermore, the red clay soils' high content of iron and aluminum oxide facilitates electrostatic attraction with plastic, more so synthetic fibers and microparticles. This attraction results in stable microplastic-soil aggregate formation

that inhibits further movement. Nevertheless, under dry conditions, red clay soil becomes subject to cracking, and as such, cracks can facilitate deeper microplastic movement into the subsurface during subsequent water infiltration, thus providing possible pathways for groundwater contamination. Microplastics are introduced into red clay soil through multiple means, such as agricultural activities, atmospheric deposition, stormwater runoff, and plastic degradation (Uwamungu et al., 2022). Red clay's low permeability and fine particle size facilitate the retention of microplastics in the topsoil, preventing leaching but leading to long-term buildup.

Most East Tennessee farming operations use plastic mulch films, irrigation tubing, and polymer-coated fertilizers, which all degrade over time and produce microplastics into the soil. Moreover, biosolids and manure-based fertilizers—usually obtained from wastewater treatment facilities—can introduce synthetic fibers and microplastic debris into the soil. Atmospheric deposition is also involved in the phenomenon, where atmospheric microplastics settle on the soil surface, especially the open fields and farmlands where they become incorporated into the surface layers through mechanisms such as rainfall, wind action, or tillage (Uwamungu et al., 2022). Stormwater runoff also mobilizes microplastics from roads, urban locations, and fresh-water ponds to the soils in the surroundings, especially where pond overflow goes into nearby farmlands or low areas of drainage. In rural regions, inadequate disposal of plastic materials, exemplified by open incineration or ineffective management of landfills, significantly adds to soil pollution, as plastics degrade over time and emit smaller particles into the surrounding environment. Despite the capacity of red clay soil to retain microplastics efficiently, numerous natural processes can nonetheless promote their dispersion (Uwamungu et al., 2022).

Under heavy rainfall events, surface runoff and erosion may resuspend microplastics, particularly in agricultural fields, floodplains, and slopes, where runoff carries sediment and plastic particles into adjacent water bodies. Since red clay is fine-grained, soil particles and microplastics can easily be suspended in runoff water, leading to the accumulation of pollutants in ponds, streams, and karst groundwater recharge zones. Additionally, soil shrinkage and cracking during the dry season can create preferential flow paths, through which microplastics are able to bypass the normally slow rates of infiltration and travel deeper into the soil with the next influx of water. Plant roots, earthworms, and soil-dwelling insects also play a role in the transport of microplastics, as biological activity redistributes plastic particles through mixing with deeper layers of soil or entrapping them in root networks.

Chapter 5. Summary, Limitations and Conclusions

Our investigation into environmental microplastic contamination in semi-urbanized farmland in Blount County, Tennessee, revealed a diverse distribution of microplastic types, including fibers, fragments, films, microbeads, and pellets. These microplastics were identified across five distinct environmental media: atmospheric deposition, groundwater, precipitation from Hurricane Helene (September 2024), soil, and surface water. Among these, microplastic fibers were the most frequently observed type across all samples. This finding is consistent with existing literature and aligns with the widespread generation of microplastic fibers through urban and human activities such as textile use and laundering.

Fragments were the second most common microplastic type detected, likely resulting from the breakdown of larger plastic materials. Their presence in media such as atmospheric deposition and precipitation may stem from the fragmentation of low-density plastic, which are then suspended in the air and deposited across the landscape. These environments—characterized by lower-density plastic pollution—consistently showed high concentrations of fibers, fragments, and films, all of which are lightweight and easily transported. In our methodology, fragments were defined as irregularly shaped plastic particles that did not lay completely flat on the filter paper; flat pieces were categorized as films. While some ambiguity may exist between these classifications, especially when distinguishing between fibers and thin fragments, careful microscopy and observational criteria were used to minimize misidentification.

The most diverse microplastic profiles were found in hydrological reservoirs, specifically groundwater and surface water samples. These media contained fibers and fragments as well as films, microbeads, pellets, and foams. This diversity may result from the dynamic exchange between surface water and shallow groundwater, allowing microplastics to move between systems. Our data supports this hypothesis, with strong correlations in both microplastic types and colors between groundwater and surface water samples. However, differences were also observed, likely due to the slower infiltration and transport rates associated with groundwater, which can delay microplastic movement compared to surface water systems.

Ponds—our primary surface water reservoirs—acted as sinks for microplastic accumulation, allowing for the long-term storage of denser polymer types. This is evident in the higher prevalence of pellets, fragments, and microbeads in these samples, which would be more likely to settle and persist in static water bodies. The longer residence time of microplastics in

ponds increases the likelihood of sampling higher density microplastics that might otherwise sink or degrade in flowing systems.

5.1 Notable Observations: Purple Microplastics and Color Distribution

A striking trend observed in our study was the consistent presence of purple plastic fibers and purple-colored microplastic particles across multiple environmental media. These were most concentrated in surface water samples, with moderate presence in groundwater, and a notable abundance in both Hurricane Helene precipitation and dry atmospheric deposition samples. This suggests a likely localized source of contamination, possibly from laundry-related fiber shedding, a nearby school district, or community use of purple-colored plastic materials. The widespread appearance of this color across different samples point to recurring, regional input rather than isolated contamination events.

Beyond the purple fibers, there was also strong continuity in microplastic color distribution between reservoirs. For example, the colors present in atmospheric or precipitation samples often mirrored those found in surface water, though surface water showed the greatest overall variation. This variation is expected, as surface water likely serves as a long-term reservoir for microplastic accumulation, offering a temporal record of pollution trends, whereas atmospheric and precipitation samples capture short-term deposition snapshots.

5.2 Chemical Composition

The chemical composition of microplastics detected in our environmental samples varied considerably. Using the PSR+ spectroradiometer, we were able to identify multiple types of plastic polymers, including low-density polyethylene (LDPE), nylon, polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) across several sample types. In certain samples, we observed absorption features that appeared to be a mixture of LDPE and nylon. These signatures exhibited characteristics of both Nylon 12 and LDPE, but due to spectral overlap and signal ambiguity, we could not conclusively determine whether they represented a single new material or a combination of the two.

In every environmental sample analyzed, we identified some form of microplastic contamination using spectroradiometer measurements. For dry atmospheric deposition, two primary microplastic types were detected: LDPE and nylon. LDPE was most associated with thin films, which were observed as clear or shiny plastic materials under the microscope. Samples rich in these films consistently matched LDPE spectral signatures. In contrast, samples with a higher concentration of fibers correlated more strongly with nylon absorption features. These

nylon fibers may originate from nearby fishing activity or textile production, or possibly from residential use of nylon-based materials that degrade and become airborne over time.

In the groundwater samples, we again detected LDPE and PVC. The LDPE signals likely originated from observed plastic films, which were confirmed visually and spectrally. The PVC signals were strongest in samples containing microplastic fragments rather than fibers. This may be due to contamination from aging PVC infrastructure such as well piping. However, since PVC was also observed in surface water and soil samples, we cannot definitively attribute its presence to well components alone.

Precipitation samples exhibited a mixture of both nylon and LDPE. Samples with more plastic films produced stronger LDPE signals, while samples with more fibrous material tended to have more absorption features that correlated with nylon. The most diverse range of plastic types, both in chemical composition and physical form, was observed in the soil and surface water samples. Soil samples contained PVC, PS, PP, and LDPE, and despite having a lower numerical particle count, they included a greater variety of dense microplastic types such as fragments, foams, and pellets. These high-density particles produce stronger, clearer absorption signals due to less interference and greater surface area.

In surface water, we detected three main plastic types: nylon, LDPE, and PVC. LDPE was commonly found in association with both films and fibers. PVC was generally associated with white or clear fragments, while green microplastic fibers—frequently found in surface water—showed strong nylon signatures. We believe many of these nylon fibers originated from fishing lines, which are typically nylon-based and often green in color. This hypothesis is supported by the common presence of fishing activity at sample sites. Even after hot needle testing, these fibers retained their green coloration and structural integrity, suggesting they are composed of durable nylon polymers.

5.3 Limitations

The effectiveness of the contact probe method is highest in soil samples, where we detected the broadest range of polymer types. However, the method’s accuracy diminishes when samples contain a high concentration of microplastic fibers. Fiber-based microplastics often fail to generate a strong enough signal to exceed the threshold required for confident identification. For a polymer to be classified, its spectral signature must meet predefined reflectance criteria at specific wavelengths and fit within the known standard library. Signals that were ambiguous or too weak were excluded from analysis, meaning that our current methodology may underreport

the true extent of microplastic contamination.

The contact probe operates by measuring reflectance within a fixed field of view. The stronger the concentration and surface area of a specific polymer within that view, the more clearly its spectral signature is detected. Dense particles like fragments, films, and pellets have greater surface area and pixel density, making them easier to detect than thin, scattered fibers. As a result, this methodology performs best in samples with a higher concentration of dense microplastic types. Soil samples, which generally contained more fragments and pellets, consistently produced stronger signals and more distinct absorption features when compared to standards, making soil the most reliable medium for detection with this approach.

To minimize bias, we implemented several procedural safeguards. Each sample was measured multiple times, often by different individuals, and always compared against known standards to ensure consistent and accurate microplastic identification, both in terms of type and chemical composition. Despite these efforts, the process of building the PLSR models involved numerous steps where human error could have occurred, potentially affecting either the environmental sampling results or the model outputs themselves. For example, during the preparation of the soil and microplastic mixtures used for the PLSR model, several manual tasks were involved, including grinding, weighing, and combining the materials. At any of these steps, it is possible that a slight overestimation or underestimation of plastic content could have occurred, thereby introducing outliers or skewing the dataset. Additionally, all environmental samples were collected manually, which introduces the possibility of sample bias—whether due to convenience, accessibility of collection locations, or subconscious selection of areas that appeared more promising. Similarly, the identification of microplastics under a microscope is inherently subjective, especially when classifying plastic type or color, as these categories can vary significantly between researchers and studies depending on the classification criteria used.

While no experimental process is entirely free of human error, we believe the safeguards implemented—combined with repeated validation and cross-checking—minimized its impact. Given the consistency in our results and the strong performance of the PLSR models, we do not believe that human error played a significant or detrimental role in either the environmental detection of microplastics or the construction of the models themselves.

5.4 Conclusions

The overall conclusion of our study is that the PSR+ spectroradiometer can be effectively used not only in mining and geological applications, but also in the identification of microplastic

materials across various environmental media. Although the PSR+ is currently employed in fields such as wildlife and fisheries management, its use in microplastic detection has been largely unexplored. Through the development and application of PLSR (Partial Least Squares Regression) models, we have demonstrated that the PSR+ spectroradiometer can identify microplastic materials—often invisible to the naked eye—in soil systems.

This finding suggests significant potential for the PSR+ in agricultural sectors, especially in environments where the sources and movement of plastics are relatively well-controlled. For instance, agricultural systems that routinely use plastic mulches—both biodegradable and conventional—could benefit from the PSR+ for non-destructive detection of residual plastic contamination in soils. However, there are limitations. One critical constraint is the need for a comprehensive spectral library of known plastic standards for accurate comparison with environmental samples. Additionally, the PSR+ struggles to detect the most abundant type of microplastic: fibers. This is primarily due to the limited pixel resolution available through the contact probe attachment, which was the only detection method used in this study.

The newly developed methodology demonstrates the applications and potential uses of the PSR+ spectrometer for microplastic analysis and identification in soils and other environmental mediums. However, our findings suggest that the contact probe may not be ideal for all environmental contexts. One limitation of the contact probe is its narrow viewing window, which can lead to the oversight of significant microplastic contamination if the sample falls outside the probe's measurement range. Additionally, the portable spectroradiometer, when used with the contact probe, can only capture surface-level data, as the light does not penetrate deeply into the soil. This limitation means that the spectrometer can only detect microplastic contamination in the upper layers of soil during field measurements. Consequently, scientists and researchers using this or similar devices should complement field data with environmental samples for lab analysis. Laboratory analysis could involve examining the entire soil profile for microplastic contamination or focusing on extracting microplastics from the soil for easier measurement using either the contact probe or another attachment compatible with the portable spectrometer.

Despite these challenges, our results show that the PSR+ contact probe is capable of detecting plastic fragments and higher-density polymeric materials in soil systems. It also proved effective at identifying these polymers directly from filter papers following vacuum filtration, provided the microplastic are present in sufficient concentration within the probe’s field of view.

In essence, the PSR+ is most effective when it can “see” the plastic—either visibly or through concentrated accumulation in the sample. This makes the technology especially suitable for areas where prior knowledge of plastic contamination exists. The PSR+ offers a portable, non-destructive method for in-field microplastic detection, with potential for real-time screening of both macro plastics and microplastics. Furthermore, measurements collected with the PSR+ can be paired with lab-based techniques such as FTIR, pyrolysis-GC/MS, or thermal degradation analysis for more detailed chemical characterization.

Overall, we conclude that the PSR+ spectroradiometer has strong potential as a field-deployable tool for microplastic detection, particularly in soil systems with high-density polymer contamination. Furthermore, the results from the environmental section of this study show that PSR+ has the potential for identification of plastic polymers in very small quantification. This thesis has shown that the PSR+ can be used with a contact probe for studies for chemometric modeling in the future with adequate results. With the continued development of PLSR models, data collected in the field can be processed in-house for rapid and reliable microplastic identification and quantification. The PSR+ has a bright future in microplastic research whether it be through direct measurements taken in the field with a contact probe or laboratory-based studies using a benchtop attachment. Furthermore, the ability to mount the PSR+ on a drone positions the PSR+ as a promising instrument for expanding the toolkit of environmental microplastic research.

References

Abbasi, S. (2021). Microplastics washout from the atmosphere during a monsoon rain event. *Journal of Hazardous Materials Advances*, *4*, 100035. https://doi.org/10.1016/j.hazadv.2021.100035

Abbasi, S., Keshavarzi, B., Moore, F., Turner, A., Kelly, F. J., Dominguez, A. O., & Jaafarzadeh, N. (2019). Distribution and potential health impacts of microplastics and microrubbers in air and street dusts from Asaluyeh County, Iran. *Environmental Pollution*, *244*, 153–164. https://doi.org/10.1016/j.envpol.2018.10.039

Aeschlimann, M., Li, G., Kanji, Z. A., & Mitrano, D. M. (2022). Potential impacts of atmospheric microplastics and nanoplastics on cloud formation processes. *Nature Geoscience*, *15*(12), 967–975. https://doi.org/10.1038/s41561-022-01051-9

Allen, S., Allen, D., Baladima, F., Phoenix, V. R., Thomas, J. L., Le Roux, G., & Sonke, J. E. (2021). Evidence of free tropospheric and long-range transport of microplastic at Pic du Midi Observatory. *Nature Communications*, *12*(1). https://doi.org/10.1038/s41467-021-27454-7

Allen, S., Allen, D., Phoenix, V. R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., Binet, S., & Galop, D. (2019). Atmospheric transport and deposition of microplastics in a remote mountain catchment. *Nature Geoscience*, *12*(5), 339–344. https://doi.org/10.1038/s41561-019-0335-5

Ashkan Jahandari. (2023). Microplastics in the urban atmosphere: sources, occurrences, distribution, and potential health implications. *Journal of Hazardous Materials Advances*, *12*, 100346–100346. https://doi.org/10.1016/j.hazadv.2023.100346

Athey, S. N., Albotra, S. D., Gordon, C. A., Monteleone, B., Seaton, P., Andrady, A. L., Taylor, A. R., & Brander, S. M. (2020). Trophic transfer of microplastics in an estuarine food chain and the effects of a sorbed legacy pollutant. *Limnology and Oceanography Letters*, *5*(1), 154–162. https://doi.org/10.1002/lol2.10130

Balestra, V., Galbiati, M., Lapadula, S., Zampieri, V., Cassarino, F., Gajdošová, M., Barzaghi, B., Manenti, R., Ficetola, G. F., & Bellopede, R. (2024). Microplastic pollution calls for urgent investigations in stygobiont habitats: A case study from Classical karst. *Journal of Environmental Management*, *356*, 120672. https://doi.org/10.1016/j.jenvman.2024.120672

Barrows, A. P. W., Neumann, C. A., Berger, M. L., & Shaw, S. D. (2017). Grab vs. neuston tow net: a microplastic sampling performance comparison and possible advances in the field. *Analytical Methods*, *9*(9), 1446–1453. https://doi.org/10.1039/C6AY02387H

Ben Stride, Abolfathi, S., Bending, G. D., & Pearson, J. (2024). Quantifying microplastic dispersion due to density effects. *Journal of Hazardous Materials*, *466*, 133440. https://doi.org/10.1016/j.jhazmat.2024.133440

Ben-Dor, E. (1997). The reflectance spectra of organic matter in the visible near-infrared and short wave infrared region (400–2500 nm) during a controlled decomposition process. *Remote Sensing of Environment*, *61*(1), 1–15. https://doi.org/10.1016/s0034-4257(96)00120-4

Bergmann, M., Mützel, S., Primpke, S., Mine Banu Tekman, Trachsel, J., & Gerdts, G. (2019). *Microplastic in snow from European and Arctic sites*. https://doi.org/10.1594/pangaea.901447

Bhatt, V., & Chauhan, J. S. (2022). Microplastic in freshwater ecosystem: bioaccumulation, trophic transfer, and biomagnification. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-24529-w

Bhuyan, Md. S. (2022). Effects of Microplastics on Fish and in Human Health. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.827289

Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., & Sukumaran, S. (2020). Plastic rain in protected areas of the United States. *Science*, *368*(6496), 1257–1260. https://doi.org/10.1126/science.aaz5819

Brahney, J., Mahowald, N., Prank, M., Cornwell, G., Klimont, Z., Matsui, H., & Prather, K. A. (2021). Constraining the atmospheric limb of the plastic cycle. *Proceedings of the National Academy of Sciences*, *118*(16). https://doi.org/10.1073/pnas.2020719118

Busse, H. L., Ariyasena, D. D., Orris, J., & Freedman, M. A. (2024). Pristine and Aged Microplastics Can Nucleate Ice through Immersion Freezing. *ACS ES&T Air*. https://doi.org/10.1021/acsestair.4c00146

Cakaj, A., Lisiak-Zielińska, M., Kinga Drzewiecka, Budka, A., Borowiak, K., Drapikowska, M., Arbnore Cakaj, Erjon Qorri, & Piotr Szkudlarz. (2023). Potential Impact of Urban Land Use on Microplastic Atmospheric Deposition: A Case Study in Pristina City, Kosovo. *Sustainability*, *15*(23), 16464–16464. https://doi.org/10.3390/su152316464

Corradini, F., Bartholomeus, H., Huerta Lwanga, E., Gertsen, H., & Geissen, V. (2019). Predicting soil microplastic concentration using vis-NIR spectroscopy. *Science of the Total Environment*, *650*, 922–932. https://doi.org/10.1016/j.scitotenv.2018.09.101

De Falco, F., Di Pace, E., Cocca, M., & Avella, M. (2019). The Contribution of Washing Processes of Synthetic Clothes to Microplastic Pollution. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-43023-x

Dóra Zacháry, Tibor Filep, Jakab, G., Ringer, M., Réka Balázs, Tibor Németh, & Szalai, Z. (2022). The effect of mineral composition on soil organic matter turnover in temperate forest soils. *Journal of Soils and Sediments*, *23*(3), 1389–1402. https://doi.org/10.1007/s11368-022-03393-8

Dris, R., Gasperi, J., Saad, M., Mirande, C., & Tassin, B. (2016). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? *Marine Pollution Bulletin*, *104*(1-2), 290–293. https://doi.org/10.1016/j.marpolbul.2016.01.006

Duis, K., & Coors, A. (2016). Microplastics in the Aquatic and Terrestrial environment: Sources (with a Specific Focus on Personal Care products), Fate and Effects. *Environmental Sciences Europe*, *28*(1). https://doi.org/10.1186/s12302-015-0069-y

Dümichen, E., Barthel, A.-K., Braun, U., Bannick, C. G., Brand, K., Jekel, M., & Senz, R. (2015). Analysis of polyethylene microplastics in environmental samples, using a thermal decomposition method. *Water Research*, *85*, 451–457. https://doi.org/10.1016/j.watres.2015.09.002

Elvira Colmenarejo Calero, Manca Kovač Viršek, & Mali, N. (2024). Microplastics in Groundwater: Pathways, Occurrence, and Monitoring Challenges. *Water*, *16*(9), 1228–1228. https://doi.org/10.3390/w16091228

Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., Galgani, F., Ryan, P. G., & Reisser, J. (2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. *PloS ONE*, *9*(12), e111913. https://doi.org/10.1371/journal.pone.0111913

Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., & Stohl, A. (2020). Atmospheric transport is a major pathway of microplastics to remote regions. *Nature Communications*, *11*(1). https://doi.org/10.1038/s41467-020-17201-9

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever

made. *Science Advances*, *3*(7).

Habib, D., Locke, D. C., & Cannone, L. J. (1998). Synthetic Fibers as Indicators of Municipal Sewage Sludge, Sludge Products, and Sewage Treatment Plant Effluents. *Water, Air, and Soil Pollution*, *103*(1/4), 1–8. https://doi.org/10.1023/a:1004908110793

Hale Tatlı, Kenan Gedik, & Abdullah Altunışık. (2025). Distribution of microplastics in tadpoles, adults, and habitats of three water frogs of Pelophylax spp. *Environmental Sciences Europe*, *37*(1). https://doi.org/10.1186/s12302-025-01065-1

Hale, R. C., Seeley, M. E., La Guardia, M. J., Mai, L., & Zeng, E. Y. (2020). A Global Perspective on Microplastics. *Journal of Geophysical Research: Oceans*, *125*(1). https://doi.org/10.1029/2018jc014719

Han, X., Pan, B., Li, D., Liu, X., Liu, X., Hou, Y., & Li, G. (2024). Heterogenization of microplastic communities in lakes of the Qinghai-Tibetan Plateau driven by tourism and transport activities. *Journal of Hazardous Materials*, *477*, 135255–135255. https://doi.org/10.1016/j.jhazmat.2024.135255

Hansen, A. M., Kraus, T. E. C., Pellerin, B. A., Fleck, J. A., Downing, B. D., & Bergamaschi, B. A. (2016). Optical properties of dissolved organic matter (DOM): Effects of biological and photolytic degradation. *Limnology and Oceanography*, *61*(3), 1015–1032. https://doi.org/10.1002/lno.10270

Harsha, V., Abhiram, P., & Prakash, D. B. (2024). Theoretical Review on Microplastic Pollution: A Multifaceted Threat to Marine Ecosystems, Human Health, and Environment. *IgMin Research*, *2*(6), 460–468. https://doi.org/10.61927/igmin203

Hoang, V.-H., Nguyen, M.-K., Hoang, T.-D., Rangel-Buitrago, N., Lin, C., Pham, M.-T., Ha, M. C., Nguyen, T. P., Shaaban, M., Chang, S. W., & Nguyen, D. D. (2025). Microplastic characteristics, transport, risks, and remediation in groundwater: a review. *Environmental Chemistry Letters*. https://doi.org/10.1007/s10311-025-01825-8

Huang, J.-N., Xu, L., Wen, B., Gao, J.-Z., & Chen, Z.-Z. (2024). Characteristics and risks of microplastic contamination in aquaculture ponds near the Yangtze Estuary, China. *Environmental Pollution*, *343*, 123288–123288. https://doi.org/10.1016/j.envpol.2024.123288

Huang, Y., He, T., Yan, M., Yang, L., Gong, H., Wang, W., Qing, X., & Wang, J. (2021). Atmospheric transport and deposition of microplastics in a subtropical urban

environment. *Journal of Hazardous Materials*, *416*, 126168. https://doi.org/10.1016/j.jhazmat.2021.126168

Jones, N. R., de Jersey, A. M., Lavers, J. L., Rodemann, T., & Rivers-Auty, J. (2024). Identifying laboratory sources of microplastic and nanoplastic contamination from the air, water, and consumables. *Journal of Hazardous Materials*, *465*, 133276. https://doi.org/10.1016/j.jhazmat.2023.133276

Kaiser, D., Kowalski, N., & Waniek, J. J. (2017). Effects of biofouling on the sinking behavior of microplastics. *Environmental Research Letters*, *12*(12), 124003. https://doi.org/10.1088/1748-9326/aa8e8b

Kalogerakis, N., Karkanorachaki, K., Kalogerakis, G. C., Triantafyllidi, E. I., Gotsis, A. D., Partsinevelos, P., & Fava, F. (2017). Microplastics Generation: Onset of Fragmentation of Polyethylene Films in Marine Environment Mesocosms. *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00084

Kudla, Y. M., Ijzerman, M. M., C. James Bennett, Gillis, P. L., Kidd, K. A., & Prosser, R. S. (2024). Quantifying Effects and Ingestion of Several Pristine Microplastics in Two Early Life Stages of Freshwater Mussels. *Environmental Toxicology and Chemistry*. https://doi.org/10.1002/etc.5993

Law, K. L., Moret-Ferguson, S., Maximenko, N. A., Proskurowski, G., Peacock, E. E., Hafner, J., & Reddy, C. M. (2010). Plastic Accumulation in the North Atlantic Subtropical Gyre. *Science*, *329*(5996), 1185–1188. https://doi.org/10.1126/science.1192321

Lee, J., Cha, J., Ha, K., & Stefano Viaroli. (2024). Microplastic pollution in groundwater: a systematic review. *Environmental Pollutants & Bioavailability*, *36*(1). https://doi.org/10.1080/26395940.2023.2299545

Leppänen, I., Lappalainen, T., Lohtander, T., Jonkergouw, C., Arola, S., & Tammelin, T. (2022). Capturing colloidal nano- and microplastics with plant-based nanocellulose networks. *Nature Communications*, *13*(1), 1814. https://doi.org/10.1038/s41467-022-29446-7

Li, J., Zhang, J., Ren, S., Huang, D., Liu, F., Li, Z., Zhang, H., Zhao, M., Cao, Y., Samson Mofolo, Liang, J., Xu, W., Jones, D. L., Chadwick, D. R., Liu, X., & Wang, K. (2023). Atmospheric deposition of microplastics in a rural region of North China Plain. *Science of the Total Environment*, *877*, 162947–162947. https://doi.org/10.1016/j.scitotenv.2023.162947

Liu, F., Vianello, A., & Vollertsen, J. (2019). Retention of microplastics in sediments of urban and highway stormwater retention ponds. *Environmental Pollution*, *255*, 113335. https://doi.org/10.1016/j.envpol.2019.113335

Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L., & Li, D. (2019). Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. *Science of the Total Environment*, *675*, 462–471. https://doi.org/10.1016/j.scitotenv.2019.04.110

Liu, S., Shi, J., Wang, J., Dai, Y., Li, H., Li, J., Liu, X., Chen, X., Wang, Z., & Zhang, P. (2021). Interactions Between Microplastics and Heavy Metals in Aquatic Environments: A Review. *Frontiers in Microbiology*, *12*. https://doi.org/10.3389/fmicb.2021.652520

Liu, Y., Nie, Z., Meng, Y., Liu, G., Chen, Y., & Chai, G. (2024). Influence of meteorological conditions on atmospheric microplastic transport and deposition. *Environmental Research*, 120460–120460. https://doi.org/10.1016/j.envres.2024.120460

Lozano, Y. M., Aguilar-Trigueros, C. A., Onandia, G., Maaß, S., Zhao, T., & Rillig, M. C. (2021). Effects of microplastics and drought on soil ecosystem functions and multifunctionality. *Journal of Applied Ecology*, *58*(5), 988–996. https://doi.org/10.1111/1365-2664.13839

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: A review. *Frontiers in Public Health*, *8*(14), 1–13. NCBI. https://doi.org/10.3389/fpubh.2020.00014

Mansa, R., & Zou, S. (2021). Thermogravimetric analysis of microplastics: A mini review. *Environmental Advances*, *5*, 100117. https://doi.org/10.1016/j.envadv.2021.100117

McGuirk, S. L., Cairns, I. H., & Evans, B. J. (2024). Effects of Sample Handling on Visible and Near-Infrared Soil Reflectance. *Applied Spectroscopy Practica*, *2*(3). https://doi.org/10.1177/27551857241266855

Mendrik, F., Fernández, R., Hackney, C. R., Waller, C., & Parsons, D. R. (2023). Non-buoyant microplastic settling velocity varies with biofilm growth and ambient water salinity. *Communications Earth & Environment*, *4*(1), 1–9. https://doi.org/10.1038/s43247-023-00690-z

Miller, M. E., Hamann, M., & Kroon, F. J. (2020). Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. *PLOS ONE*, *15*(10), e0240792. https://doi.org/10.1371/journal.pone.0240792

Mintenig, S. M., Löder, M. G. J., Primpke, S., & Gerdts, G. (2019). Low numbers of microplastics detected in drinking water from ground water sources. *Science of the Total Environment, 648*, 631–635. https://doi.org/10.1016/j.scitotenv.2018.08.178

Panno, S. V., Kelly, W. R., Scott, J., Zheng, W., McNeish, R. E., Holm, N., Hoellein, T. J., & Baranski, E. L. (2019). Microplastic Contamination in Karst Groundwater Systems. *Groundwater*, *57*(2), 189–196. https://doi.org/10.1111/gwat.12862

Pfohl, P., Wagner, M., Meyer, L., Domercq, P., Praetorius, A., Hüffer, T., Hofmann, T., & Wohlleben, W. (2022). Environmental Degradation of Microplastics: How to Measure Fragmentation Rates to Secondary Micro- and Nanoplastic Fragments and Dissociation into Dissolved Organics. *Environmental Science & Technology*, *56*(16), 11323–11334. https://doi.org/10.1021/acs.est.2c01228

Pieniazek, L. S., McKinney, M. L., Carr, J. A., & Shen, L. (2024). Microplastic Analysis in Soil Using Ultra-High-Resolution UV–Vis–NIR Spectroscopy and Chemometric Modeling. *Microplastics*, *3*(2), 339–354. https://doi.org/10.3390/microplastics3020021

Pivokonsky, M., Cermakova, L., Novotna, K., Peer, P., Cajthaml, T., & Janda, V. (2018). Occurrence of microplastics in raw and treated drinking water. *Science of the Total Environment, 643*, 1644–1651. https://doi.org/10.1016/j.scitotenv.2018.08.102

Prajapati, A., Narayan Vaidya, A., & Kumar, A. R. (2022). Microplastic properties and their interaction with hydrophobic organic contaminants: a review. *Environmental Science and Pollution Research*, *29*(33), 49490–49512. https://doi.org/10.1007/s11356-022-20723-y

Prata, J. C., Padrão, J., Khan, M. T., & Walker, T. R. (2024). Do's and don'ts of microplastic research: a comprehensive guide. *Water Emerging Contaminants & Nanoplastics*, *3*(21). https://doi.org/10.20517/wecn.2023.61

Primpke, S., Fischer, M., Lorenz, C., Gerdts, G., & Scholz-Böttcher, B. M. (2020). Comparison of pyrolysis gas chromatography/mass spectrometry and hyperspectral FTIR imaging spectroscopy for the analysis of microplastics. *Analytical and Bioanalytical Chemistry*, *412*(30), 8283–8298. https://doi.org/10.1007/s00216-020-02979-w

Pukos, S., Maszczyk, P., Dąbrowski, K., Zebrowski, M. L., & Babkiewicz, E. (2023). The effect of planktivorous fish on the vertical flux of polystyrene microplastics. *The European Zoological Journal*, *90*(1), 401–413. https://doi.org/10.1080/24750263.2023.2217199

Raza, M., Lee, J.-Y., & Cha, J. (2022). Microplastics in soil and freshwater: Understanding

sources, distribution, potential impacts, and regulations for management. *Science Progress*, *105*(3), 003685042211266. https://doi.org/10.1177/00368504221126676

Ross, M. S., Loutan, A., Groeneveld, T., Molenaar, D., Kroetch, K., Bujaczek, T., Kolter, S., Moon, S., Huynh, A., Khayam, R., Franczak, B. C., Camm, E., Arnold, V. I., & Ruecker, N. J. (2023). Estimated discharge of microplastics via urban stormwater during individual rain events. *Estimated Discharge of Microplastics via Urban Stormwater during Individual Rain Events*, *11*. https://doi.org/10.3389/fenvs.2023.1090267

Sa'adu, I., & Farsang, A. (2023). Plastic contamination in agricultural soils: a review. *Environmental Sciences Europe*, *35*(1). https://doi.org/10.1186/s12302-023-00720-9

Sarmite Kernchen, Schmalz, H., Martin, Georgi, C., Einhorn, A., Greiner, A., Nölscher, A. C., Laforsch, C., & Held, A. (2024). Atmospheric deposition studies of microplastics in Central Germany. *Air Quality, Atmosphere & Health*. https://doi.org/10.1007/s11869-024-01571-w

Schöpfer, L., Menzel, R., Schnepf, U., Ruess, L., Marhan, S., Brümmer, F., Pagel, H., & Kandeler, E. (2020). Microplastics Effects on Reproduction and Body Length of the Soil-Dwelling Nematode Caenorhabditis elegans. *Frontiers in Environmental Science*, *8*. https://doi.org/10.3389/fenvs.2020.00041

Singh, A., & Mishra, B. K. (2023). Microplastic in personal care products: An overlooked environmental concern. *Journal of Cleaner Production*, *427*(139082), 139082. https://doi.org/10.1016/j.jclepro.2023.139082

Song, J., Wang, C., & Li, G. (2024). Defining Primary and Secondary Microplastics: A Connotation Analysis. *ACS ES & T Water*, *4*(6). https://doi.org/10.1021/acsestwater.4c00316

Tatsii, D., Bucci, S., Taraprasad Bhowmick, Guettler, J., Bakels, L., Bagheri, G., & Stohl, A. (2023). Shape Matters: Long-Range Transport of Microplastic Fibers in the Atmosphere. *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.3c08209

Thendo Mutshekwa, Fulufhelo Mulaudzi, Maiyana, V. P., Lubabalo Mofu, Munyai, L. F., & Murungweni, F. M. (2025). Atmospheric deposition of microplastics in urban, rural, forest environments: A case study of Thulamela Local Municipality. *PloS ONE*, *20*(3), e0313840–e0313840. https://doi.org/10.1371/journal.pone.0313840

Thompson, R. C., Courtene-Jones, W., Boucher, J., Pahl, S., Raubenheimer, K., & Koelmans, A.

A. (2024). Twenty years of microplastics pollution research—what have we learned? *Science*, *386*(6720). https://doi.org/10.1126/science.adl2746

Uwamungu, J. Y., Wang, Y., Shi, G., Pan, S., Wang, Z., Wang, L., & Yang, S. (2022). Microplastic contamination in soil agro-ecosystems: A review. *Environmental Advances*, 100273. https://doi.org/10.1016/j.envadv.2022.100273

Viaroli, S., Lancia, M., & Re, V. (2022). Microplastics contamination of groundwater: Current evidence and future perspectives. A review. *Science of the Total Environment*, *824*, 153851. https://doi.org/10.1016/j.scitotenv.2022.153851

Vijay Kumar Aralappanavar, Mukhopadhyay, R., Yu, Y., Liu, J., Bhatnagar, A., Sarva Mangala Praveena, Li, Y., Paller, M., Adyel, T. M., Jörg Rinklebe, Bolan, N. S., & Sarkar, B. (2024). Effects of microplastics on soil microorganisms and microbial functions in nutrients and carbon cycling – A review. *Science of the Total Environment*, *924*, 171435–171435. https://doi.org/10.1016/j.scitotenv.2024.171435

Weber, C. J., Rillig, M. C., & Bigalke, M. (2023). Mind the gap: forest soils as a hidden hub for global micro- and nanoplastic pollution. *Microplastics and Nanoplastics*, *3*(1). https://doi.org/10.1186/s43591-023-00067-1

Wright, S. L., Ulke, J., Font, A., Chan, K. L. A., & Kelly, F. J. (2020). Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environment International*, *136*, 105411. https://doi.org/10.1016/j.envint.2019.105411

Xie, Y., Wang, H., Guo, Y., Wang, C., Cui, H., & Xue, J. (2023). Effects of microplastic contamination on the hydraulic, water retention, and desiccation crack properties of a natural clay exposed to leachate. *Journal of Environmental Management*, *351*, 119858. https://doi.org/10.1016/j.jenvman.2023.119858

Xiong, X., Xie, S., Feng, K., & Wang, Q. (2022). Occurrence of microplastics in a pond-river-lake connection water system: How does the aquaculture process affect microplastics in natural water bodies. *Journal of Cleaner Production*, *352*, 131632. https://doi.org/10.1016/j.jclepro.2022.131632

Yang, B., Wu, L., Feng, W., & Lin, Q. (2024). Global perspective of ecological risk of plastic pollution on soil microbial communities. *Frontiers in Microbiology*, *15*. https://doi.org/10.3389/fmicb.2024.1468592

Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers,

especially polystyrene: review. *SpringerPlus*, *2*(1). https://doi.org/10.1186/2193-1801-2-398

Zhang, J., Ding, W., Zou, G., Wang, X., Zhao, M., Guo, S., & Chen, Y.-H. (2022). *Urban pipeline rainwater runoff is an important pathway for land-based microplastics transport to inland surface water: A case study in Beijing*. *861*, 160619–160619. https://doi.org/10.1016/j.scitotenv.2022.160619

Zhang, Y., Kang, S., Allen, S., Allen, D., Gao, T., & Sillanpää, M. (2020). Atmospheric microplastics: A review on current status and perspectives. *Earth-Science Reviews*, *203*, 103118. https://doi.org/10.1016/j.earscirev.2020.103118

Vita

Jake Carr was born in Seymour, Tennessee. He graduated from Walters State Community College in 2019 with an Associate of Science in General Studies. He later received his Bachelor of Science in Geology from the University of Tennessee, Knoxville in 2022. During his tenure at both institutions, he developed a passion for following the clues left behind by humans or nature to better understand the interactions between humanity and Mother Earth. In 2023, he began pursuing a Master of Science in Geology and Environmental Sciences at the University of Tennessee, Knoxville. His research focuses on microplastic contamination and the use of reflectance UV–Vis–NIR spectroscopy in environmental monitoring. During his academic career, Jake has worked as a Graduate Teaching Assistant, Tutor, Peer Coach, Student Disability Services Worker, and Laboratory Operations Manager. He is the co-author of a peer-reviewed article published in *Microplastics* (2024).