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The Strategic Role of the Pharmacist in Environmental Risk Management

Nana Shashiashvili

Associate Professor,Georgian Technical University, Department of Pharmacy;

Tbilisi State Medical University, Department of Social and Clinical Pharmacy

ABSTRACT

The environmental consequences of pharmaceutical substances have become a pressing global issue. Emerging interdisciplinary fields such as eco-pharmacology and eco-pharmacovigilance focus on studying and preventing the harmful effects of pharmaceutical products on ecosystems. This article examines the main routes through which these compounds enter the environment, including wastewater discharge, improper disposal of unused medications, veterinary drug usage in agriculture, and pharmaceutical industry waste. It outlines the environmental impacts of these pollutants, such as endocrine disruption in aquatic life (fish and amphibians), the spread of antibiotic resistance, imbalances in aquatic microbiomes, and growth inhibition in plants. The responsibilities of pharmacists now extend beyond traditional roles, involving the promotion of sustainable prescribing practices, educating patients, engaging in policy development with an environmental focus, and supporting systems for proper drug disposal. This article stresses the need for enhanced public awareness, cross-disciplinary cooperation, and the implementation of comprehensive strategies to maintain ecological safety in pharmaceutical practices, thereby protecting both human health and the environment.

Keywords: Eco-pharmacovigilance, Environmental pharmacovigilance; Eco-pharmacology, Pharmacist, Pharmacoenvironmentology.

Introduction

Pharmacovigilance, as defined by the World Health Organization, encompasses the monitoring, evaluation, and prevention of adverse drug reactions in both humans and animals. In recent years, however, growing attention from scientists, regulatory bodies, and environmental organizations has shifted toward examining the environmental impact of pharmaceutical substances. This evolving field is often referred to as eco-pharmacology. Yet, the term lacks precise definitional boundaries. A more targeted and specialized approach introduces the concept of pharmacoenvironmentology, which

focuses on investigating the environmental consequences of pharmaceuticals, even when they are used appropriately for therapeutic purposes.

The associated risks become particularly apparent when medicines enter the environment due to improper disposal, excessive use, or careless waste management practices. For instance, the overuse of antibiotics and their subsequent release into ecosystems creates favorable conditions for the development of resistant microorganisms—a phenomenon now recognized as one of the most pressing global threats to public health.

Unfortunately, the systematic management of this issue remains underdeveloped. There is currently no internationally harmonized framework for the consistent and comprehensive assessment or monitoring of the ecological impact of pharmaceuticals. In many countries, national strategies are either entirely absent or limited to non-binding recommendations. This situation highlights the urgent need for an interdisciplinary approach that effectively integrates pharmacological, ecological, and regulatory perspectives.

Ensuring environmental safety across the entire pharmaceutical lifecycle—from manufacturing and distribution to consumption and disposal—has become an essential component of pharmaceutical practice. The presence of pharmaceutical residues in the environment poses significant threats to living organisms. In this context, the role of the pharmacist is expanding beyond patient counseling to encompass responsibilities as an environmental steward—actively contributing to the appropriate distribution and disposal of medications.

Eco-pharmacovigilance thus opens new avenues for expanding pharmacists' professional competencies, calling for their active involvement not only in policy development but also in raising public awareness and promoting sustainable pharmaceutical use.

Research Objective

This study aims to explore the significance of pharmaco-ecology and eco-pharmacovigilance in modern pharmaceutical practice. It focuses on identifying the primary pathways through which medicinal substances enter natural ecosystems and assessing their impact on human health, biodiversity, and ecosystem functionality. Moreover, the research seeks to define the evolving professional role of pharmacists in raising public awareness, managing ecological risks, and implementing preventive measures related to pharmaceutical pollution.

Research Methodology

The study is based on a comprehensive analysis of secondary data, including peer-reviewed publications and thematic literature in scientific and professional journals. A qualitative content analysis and thematic review approach was employed to identify key trends and threats associated with the environmental impact of pharmaceutical agents.

Results

In today's world, safeguarding ecosystems is becoming an increasingly urgent priority. Traditionally, pharmacovigilance has concentrated on evaluating the safety of pharmaceuticals in humans and animals. However, it is now evident that after therapeutic agents are administered and excreted, they continue to exert biological effects—this time on the environment.

Eco-pharmacovigilance (EPV) represents a logical extension of conventional pharmacovigilance and involves the monitoring of pharmaceuticals in the environment, evaluating their effects on non-target organisms, and managing potential ecological risks. Achieving these objectives requires the development of reliable databases, the collection of robust data, and the establishment of standardized methodologies. Equally crucial is the formation of interdisciplinary collaborations that bring together toxicologists, ecologists, pharmacists, and policy-makers.

The ecological "journey" of pharmaceutical compounds begins the moment they are administered. Due to their chemical stability and resistance to degradation, active pharmaceutical ingredients (APIs) can persist in the environment for extended periods, causing unintended effects across various biological species. Although medications are designed to modulate physiological processes in humans, similar pathways exist in other organisms, leading to unanticipated interactions with wildlife.

In response to these challenges, emerging scientific disciplines such as pharmacoenvironmentology and eco-pharmacology developed. While closely related, each focuses on slightly different aspects. Pharmacoenvironmentology investigates the environmental fate and consequences of therapeutics administered at standard clinical doses. In contrast, eco-pharmacology takes a broader view, encompassing not only medications but also other personal care products (PPCPs) such as cosmetics, sunscreens, fragrances, and even pesticides. Both fields share a common concern: understanding and mitigating the environmental impacts of pharmaceutical and related substances.

Although the diversity of terminology can create some confusion among professionals, these disciplines ultimately converge on a shared goal—reducing the negative ecological footprint of pharmaceutical products.

Eco-pharmacovigilance requires a holistic and systems-oriented approach, and it is increasingly being recognized as a matter of global concern. Its core objectives include:

- Continuous monitoring of pharmaceutical compound concentrations in various environmental compartments;
- Assessment of bioaccumulation, toxicity, and persistence of medicinal substances in non-target species;
- Development of regulatory frameworks that establish acceptable environmental thresholds and promote the use of pharmaceuticals with lower ecological impact;
- Raising awareness among healthcare professionals and the general public to encourage rational drug use and proper disposal practices;
- Supporting research and innovation aimed at the advancement of environmentally safer technologies.

The traditional notion of pharmaceutical safety must be expanded beyond clinical efficacy and patient outcomes. It is imperative to consider the ecological footprint of medicinal products across their entire life cycle—including manufacturing, use, and disposal. Integrating environmental considerations into all stages of a drug's development and utilization is essential for building a truly sustainable healthcare system.

Eco-pharmacovigilance, therefore, is not solely a scientific discipline—it is a shared global responsibility. It demands active engagement from the scientific community, robust and adaptive regulatory mechanisms, and forward-thinking innovation to ensure that the progress achieved in modern medicine does not come at the expense of ecological stability [1,2,3].

A comparative overview of eco-pharmacology and pharmacoenvironmentology, including their key distinctions and practical applications, is presented in Table 1.

Table 1. Comparative Overview of Eco-pharmacology and Pharmacoenvironmentology

Criterion	Eco-pharmacology	Pharmacoenvironmentology
Focus	Environmental impact of pharmaceuticals and personal care products (PPCPs)	Environmental presence and consequences of pharmaceuticals used in therapy
Subject of Study	Pharmaceuticals, cosmetics, perfumes, sunscreens, pesticides, and other PPCPs	Pharmaceuticals administered to humans and animals
Target Effects	Assesses impact on both target and non-target organisms	Evaluates unintended effects on non-target organisms
Methodological Approach	Interdisciplinary: pharmacy, ecology, chemistry, toxicology	Environmental sciences, ecotoxicology, clinical pharmacology
Main Objective	Prediction and prevention of ecological harm	Analysis of environmental distribution and effects of active pharmaceutical ingredients (APIs)
Practical Application	Design of environmentally safer products and development of sustainable policies	Risk assessment and enhancement of regulatory frameworks
Terminological Breadth	Broader scope encompassing various product categories	Narrower scope focused specifically on medicinal products

Among global environmental challenges, the release of pharmaceuticals into the environment remains one of the least studied yet increasingly alarming issues. Recent scientific investigations have demonstrated that a range of pharmaceutical compounds—including antibiotics, antidepressants,

hormones, and analgesics—can now be detected across nearly all ecosystems. These substances have been identified in drinking water, surface and groundwater, treated effluents, and even within aquatic and terrestrial organisms (biota).

The primary sources of this contamination are linked to human and veterinary pharmaceutical usage, with subsequent excretion into wastewater systems. Additional pathways include industrial discharges, leachates from landfills, runoff from aquaculture, and insufficient waste management. A particular concern is the high concentration of active pharmaceutical ingredients (APIs) found in the vicinity of pharmaceutical manufacturing sites.

Although advances in medical science and the widespread availability of medications have undoubtedly improved human and animal health, they have also led to the unprecedented accumulation of pharmaceutical residues in the environment. This issue first gained attention in 1976 when drug residues were detected in the effluent of the Big Blue River wastewater treatment plant in Kansas City, USA—a discovery that marked a turning point in the global awareness of pharmaceutical pollution. Subsequent studies confirmed the presence of pharmaceuticals not only in drinking water but also in rivers and groundwater systems.

A notable example comes from Hyderabad, India, where research near pharmaceutical production facilities revealed concentrations of the antibiotic ciprofloxacin in local rivers exceeding the allowable levels in European drinking water standards by over 1,000-fold. In Sweden, traces of felodipine were identified, a compound known to disrupt the endocrine systems of fish after prolonged exposure.

The persistent presence of pharmaceuticals in the environment contributes to chronic contamination and can exert adverse effects on a variety of organisms. Documented ecological impacts include inhibited growth of aquatic plants, decreased fish populations, impaired liver function, altered reproductive and morphological development, and behavioral abnormalities in mollusks.

Particularly concerning is the role of antibiotics in promoting antimicrobial resistance (AMR), which poses a severe threat to both ecosystems and public health. The emergence and spread of resistant microbial strains are directly linked to environmental exposure. According to data from 2019, AMR was associated with approximately 1.27 million deaths worldwide, underscoring the global scale of the problem.

Despite the growing body of evidence, the ecotoxicological assessment of pharmaceuticals remains insufficient. A 2024 study by Spilsparm et al. revealed that only 1.5% of all medicinal products authorized in the European Union had undergone formal environmental risk evaluations.

Since the initial discovery of pharmaceutical residues in Kansas City's wastewater, research has expanded significantly. Compounds such as diclofenac, fluoxetine, ethinylestradiol, and even cocaine have been detected in various water systems, raising critical questions about their circulation and persistence within ecological food webs.

Once excreted from the body, pharmaceuticals may enter the environment either in their original, active form or as transformed metabolites. Many unchanged drug compounds retain biological activity, continuing to exert effects on living organisms. Numerous studies have shown trace concentrations of pharmaceuticals in drinking water, often at parts per million (ppm) or parts per trillion (ppt) levels. According to the U.S. Geological Survey, at least one pharmaceutical was present in 80% of tested water samples. The primary routes of contamination include human excretion and the improper disposal of unused medications.

Veterinary pharmaceuticals such as avermectins—including ivermectin and moxidectin—are of particular concern due to their long-lasting activity. Once excreted in feces, these compounds can disrupt soil biodiversity, hinder natural biodegradation processes, and adversely affect invertebrate populations, thereby disturbing ecological balance.

One of the critical challenges in managing pharmaceutical waste is the improper disposal of unused or expired medications through household waste streams. In several countries, including Germany and Australia, a significant portion of the population continues to dispose of medications in this manner. This practice contributes significantly to pharmaceutical pollution, a problem further exacerbated by insufficient regulatory oversight, limited public awareness, and a complex mix of legal and ethical concerns [4,5].

From an ecological, public health, and environmental protection standpoint, pharmaceutical contamination represents a pressing global issue. Effective mitigation demands a multidisciplinary strategy that includes strengthening regulatory frameworks, enhancing public and producer education, and implementing robust controls at the sources of contamination. The persistence of pharmaceutical residues in the environment underscores the growing interdependence between healthcare and environmental sciences. These fields increasingly overlap, sharing methodologies such as data collection, risk assessment, diagnostics, symptom evaluation, prevention strategies, and predictive analysis. Advancements in one discipline frequently inform and support the progress of the other, facilitating comprehensive and systemic improvements.

Promoting the rational use of medicines not only optimizes patient outcomes but also reduces their environmental burden. While environmental risk assessment (ERA) of pharmaceuticals remains underdeveloped, pharmacovigilance systems aimed at monitoring adverse effects in humans and animals are already well established. It is, therefore, both reasonable and necessary to broaden the scope of pharmacovigilance to encompass the environmental dimensions of pharmaceutical safety.

Growing attention is being paid to the environmental impact of both pharmaceuticals and personal care products. As a result, environmental risk assessments have become a regulatory requirement for both human and veterinary medicinal products. Although the European Medicines Agency (EMEA) has issued guidelines in this area, these documents often require further adaptation and flexibility to reflect regional and environmental specificities.

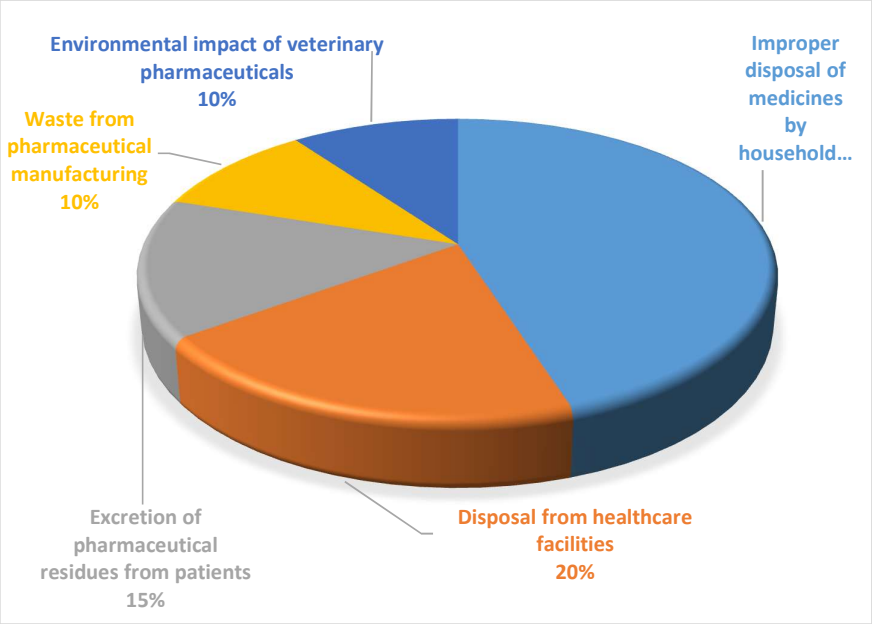
The environmentally sound disposal of medicinal products continues to be a largely unresolved issue. As expired and unused pharmaceuticals will inevitably accumulate, the establishment of clear and enforceable guidelines for their disposal is essential. While global institutions such as the World Health Organization (WHO), the World Bank, the European Union, and the U.S. Food and Drug Administration (FDA) acknowledge the problem, regulatory responses remain inconsistent and frequently inadequate—particularly in low- and middle-income countries. Therefore, the development of integrated strategies that govern the full life cycle of pharmaceuticals—from production to end-use—while incorporating environmentally responsible measures, is urgently required.

Pharmaceutical residues are a growing environmental concern, with multiple pathways contributing to their dispersion in ecosystems. The improper disposal of medicines, particularly by households, healthcare facilities, and pharmaceutical industries, significantly impacts the environment. The following chart highlights the main sources of pharmaceutical contamination and their relative contribution to the overall environmental burden.

- Improper Disposal of Medicines by Households (45%) – Households often dispose of unused or expired medications improperly, contributing to water and soil contamination. This is the leading source of pharmaceutical pollution.
- Disposal from Healthcare Facilities (20%) – Healthcare facilities, including hospitals and clinics, are another major source of pharmaceutical waste, often due to inappropriate disposal practices.
- Excretion of Pharmaceutical Residues from Patients (15%) – Patients excrete pharmaceutical residues through urine and feces, which can contaminate water supplies, especially in areas lacking proper wastewater treatment systems.
- Waste from Pharmaceutical Manufacturing (10%) – Pharmaceutical manufacturing processes also contribute to environmental pollution, particularly when waste is not properly managed.
- Environmental Impact of Veterinary Pharmaceuticals (10%) – The use of veterinary pharmaceuticals in agriculture, including for livestock and pets, is another important contributor to environmental contamination [6, 7,8].

The data presented in the Figure (N1) underscores the significant role that improper disposal and inadequate management of pharmaceutical waste play in environmental contamination. The most prominent source of pharmaceutical pollution comes from households, followed by healthcare facilities and manufacturing processes. To mitigate these impacts, there is a critical need for comprehensive waste management policies, public education on proper disposal methods, and the promotion of sustainable practices across all sectors involved in pharmaceutical use. Effective environmental safeguards will require cooperation between healthcare professionals, patients, regulatory bodies, and industries to reduce pharmaceutical residues in the environment.

Figure N1. Key Sources of Pharmaceutical Environmental Contamination



Eco-pharmacovigilance is an evolving interdisciplinary domain that bridges pharmacology with environmental health, focusing on the identification, prevention, and mitigation of the ecological impacts associated with pharmaceutical substances throughout their entire lifecycle—from development and use to final disposal. As active pharmaceutical ingredients (APIs) and their byproducts increasingly infiltrate natural ecosystems, they pose growing threats to biodiversity, environmental equilibrium, and public health. This makes eco-pharmacovigilance not only a scientific necessity but also a societal imperative.

While pharmaceuticals are designed to exert specific effects within the human body, a significant proportion of these substances—and their metabolites—escape into the environment through various routes. These include improper disposal of unused or expired medications, patient excretion, waste discharges from pharmaceutical manufacturing sites, and the application of veterinary drugs in agriculture. Once released, these compounds can contaminate soil, air, and water systems, leading to widespread ecological consequences.

Some of the major environmental concerns linked to pharmaceutical pollution include:

- Endocrine disruption in aquatic organisms, affecting reproductive and developmental systems in species such as fish and amphibians;
- Emergence of antimicrobial resistance due to continuous exposure of microorganisms to subtherapeutic concentrations of antibiotics;
- Destabilization of microbial ecosystems, particularly in aquatic environments, leading to long-term biodiversity loss;
- Impaired plant health and growth, as pharmaceutical residues accumulate in soil and alter its biological integrity.

In this context, eco-pharmacovigilance emerges not only as a scientific framework but also as a collective responsibility shared by healthcare providers, pharmaceutical companies, regulators, and

society at large. Among healthcare professionals, pharmacists are uniquely equipped to lead the integration of environmental stewardship into medication management and healthcare delivery [9,10].

Discussion

The Expanding Role of Pharmacists in Eco-pharmacovigilance

Pharmacists are on the frontline of medication use and are ideally positioned to influence practices that directly or indirectly affect the environment. Their responsibilities in promoting eco-pharmacovigilance extend far beyond traditional roles and encompass public education, sustainable prescribing, waste management, and policy advocacy. Their multifaceted contribution includes:

1. Public and Patient Education. Pharmacists play a key role in raising awareness about the environmental risks of improper medication disposal. Through patient counseling, community outreach, and educational campaigns, they can empower individuals to dispose of medications responsibly, thereby minimizing environmental contamination.
2. Implementation of Safe Disposal Systems. By advocating for and helping to establish structured drug take-back programs and secure disposal facilities, pharmacists ensure that expired or unused medications are not discarded in household waste or flushed into sewage systems. Their active involvement is crucial in making these systems accessible and effective.
3. Sustainable Medication Use and Prescribing Practices. Pharmacists, in collaboration with prescribers, can guide the selection and use of medications that are less persistent or toxic to the environment. They can help optimize dosage regimens to prevent excess and advocate for reduced use of antibiotics, aligning therapeutic goals with ecological responsibility.
4. Participation in Policy Development and Environmental Governance. With their technical expertise and practical insights, pharmacists can contribute to the formulation of environmental regulations related to pharmaceuticals. This may include guidelines for manufacturing emissions, monitoring of pharmaceutical residues in water supplies, or regulations governing waste disposal.
5. Promotion of Green Pharmacy Principles. Pharmacists can support and drive the adoption of environmentally sustainable practices across the pharmaceutical supply chain. This includes encouraging eco-friendly packaging, supporting research into biodegradable drug formulations, and participating in efforts to assess and improve the environmental profiles of existing medications.

Beyond the Counter: Pharmacists as Environmental Advocates

Pharmacists must be recognized as integral stakeholders in creating a sustainable pharmaceutical future. Their role should extend beyond dispensing to include active participation in:

- Research initiatives focused on pharmaceutical pollution and its mitigation;
- Advising municipal and national authorities on drug waste management strategies;
- Embedding environmental considerations into chronic disease management and long-term therapy planning;
- Promoting the use of pharmaceuticals with a favorable environmental risk profile when clinically appropriate.

Ultimately, the core principles of sustainable pharmaceutical practice—rational prescribing, informed patient behavior, and ecologically sound disposal—can only be achieved through the proactive engagement of pharmacists. By aligning clinical effectiveness with ecological awareness, pharmacists contribute not only to patient health but also to the preservation of our planet's ecological balance.

In an era where healthcare and sustainability are increasingly intertwined, pharmacists are no longer just dispensers of medicines—they are environmental stewards, educators, and policy influencers. Their leadership is essential to transforming eco-pharmacovigilance from a theoretical framework into a practical, everyday reality in global health systems [11,12].

Conclusion

The environmental impact of pharmaceuticals has become a major global issue, with pharmacists in a unique position to play a central role in addressing this challenge. Each stage of the pharmaceutical supply chain—manufacturing, distribution, use, and disposal—requires specific actions to reduce its ecological impact.

Pharmacists have the opportunity to lead by example, integrating sustainability into pharmaceutical practice. This requires a thorough reevaluation of prescribing, dispensing, and disposal practices to minimize the environmental footprint of medications.

Eco-pharmacovigilance is closely tied to the everyday tasks of pharmacists. To effectively contribute, they must be equipped with scientific knowledge and practical skills to manage pharmaceuticals responsibly, educate patients about appropriate usage and disposal, and support environmental preservation efforts. Eco-pharmacovigilance is a growing field that emphasizes the connection between pharmacological safety and environmental stewardship.

As the environmental effects of pharmaceuticals intensify, pharmacists' role in ensuring safe usage, disposal, and regulation of these products becomes even more critical. By embedding eco-pharmacovigilance principles into routine practice, pharmacists can help reduce the ecological risks associated with pharmaceuticals, promoting a healthier, more sustainable future.

Looking forward, pharmacists are poised to become key figures in the ecological chain, driving sustainable healthcare systems and environmental preservation. Their position at the intersection of public health and environmental protection allows them to shape practices and policies that balance therapeutic efficacy with ecological integrity.

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ფარმაცევტის სტრატეგიული როლი ეკოლოგიური საფრთხეების მართვაში

ნანა შაშიაშვილი

ასოცირებული პროფესორი საქართველოს ტექნიკური უნივერსიტეტი, ფარმაციის დეპარტამენტი
თბილისის სახელმწიფო სამედიცინო უნივერსიტეტი, სოციალური და კლინიკური ფარმაციის დეპარტამენტი

აბსტრაქტი

ფარმაცევტული პროდუქტით გამოწვეული გარემოზე ზემოქმედება თანამედროვე ეკოლოგიური საფრთხის მნიშვნელოვან წყაროს წარმოადგენს. მედიკამენტების აქტიური კომპონენტების გარემოში მოხვედრა, არასათანადოდ განადგურებული პრეპარატების, საკანალიზაციო სისტემების, სოფლის მეურნეობაში გამოყენებული ვეტერინარული საშუალებებისა და წამლის წარმოებიდან წარმოშობილი ნარჩენების მეშვეობით, ქმნის ფარმაკოეკოლოგიური რისკების კომპლექსს. ამ პრობლემის საპასუხოდ, თანამედროვე ფარმაცევტურ პრაქტიკაში ყალიბდება ახალი ინტერდისციპლინური დარგები: ფარმაკოეკოლოგია და ეკოფარმაკოუსაფრთხოება, რომლის მიზანია გარემოზე მედიკამენტების ზემოქმედების შეფასება, პრევენციული ღონისძიებების დაგეგმვა და მდგრადი განვითარების ხელშეწყობა. წარმოდგენილ კონტექსტში ფარმაცევტის როლი სცილდება ტრადიციულ ჩარჩოებს და მოითხოვს აქტიურ მონაწილეობას ეკოლოგიური რისკების მართვაში: არასასურველი პრეპარატების განადგურების პროცესების ზედამხედველობას, გარემოსდაცვითი განათლების პროგრამებში ჩართულობას, საზოგადოებრივი ცნობიერების ამაღლებას და გარემოზე ორიენტირებული საკანონმდებლო ინიციატივების მხარდაჭერას. გარდა ამისა, ფარმაცევტებს შეუძლიათ მნიშვნელოვანი წვლილი შეიტანონ ეკოლოგიურად უსაფრთხო საშუალებების პოპულარიზაციასა და იმ პროტოკოლების შემუშავებაში, რომლებიც ხელს შეუწყობს ეკოსისტემის გაჯანსაღებას. პროფესიული საქმიანობის გაფართოება გარემოსდაცვითი მიმართულებით სასიცოცხლოდ მნიშვნელოვანია ბიომრავალფეროვნების შენარჩუნებისა და გლობალური ეკოლოგიური გამოწვევების წინააღმდეგ ბრძოლის მიმართულებით.

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