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PLASTIC WASTE POLLUTION IN MINNESOTA: ECOLOGICAL AGRICULTURAL AND PUBLIC HEALTH IMPACTS AND INTEGRATING SOFTWARE-DRIVEN SOLUTIONS

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Abstract: *This research paper investigates the pervasive issue of plastic waste pollution in Minnesota, highlighting its ecological, agricultural, and public health implications. It examines the broad spectrum of plastic waste, from large consumer items to microplastics, and the detrimental effects on ecosystems, wildlife, human health, and agriculture. The study explores technological and software-driven solutions, such as waste tracking systems and AI-based recycling technologies, as well as policy approaches that can mitigate plastic pollution. The research includes a review of key studies and provides recommendations for future sustainable waste management in the state.*

Key words: Plastic waste, Minnesota, Public Health, Ecological Agricultural.

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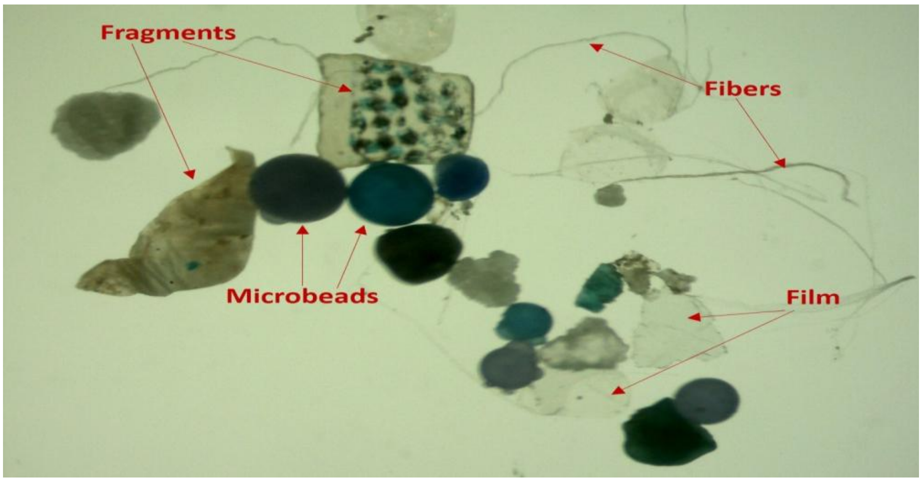
Introduction

Plastic waste pollution is a global environmental crisis that affects ecosystems, agriculture, and human health. Americans use 100 billion plastic bags a year, which require 12 million barrels of oil to manufacture (Clean Water Action, n.d.). Minnesotans throw away more than 500 tons of plastic bags and packaging every day. The Minnesota Pollution Control Agency states that in Minnesota plastic bag recycling is less than 10 percent (MPCA, 2022). It is estimated that 22 million pounds of plastic pollution enter the Great Lakes annually. In Minnesota, plastic waste has become an urgent issue, exacerbated by its widespread use in packaging, consumer goods, and industrial applications. While plastics offer convenience and cost-effectiveness, their long-lasting presence in the environment is causing serious harm to both the natural world and human society. The variety of plastic materials—from single-use plastics like bags, bottles, and wrappers to microplastics in water sources—poses significant challenges for waste management. Despite efforts to reduce plastic consumption, millions of pounds of plastic waste still enter landfills, rivers, lakes, and oceans every year, contributing to environmental degradation and health risks. In Minnesota, major waterways such as the Mississippi River and Lake Superior serve as conduits for plastic pollution, impacting both local biodiversity and public health.

Figure 01: Microplastics Proliferate in Lake Superior



https://www.agatemag.com/2021/05/microplastics-proliferate-in-lake-superior/

Lifecycle of Plastic Waste in Minnesota

Production and Distribution

Plastic waste begins with the production of plastic materials, derived from petroleum-based polymers like polyethylene, polypropylene, and PVC. In Minnesota, industrial production is significant, with key facilities such as the Flint Hills Resources refinery in Rosemount (MPCA, 2022). While these industries provide jobs and products used in various sectors, they also contribute to environmental pollution and plastic waste. The need to end the use of single-use plastic bags is vital to the long-term health of our water and planet. Plastics are made up of roughly 13,000 different chemicals, with 3,200 of those being listed as chemicals of concern (Rochman et al., 2019). Health impacts from the chemicals in plastic include cardiovascular disease and stroke, infertility, cancer, thyroid problems, obesity, diabetes, and more. In 2015, the Minneapolis City Council took steps to ban the use of plastic bags at grocery and retail stores in Minneapolis in an effort to reduce plastic pollution (City of Minneapolis, 2021). Unfortunately, despite passage of the ordinance in 2016, the legislature acted in 2017 and passed language prohibiting cities from banning the use of plastic/disposable bags. Currently, Minneapolis and Duluth both charge a 5-cent fee for plastic bags within their city limits to encourage the use of reusable bags. Plastics are distributed through various supply chains and industries, and despite the growing awareness of plastic pollution, large volumes of plastic products are still consumed annually. Packaging materials, including bottles, containers, and wrappers, contribute to the accumulation of plastic waste in urban and rural areas alike.

Usage Patterns

The usage of plastics, especially single-use plastics like bags, bottles, and packaging, remains high in Minnesota. Americans use an average of 365 plastic bags per person per year compared to people in Denmark, who use an average of four plastic bags per year. In 2015 about 730,000 tons of plastic bags, sacks and wraps were generated (including PS, PP, HDPE, PVC & LDPE) in the U.S., but more than 87 percent of those items are never recycled, winding up in landfills and the water (Clean Water Action, n.d.). One study estimated the cost of clean-up and landfill at 17 cents per bag. It shows how they calculated the cost per bag for the 50 million bags used in that city per year. These costs are similar across the U.S. (https://cleanwater.org_0.pdf). Surveys conducted in major urban areas, such as Minneapolis-St. Paul, indicate that despite growing awareness, a significant portion of consumers still regularly use plastic products. Retailers like Target and Cub Foods have begun implementing plastic bag recycling programs, yet participation remains limited, and many plastics end up in landfills or as litter.

Disposal and Waste Management

Minnesota's waste management infrastructure has struggled to keep up with the sheer volume of plastic waste. It takes 1,000 years for a plastic bag to degrade in a landfill. Unfortunately, the bags do not break down completely but instead photo-degrade, becoming microplastics that absorb toxins and continue to pollute the environment. Although efforts to increase recycling rates have been made, plastic waste still represents a significant burden for local governments. The Minnesota Pollution Control Agency (MPCA) estimates that around 30-40 percent of plastics end up in landfills, with the rest either being incinerated or escaping into the environment (MPCA, 2022). Plastics are notorious for jamming sorting machinery at Material Recovery Facilities (MRFs), making it difficult to effectively recycle them. Rural areas, where access to recycling programs is limited, often bear the brunt of this waste issue.

Ecological Impacts

Impact on Wildlife

Minnesota's diverse wildlife, from terrestrial animals to aquatic species, face significant threats from plastic pollution. In particular, larger animals ingest plastic debris, causing harm to their digestive systems and overall health. Microplastics have been found in wild species, potentially affecting reproduction and food chain dynamics (Thompson et al., 2009). Additionally, plastics may carry toxic chemicals, further exacerbating their impact on wildlife.

Microplastics in Freshwater Ecosystems

The impact of microplastics in Minnesota's freshwater ecosystems is significant. Studies show that microplastics are present in both the Mississippi River and Lake Superior, often due to runoff from urban areas (Hemphill, 2021). These small plastic particles accumulate in water systems and enter the food chain, threatening aquatic biodiversity and affecting the health of aquatic species. Microplastics are roughly the same size as the food sources for many creatures living in water. These tiny pieces can get tangled up in aquatic organisms, and when ingested, they can block the critters' digestive systems. In addition, some of the materials used to produce plastics are endocrine disruptors, which can interfere with many life processes. In humans these chemicals can lead to learning disabilities, faulty brain or sexual development, and cancers. Another danger lies in the toxic substance's plastics can carry with them. There are plenty of tiny pieces of metals, bacteria, and organic compounds in the water, and plastics can absorb these, leaching them over time. Persistent, bio-accumulative, and toxic substances can be especially destructive because some of them can hitch a ride on microplastics, enter an organism, detach from the plastic, and then magnify as they move up the food web. These include DDT (a now-banned pesticide), dioxins (by-products of industrial processes and waste incineration), polycyclic aromatic hydrocarbons (PAHs, which come from coal-burning, wildfires, and grilled foods), Per- and polyfluoroalkyl substances (PFAS, found in grease-resistant paper, food packaging, and non-stick cookware), and polychlorinated biphenyls (PCBs, used in electrical equipment and paints until it was banned in 1979). Thus, the sport fish that humans love to catch and eat may have much higher levels of these toxic compounds than the algae or smaller fish which serve as food for larger fish (Source: Stephanie Hemphill, https://www.agatemag.com/2021/05/microplastics-proliferate-in-lake-superior/).

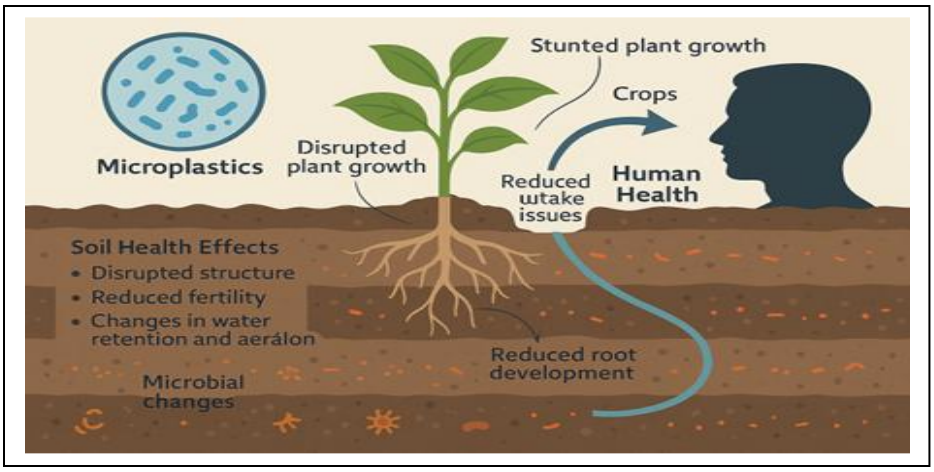
Impact on Protected Areas
Even protected areas such as the Boundary Waters Canoe Area Wilderness (BWCA) are not immune to plastic pollution. Research has revealed that remote lakes within the BWCA have become contaminated with microplastics, which may affect water quality and the ecological balance (USGS, 2022).

Agricultural Consequences
Plastic Mulch and Soil Health
In Minnesota's agricultural sectors, plastic mulch is commonly used to improve crop yields by retaining soil moisture and controlling weeds. However, plastic residues from mulch degrade soil quality over time, reducing soil porosity and harming the microorganisms necessary for healthy crop growth. This leads to long-term soil degradation and reduces agricultural productivity (Steinmetz et al., 2016).

Microplastics in Agricultural Soil
Microplastics have also been detected in agricultural soil, with concentrations reaching over 500 particles per kilogram. These microplastics affect soil structure and water retention capabilities, further compromising the agricultural environment. Biodegradable plastic mulches (BDMs) like polylactic acid (PLA) and polybutylene adipate terephthalate (PBAT) alter soil microbial communities differently than traditional polyethylene (PE) mulch, enriching potential pathogens and degradation-related taxa (Xiao et al., 2021). Over five months, BDMs showed higher microbial diversity fluctuations and stochastic community assembly (drift/dispersal), while PE exhibited more selective processes. Key biomarkers like Ramlibacter (order Burkholderiales) were linked to BDMs, suggesting roles in plastic degradation but also highlighting risks of pathogen enrichment. Despite being eco-friendly alternatives, BDMs may harbor pathogens at levels comparable to or higher than PE, posing concerns for crop and human health. The study underscores the need to balance biodegradability benefits with potential ecological trade-offs in agricultural soils.

Contamination in Animal Feed
Plastic contamination also extends to animal agriculture, with livestock ingesting microplastics from contaminated feed or silage wrapping. This may lead to plastics entering the human food chain, raising concerns about the potential health impacts on consumers (Lwanga et al., 2017).

Figure 02: Microplastics in Agricultural Soil



Source:https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2021.785737/full

Public Health and Environmental Justice

Chemical Leaching and Human Exposure

Plastics are often treated with chemicals like phthalates, bisphenol A (BPA), and flame retardants, which can leach into the environment as plastics break down. These chemicals are known endocrine disruptors, and studies have linked them to a variety of health issues, including reproductive and developmental disorders (Rochman et al., 2019). In Minnesota, rural communities with high concentrations of plastic pollution are at greater risk due to limited access to waste management services.

Urban-Rural Divide

The disparity in waste management services between urban and rural areas exacerbates the plastic waste issue. Urban areas like Minneapolis and St. Paul have more advanced recycling systems, but rural areas still face challenges in managing plastic waste. This results in uneven exposure to plastic pollution and environmental health risks (MPCA, 2022).

Indigenous and Tribal Communities

Indigenous communities, such as the Red Lake Nation, are particularly vulnerable to the impacts of plastic pollution. These communities rely on natural resources like water and land for their livelihood, and plastic waste poses a threat to their traditional ways of life. Initiatives like the Red Lake Nation's zero-waste policy serve as examples of how community-led efforts can help mitigate plastic pollution (Red Lake DNR, 2023).

Policy and Regulation

Minnesota's Plastic Waste Reduction Initiatives

Minnesota has taken a proactive approach to plastic waste reduction, implementing a statewide plastic bag ban in 2024. The state has also passed legislation promoting extended producer responsibility (EPR), requiring companies to take responsibility for the waste their products create. These policies aim to reduce the amount of plastic waste that ends up in landfills and the environment (MPCA, 2024).

Comparative State Approaches

States like Illinois and Wisconsin have adopted various approaches to plastic waste management, including plastic bag taxes and voluntary recycling programs. However, Minnesota's comprehensive ban on plastic bags and the implementation of EPR represent some of the most robust regulatory efforts in the Midwest (NRDC, 2023).

Extended Producer Responsibility

EPR is a key policy initiative in Minnesota, where companies are required to fund recycling programs for plastic products. There is a need to end the use of single-use plastic bags to support long term health of our water and planet. Plastics are made up of roughly 13,000 different chemicals, with 3,200 of those being listed as chemicals of concern. In 2015, the Minneapolis City Council took steps to ban the use of plastic bags at grocery and retail stores in Minneapolis to reduce plastic pollution. Unfortunately, despite passage of the ordinance in 2016, the legislature acted in 2017 and passed language prohibiting cities from banning the use of plastic/disposable bags. Currently, Minneapolis and Duluth both charge a 5-cent fee for plastic bags within their city limits in an effort to encourage the use of reusable bag (City of Minneapolis, 2021). This shift in responsibility aims to reduce plastic waste by encouraging producers to design products that are easier to recycle and less harmful to the environment.

Software-Driven Waste Tracking

Overview:

Software-driven waste tracking solutions are essential for providing real-time data and insights into plastic waste generation and management. By leveraging digital technologies such as mobile applications, artificial intelligence (AI), and geographic information systems (GIS), municipalities and businesses can monitor waste flows, improve recycling rates, and ensure waste reduction targets are met (Jambeck et al., 2005; Thompson et al., 2005).

How it Works:

- Tracking Systems: Software platforms can monitor plastic waste across multiple touchpoints, such as collection bins, sorting facilities, and recycling centers. Data from these systems helps waste management companies analyze consumption patterns, recycling rates, and contamination levels in waste streams (Koelmans & Besseling, 2005).
- AI Integration: AI can be integrated into waste tracking systems to automate sorting, detect inefficiencies in recycling processes, and optimize waste collection routes, reducing carbon footprints and improving overall waste processing efficiency (Thompson et al., 2005).
- Mobile Apps: Apps like *Litterati* encourage users to track litter in their neighborhoods. Participants can take pictures of plastic waste and upload them to a database. These contributions help communities understand where plastic waste accumulates and how best to tackle it (Hendrickson, Minor, & Schreiner, 2018).

Use Case:

- Case Study: The City of San Francisco’s Waste Management System San Francisco has implemented software systems for tracking waste to meet its ambitious zero-waste goal. The city uses an integrated waste tracking platform that collects data from residents and businesses about the types of waste they are generating. By analyzing this data, the city can target specific waste streams for improvement, such as plastic packaging or single-use plastics.

Results:

- The software enables real-time tracking of waste generation, allowing for timely interventions in underperforming areas.
- The city has reported a decrease in contamination rates in recyclable materials, as the data allows for more accurate guidance on sorting behavior.

Recycling Innovations

Overview:

Innovative recycling technologies are transforming the efficiency and effectiveness of recycling operations. One of the most notable advancements in this field is the use of Artificial

Intelligence (AI) to optimize recycling processes (Andrady & Neal, 2004; AMP Robotics, 2024). Companies are developing AI-driven systems that can sort materials more efficiently and with greater precision than humans, thus reducing contamination and increasing recycling rates.

How it Works:

- **AI-Powered Recycling Robots:** These robots use computer vision and deep learning algorithms to identify and sort materials such as plastic, glass, metal, and paper in recycling plants. This automation not only increases sorting accuracy but also reduces labor costs and safety hazards (AMP Robotics, 2024; Thompson et al., 2005).
- **Smart Bins:** Smart bins equipped with sensors and AI can automatically monitor the volume of waste deposited. They can also provide feedback to users, encouraging better recycling behavior by providing tips or real-time information on proper disposal (Tomra, 2024; Galloway & Thompson, 2004).

Use Case:

- **Case Study:** AMP Robotics is a leading company using AI to improve recycling operations. Their robots, powered by machine learning, can identify and sort recyclable materials at a higher speed and with greater accuracy than human workers. AMP Robotics' system uses AI algorithms trained on vast amounts of visual data to detect and segregate plastic waste from other materials, such as paper and metals (AMP Robotics, 2024).

Results:

- AMP Robotics' systems have been deployed in several recycling plants across the U.S., including those in Minnesota, where they have significantly increased sorting efficiency.
- The AI-powered robots at these facilities are capable of sorting 30 items per minute, compared to just 10 per minute with traditional manual sorting.
- This technology has helped improve the purity of recyclables, reducing contamination rates and enabling higher-quality plastic recycling.
- Case Study: Tomra's Smart Bins and Reverse Vending Machines Tomra, a leader in sensor-based sorting and reverse vending machines (RVMs), offers technology that allows consumers to return plastic bottles and cans to automated machines in exchange for incentives or refunds. These RVMs use sensors to identify the material and sort it automatically. The technology has been implemented widely in European countries and is expanding in the U.S., including cities in Minnesota (Tomra, 2024; Mato et al., 2005).
- Tomra's smart bins and RVMs have led to significant increases in recycling rates in countries like Norway, which boasts an over 97 percent return rate for plastic bottles.
- Minnesota could potentially adopt this model, increasing consumer participation in recycling programs and reducing litter.

Biodegradable Alternatives

Overview:

Biodegradable plastics, made from renewable sources such as cornstarch, algae, or fungi, offer a promising alternative to conventional petroleum-based plastics. These plastics break down naturally over time, reducing the environmental burden caused by persistent plastic pollution (Andrady & Neal, 2004; Nath et al., 2024).

How it Works:

- Cornstarch-Based Plastics: Plastics made from cornstarch are compostable and degrade in natural environments, unlike conventional plastics that can persist for centuries (BioBag, 2024).
- Mycelium-Based Plastics: Mycelium, the root structure of fungi, can be used to create biodegradable packaging materials. These materials naturally break down in soil without leaving harmful residues (MycoWorks, 2024).

- Algae-Based Plastics: Algae-derived plastics are another promising alternative. Algae can be rapidly cultivated and processed into biodegradable plastic alternatives, reducing reliance on fossil fuels (Nath et al., 2024).

Use Case:

- Case Study: BioBag – Compostable Plastic Bags BioBag is a Minnesota-based company that produces biodegradable bags made from renewable resources like cornstarch. These bags are designed to decompose within a few months when exposed to composting conditions, unlike conventional plastic bags, which can take hundreds of years to break down (BioBag, 2024).

Results:

- BioBag's compostable bags are used in municipal curbside composting programs in the Twin Cities area. The company's products are part of a broader effort to reduce single-use plastics in Minnesota by offering a sustainable alternative that meets consumer needs without contributing to plastic waste.
- BioBag's success in Minnesota is part of a larger trend of biodegradable plastic adoption, with the company seeing increasing demand for its products as consumers and businesses seek more sustainable alternatives.
- Case Study: MycoWorks – Mycelium Packaging MycoWorks, a biotechnology company that produces mycelium-based packaging, has developed an innovative solution to plastic waste by replacing Styrofoam and other non-biodegradable materials with a 100 percent biodegradable alternative made from fungi. This packaging solution is stronger, lighter, and entirely compostable (MycoWorks, 2024).

Results:

- MycoWorks' mycelium-based packaging has gained traction in industries ranging from food packaging to consumer electronics.
- The material breaks down naturally within 30 days when exposed to environmental conditions, offering a substantial reduction in plastic waste.

Challenges and Future Potential:

- Despite the growing demand for biodegradable alternatives, challenges remain in scaling production and ensuring these materials are widely accepted and used. Additionally, while biodegradable plastics reduce long-term environmental damage, they still require specific conditions to break down properly, such as composting facilities or appropriate waste management systems.
- The technological innovations discussed—software-driven waste tracking, AI-powered recycling solutions, and biodegradable alternatives—represent significant advancements in the fight against plastic waste pollution. These technologies are already being implemented in various regions and industries with notable success, from smart bins to AI robots improving recycling rates to biodegradable bags replacing single-use(Nath et al., 2024; Chakraborty et al., 2025). As these technologies continue to evolve and scale, they offer a hopeful path toward a more sustainable future, reducing the burden of plastic waste on ecosystems, agriculture, and public health.
- By embracing these technological solutions and supporting policies that promote their adoption, States like Minnesota can take the lead in mitigating plastic pollution and setting an example for other regions globally.

Conclusion and Recommendations

Plastic waste pollution in Minnesota is a complex challenge that affects the environment, agriculture, and public health. The state must continue to invest in innovative technologies, improve waste management infrastructure, and adopt stricter policies to address this issue.

Recommendations

1. Expand and enforce the 2024 plastic waste reduction policies to include all forms of plastic waste.

2. Invest in research to develop and scale biodegradable plastic alternatives.
3. Support the development of software solutions for waste tracking and recycling.
4. Promote community-based initiatives to raise awareness and improve recycling participation.

The technological innovations discussed—software-driven waste tracking, AI-powered recycling solutions, and biodegradable alternatives—represent significant advancements in the fight against plastic waste pollution. These technologies are already being implemented in various regions and industries with notable success, from smart bins to AI robots improving recycling rates to biodegradable bags replacing single-use plastics. As these technologies continue to evolve and scale, they offer a hopeful path toward a more sustainable future, reducing the burden of plastic waste on ecosystems, agriculture, and public health (Galloway & Thompson, 2004; Koelmans & Besseling, 2005; Jambeck et al., 2005). By integrating technology, policy, and community action, Minnesota can take the lead in mitigating plastic pollution and ensuring a sustainable future for its ecosystems and residents.

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