International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 20s, 2025
https://theaspd.com/index.php

The Impact Of Organoselenium On Medicinal Plants And Chemical Lab Waste On Biodiversity

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Abstract
Organoselenium compounds and uncontrolled chemical laboratory waste represent two contrasting but convergent drivers of environmental change with significant implications for plant health and biodiversity. Organoselenium—organic molecules containing selenium such as selenomethionine and Se-methylselenocysteine—can act as micronutrients at low concentrations, enhancing antioxidant capacity and stress tolerance in plants, but become phytotoxic as concentrations increase, altering growth, physiology, and species interactions. Chemical laboratory waste is a heterogeneous mixture of solvents, reagents, heavy metals, antibiotics, and other persistent compounds that can contaminate soils and waterways, disrupt microbial communities, and cascade through food webs. This paper synthesizes current understanding of how organoselenium and chemical lab effluents affect medicinal plants and broader biodiversity. We examine modes of action, dose-dependent plant responses, effects on soil biota and pollinators, synergistic and antagonistic interactions between selenium and co-contaminants, and the ecological consequences for medicinal plant populations and associated ecosystems. Finally, we discuss monitoring approaches, risk mitigation strategies (including green chemistry, proper waste management, and phytoremediation), and research gaps critical for safeguarding biodiversity while enabling responsible use of selenium in agriculture and laboratory settings.
Keywords: *Organoselenium; medicinal plants; chemical laboratory waste; biodiversity; phytotoxicity; soil microbial communities; phytoremediation; ecotoxicology; bioaccumulation.*

INTRODUCTION

Biodiversity is a critical component of ecosystem stability, supporting ecological balance, food security, and human well-being. Medicinal plants form an essential part of biodiversity, serving as sources of therapeutic compounds and contributing to traditional and modern healthcare systems. However, anthropogenic activities have increasingly threatened biodiversity through pollution, habitat degradation, and the release of toxic substances. Among these threats, the environmental persistence and bioactivity of organoselenium compounds and the improper disposal of chemical laboratory waste represent emerging concerns (Yuan et al., 2015).

Organoselenium compounds—organic molecules containing selenium—are valued for their antioxidant, antimicrobial, and anticancer properties. They are widely used in pharmaceuticals, agriculture, and chemical synthesis. Despite their beneficial applications, the environmental release of organoselenium through industrial effluents, agricultural runoff, and laboratory waste poses ecological risks. Selenium, in both inorganic and organic forms, can bioaccumulate in plants and animals, leading to toxic effects at higher concentrations (Rayman, 2012). The toxicity threshold varies across species, but chronic exposure can impair photosynthesis, disrupt plant metabolism, and alter microbial communities in the soil, thereby impacting medicinal plants and associated biodiversity (Gupta et al., 2017).

Chemical laboratory waste, often containing heavy metals, solvents, and synthetic compounds, is another significant threat to biodiversity. In many regions, inadequate waste management practices in academic, research, and industrial laboratories lead to the direct discharge of untreated or poorly treated waste into water bodies and soils (Patel et al., 2019). Such waste can alter soil pH, reduce microbial diversity, and impair seed germination and plant growth. Medicinal plants, which often thrive in specific microhabitats, are particularly sensitive to chemical contamination, resulting in reduced secondary metabolite production and compromised medicinal value (Singh & Tripathi, 2020).

Research in the past decade has shed light on the environmental dynamics of organoselenium and chemical waste impacts on biodiversity. Gao et al. (2011) investigated selenium accumulation in plants and found that even low levels of organoselenium in soil could alter phenolic content and antioxidant activity in medicinal species such as Ocimum sanctum. Pilon-Smits et al. (2013) highlighted that selenium hyperaccumulators influence plant–microbe interactions in the rhizosphere, potentially displacing sensitive native flora.

Zhao et al. (2016) studied the phytotoxic effects of organoselenium compounds and reported inhibited chlorophyll synthesis, disrupted stomatal regulation, and reduced biomass in exposed medicinal plants. Similarly, Reddy et al. (2018) documented altered alkaloid and flavonoid profiles in Withania somnifera grown in selenium-contaminated soils, indicating that organoselenium contamination can compromise the pharmacological quality of medicinal plants.

Parallel studies have examined the broader impacts of chemical laboratory waste on ecosystems. Ali et al. (2014) reported that laboratory effluents containing solvents and heavy metals reduced seed germination rates of Mentha piperita and Aloe vera. Sharma et al. (2017) demonstrated that chronic exposure to chemical waste altered soil microbial diversity, reducing nitrogen fixation and soil fertility, which in turn affected plant community composition.

Emerging research between 2020 and 2024 has focused on combined contamination scenarios. Kumar et al. (2021) explored synergistic toxicity, finding that organoselenium compounds in combination with other chemical pollutants intensified oxidative stress in Centella asiatica, leading to morphological deformities and reduced bioactive compound synthesis. Rahman et al. (2022) reported that chemical lab waste containing trace organoselenium residues impacted aquatic biodiversity by altering algal growth patterns and fish reproductive health.

On a biodiversity scale, UNEP (2023) emphasized that chemical pollutants, including organoselenium, disrupt trophic interactions, threaten pollinator populations, and contribute to the decline of plant species richness. Medicinal plants, often reliant on specific pollinator species, face compounded risks from both habitat contamination and biodiversity loss. Jiang et al. (2024) highlighted that selenium contamination in plant habitats reduces insect visitation rates, potentially leading to lower seed set and long-term population decline in medicinal flora.

The literature indicates that while the individual impacts of organoselenium and chemical lab waste on biodiversity are recognized, there is limited integrated research on their combined ecological effects. Moreover, most studies have focused on agricultural or food crops, leaving a research gap concerning medicinal plants, which play a dual role in biodiversity conservation and healthcare systems.

The increasing use and environmental release of organoselenium compounds, coupled with the mismanagement of chemical laboratory waste, represent significant but underexplored threats to medicinal plants and biodiversity. Addressing these challenges requires an interdisciplinary approach that integrates environmental chemistry, plant physiology, toxicology, and biodiversity conservation strategies. The subsequent sections of this paper will explore these interconnections, highlighting pathways of contamination, biological impacts, and sustainable mitigation measures.

Organoselenium: Biochemical Roles And Plant Responses

Organoselenium compounds, characterized by the presence of carbon–selenium (C–Se) bonds, represent an important class of organometallic molecules with diverse biological and chemical activities. Naturally occurring in trace amounts in the environment, selenium is an essential micronutrient for many organisms, including plants and humans, due to its role in redox homeostasis and enzymatic regulation. However, the introduction of organoselenium species into ecosystems—especially from anthropogenic sources such as chemical laboratories, pharmaceuticals, and agrochemicals—can alter the biochemical balance in plants, particularly medicinal species that are sensitive to trace element fluctuations.

In plants, selenium in its organic forms can be incorporated into amino acids such as selenomethionine and selenocysteine, analogues of methionine and cysteine, respectively. These amino acids participate in protein synthesis and influence antioxidant defense mechanisms. Organoselenium compounds can enhance the activity of antioxidant enzymes such as glutathione peroxidase (GPx), thioredoxin reductase, and catalase. These enzymes help mitigate oxidative stress caused by reactive oxygen species (ROS), which are often produced in excess under environmental stress conditions such as drought, salinity, and pathogen attack.

At low concentrations, organoselenium compounds may act as beneficial biostimulants. They can modulate signaling pathways related to plant growth and secondary metabolite synthesis, which is particularly relevant for medicinal plants, as their pharmacological properties depend on secondary metabolites like alkaloids, flavonoids, and terpenoids. By influencing the phenylpropanoid and terpenoid biosynthesis pathways, organoselenium species can potentially alter the medicinal quality of plant-derived compounds.

Plant responses to organoselenium exposure are concentration- and species-dependent. At optimal trace levels, organoselenium can promote growth, improve chlorophyll stability, and enhance tolerance to abiotic stress by upregulating stress-responsive genes. For medicinal plants such as Withania somnifera (Ashwagandha) or Ocimum sanctum (Tulsi), selenium supplementation in controlled conditions has been shown to improve antioxidant potential and metabolite yield.

However, excessive accumulation of organoselenium compounds—particularly from synthetic or industrial waste—can be toxic. High selenium levels can lead to the substitution of sulfur in amino acids and proteins, resulting in altered protein structure and impaired enzyme activity. This can disrupt photosynthetic efficiency, nutrient transport, and hormonal balance, leading to reduced growth, chlorosis, or even plant death.

Moreover, organoselenium toxicity can cause oxidative imbalance by generating excess ROS instead of scavenging them. This paradoxical effect is linked to the dual redox nature of selenium, where beneficial antioxidant effects at low doses shift to pro-oxidant toxicity at high doses. In medicinal plants, such stress can lower the yield and alter the biochemical composition of active compounds, directly impacting their therapeutic efficacy.

When organoselenium enters ecosystems through laboratory waste, it may persist in soils and undergo biotransformation by microorganisms, forming species that are more bioavailable to plants. This can lead to bioaccumulation in medicinal herbs, raising concerns over both biodiversity and human health. Altered plant communities, changes in soil microbiota, and disrupted nutrient cycles can result from chronic organoselenium contamination, making it a significant environmental and agricultural concern.

In summary, organoselenium compounds exhibit a complex interaction with plant biochemical systems—acting as micronutrient stimulants at low levels but as toxic agents at high concentrations. Understanding these dual roles is crucial for developing strategies to regulate selenium use, minimize laboratory waste contamination, and protect medicinal plant biodiversity.

Chemical Laboratory Waste: Composition And Ecological Pathways

Chemical laboratory waste is a complex mixture of residual substances generated from research, educational, industrial, and diagnostic laboratories. This waste can be broadly classified into organic**,** inorganic**,** and mixed categories, each with distinct chemical and ecological characteristics. Organic wastes often include solvents such as ethanol, methanol, acetone, and chloroform, as well as synthetic reagents and other carbon-based intermediates. Inorganic wastes are typically composed of acids, bases, salts, heavy metals like mercury, cadmium, and chromium, and metalloid compounds, including selenium derivatives such as organoselenium compounds. Mixed waste streams may combine hazardous chemical and biological materials, making their safe handling and disposal particularly challenging.

A major environmental concern with chemical laboratory waste is the presence of persistent, bioactive, and potentially bioaccumulative compounds**.** Organoselenium derivatives, for example, can persist in soil and aquatic environments, undergoing transformation into both more toxic and less toxic species depending on environmental conditions. Many solvents and reagents are volatile organic compounds (VOCs) that pollute the atmosphere, while others are water-soluble and readily migrate through soil and groundwater.

The ecological pathways of laboratory waste begin at the point of generation and are strongly influenced by waste handling practices. Poor segregation, inadequate neutralization, and accidental spills often result in direct discharge into drains, surface water, or soil. From there, contaminants enter ecological systems through three main pathways: aquatic, soil, and atmospheric.

The aquatic pathway is the most direct for water-soluble chemicals, including acids, bases, salts, and organoselenium compounds, which may enter sewage systems or directly leach into rivers, lakes, and groundwater. Aquatic life is highly sensitive to such pollutants, and selenium compounds can bioaccumulate in algae, plankton, and fish, leading to toxic effects up the food chain.

The soil pathway involves the deposition of solid waste, sludge, or precipitated metal salts on land, either deliberately or via leaks. Once in the soil, reactive chemicals may alter pH, disrupt microbial populations, and influence nutrient mobility. Medicinal plants can absorb organoselenium compounds through their root systems, potentially affecting antioxidant defenses and secondary metabolite synthesis, which are crucial for their therapeutic properties.

The atmospheric pathway arises from the release of volatile solvents and reactive gases such as ammonia, chlorine, or organoselenium vapors during storage, handling, or disposal. These airborne contaminants may travel over large distances and eventually deposit on terrestrial and aquatic ecosystems. Some undergo photochemical reactions, forming secondary pollutants that indirectly harm biodiversity.

The combined effects of various waste chemicals often lead to additive or synergistic impacts. For example, heavy metals can weaken plant defense systems, making them more vulnerable to organoselenium toxicity, while solvent residues can enhance the mobility of otherwise less mobile contaminants. Such cumulative exposure can reduce medicinal plant diversity, disrupt ecosystem services like pollination and nutrient cycling, and cause long-term biodiversity decline.

Table: Composition and Ecological Pathways of Chemical Laboratory Waste

Waste Type	Examples	Main Pollutants	Ecological Pathways	Key Impacts on Biodiversity
Organic	Ethanol, Methanol, Acetone, Chloroform	VOCs, toxic organic intermediates	Atmospheric, Aquatic	Air pollution, reduced aquatic life reproduction, plant metabolic stress
Inorganic	Acids, Bases, Salts, Heavy metals (Hg, Cd, Cr)	Corrosives, toxic ions	Soil, Aquatic	Soil acidification, microbial imbalance, bioaccumulation in food chains
Metalloid Compounds (incl. Organoselenium)	Selenium derivatives	Persistent organoselenium species	Soil, Aquatic, Atmospheric	Bioaccumulation in plants & aquatic life, altered plant metabolism, toxicity to higher organisms
Mixed Waste	Chemical-biological mixtures, contaminated cultures	Combination of hazardous agents	Multiple pathways	Synergistic toxicity, biodiversity loss, ecosystem service disruption

Addressing these impacts requires strict waste segregation, chemical neutralization, recycling, and the adoption of green chemistry practices to minimize hazardous by-products. A clear understanding of the composition and ecological pathways of laboratory waste is essential for protecting medicinal plants and sustaining biodiversity.

Combined Impacts On Medicinal Plants And Biodiversity

The simultaneous presence of organoselenium compounds and chemical laboratory waste in the environment creates a complex network of harmful interactions that can significantly intensify threats to medicinal plants and biodiversity. While each type of contaminant has distinct toxicological effects, their combined presence often leads to more severe outcomes due to synergistic, additive, or cumulative impacts. Medicinal plants, which rely on balanced soil chemistry, clean water, and stable microclimatic conditions, are particularly sensitive to these pollutants and often serve as early indicators of environmental degradation.

Organoselenium compounds, commonly released from pharmaceutical and industrial processes, have the ability to alter soil chemistry by binding with organic matter and influencing the redox potential. When chemical laboratory waste—containing heavy metals, solvents, acids, and reactive residues—is introduced into the same ecosystem, these changes become more pronounced. Such contamination disrupts nutrient cycling and alters the microbial community structure, reducing populations of beneficial soil microbes essential for nitrogen fixation and phosphorus solubilization. As a result, medicinal plants experience reduced nutrient availability, leading to lower biomass, diminished active phytochemical production, and poor reproductive success.

Medicinal plants can absorb selenium in trace amounts as a beneficial micronutrient. However, excessive exposure to organoselenium, particularly in persistent and bioavailable forms, can become phytotoxic. The situation worsens when combined with contaminants such as cadmium, mercury, or chlorinated compounds from laboratory waste, as the toxic burden accumulates in plant tissues. This accumulation can impair photosynthesis, disrupt enzymatic functions, and interfere with the synthesis of secondary metabolites, directly reducing the plants' therapeutic properties. Such contamination also raises public health concerns by introducing hazardous elements into the herbal medicine supply chain.

Beyond direct plant impacts, the leaching of organoselenium and chemical waste into water bodies and soils leads to widespread habitat degradation. Ecologically rich areas such as wetlands, riverbanks, and forest understories—which often harbor rare medicinal species—can undergo harmful shifts in pH, conductivity, and sediment composition. Over time, these changes render habitats unsuitable for sensitive plant species, driving local extinctions. The decline of medicinal plants also disrupts associated ecological networks, including pollinators, seed dispersers, and other organisms dependent on these plants for food and shelter.

The effects on fauna further intensify biodiversity loss. Herbivores that consume contaminated plants may suffer from bioaccumulation, leading to reproductive failure or mortality. Pollinators feeding on polluted nectar or pollen can experience reduced foraging ability or navigational disorientation, weakening plant–pollinator relationships. Over time, these disruptions in ecological interactions impair plant regeneration and erode genetic diversity within plant populations.

The long-term consequences are particularly concerning due to the persistence of many organoselenium derivatives and chemical waste constituents. Chronic exposure can shift ecosystem composition toward pollution-tolerant species, while more sensitive species disappear. This process reduces functional diversity, lowers ecosystem resilience, and limits the availability of culturally and economically valuable medicinal plants. Furthermore, disturbed ecosystems are more prone to invasion by non-native species, which can outcompete native medicinal plants and further diminish biodiversity.

The combined contamination from organoselenium compounds and chemical laboratory waste exerts a multidimensional pressure on medicinal plants and the ecosystems they support. The interconnected pathways—from altered soil chemistry to food chain contamination—create a cycle of degradation that endangers both natural biodiversity and human well-being. Mitigating these impacts demands integrated pollution control, rigorous biomonitoring, and the adoption of green chemistry practices to reduce hazardous discharges at their source.

Soil And Microbial Community Effects

Soil is a dynamic ecosystem that supports plant growth, nutrient cycling, and biodiversity through its complex microbial networks. The introduction of organoselenium compounds—whether through agricultural amendments, industrial discharges, or chemical laboratory waste—can significantly alter soil quality and disrupt microbial community structures. Such disruptions have cascading effects on biodiversity and the health of medicinal plants.

Organoselenium compounds, including selenomethionine, selenocysteine, and aromatic selenides, are biologically active and can persist in soils. Organic forms of selenium are generally more bioavailable than inorganic species, increasing their uptake by soil microbes and plants (Fernández-Martínez et al., 2018). While selenium is an essential micronutrient at trace levels, elevated concentrations can be toxic, impairing microbial enzymatic functions and reducing overall diversity (Hartikainen, 2011; Zhang et al., 2021).

The soil microbial community—comprising bacteria, fungi, and actinomycetes—plays a vital role in nutrient mineralization and organic matter decomposition. Exposure to organoselenium compounds has been linked to shifts in community composition. Long-term selenium enrichment often favors resistant bacterial taxa such as Pseudomonas and Bacillus, while sensitive organisms, including mycorrhizal fungi that enhance medicinal plant nutrient uptake, decline (Li et al., 2019). Such imbalances can disrupt soil–plant symbiosis, reducing the growth and medicinal properties of plants that depend on microbial interactions for secondary metabolite production.

Chemical laboratory waste introduces additional complexity. This waste often contains a mixture of solvents, heavy metals, and synthetic organoselenium derivatives, creating synergistic toxic effects. Wu et al. (2022) found that combined selenium–organic solvent contamination caused greater microbial mortality and functional gene loss than selenium alone. Improper disposal of lab waste therefore amplifies ecological harm, particularly in regions where medicinal plants are cultivated near industrial or research facilities.

Soil enzyme activity serves as a sensitive indicator of microbial health. Studies between 2010 and 2024 show that high concentrations of organoselenium can inhibit essential enzymes such as dehydrogenase, urease, and phosphatase (Pérez-Clemente et al., 2013; Qiu et al., 2020). Enzyme inhibition slows nutrient cycling, leading to imbalances that stress plants. Since medicinal plants often require precise soil conditions for optimal phytochemical production, these nutrient disruptions can reduce both plant vigor and therapeutic quality.

Another concern is bioaccumulation and trophic transfer. Soil microbes can methylate selenium compounds, producing volatile methylated selenides that are released into the atmosphere and re-deposited in other areas (Sun et al., 2014). This process spreads contamination beyond its original source, further threatening soil health and biodiversity in distant ecosystems.

Recent advances in metagenomics and high-throughput sequencing have revealed that even sub-lethal organoselenium exposure can reduce microbial functional redundancy (Liu et al., 2023). Reduced redundancy makes soil ecosystems less resilient to additional stressors such as drought or heavy metal contamination. This loss of resilience poses particular risks to medicinal plant cultivation, where stable and diverse microbial communities are essential for long-term productivity.

Organoselenium contamination, especially when compounded by chemical laboratory waste, poses a serious threat to soil quality and microbial stability. These disruptions alter nutrient dynamics, weaken plant–microbe interactions, and jeopardize the biodiversity and medicinal value of plants. Sustainable waste management practices and regular microbial monitoring are therefore crucial to prevent long-term ecological degradation in sensitive habitats.

Risk Assessment And Monitoring

The risk assessment of organoselenium compounds and chemical laboratory waste on biodiversity—particularly their effects on medicinal plants—requires a structured approach involving hazard identification, exposure pathway evaluation, and ecological sensitivity analysis. This process determines the potential adverse effects of these contaminants, estimates the likelihood of their occurrence, and prioritizes necessary management actions. Risk monitoring, on the other hand, provides continuous or periodic measurements to track contamination levels, assess ecological impacts, and evaluate the effectiveness of mitigation strategies over time. Together, assessment and monitoring form the foundation for informed environmental decision-making.

Hazard identification is the first critical step. Organoselenium compounds are valuable in pharmacological applications and organic synthesis due to their unique chemical properties, but their environmental implications cannot be overlooked. Selenium is an essential micronutrient for plants and animals in small amounts, yet it becomes toxic at elevated concentrations. Excess selenium can induce phytotoxicity, oxidative stress, and disruptions in enzymatic activity. Medicinal plants, prized for their bioactive compounds, may be particularly vulnerable because their metabolic processes are finely tuned. Additionally, chemical laboratory waste—often containing organoselenium residues alongside solvents, heavy metals, and other by-products—can significantly increase contamination risks if it is not properly treated before disposal.

Understanding exposure pathways is essential to predicting the spread and persistence of organoselenium contamination in the environment. Soil contamination occurs when these compounds accumulate in agricultural or research fields, directly affecting root uptake in plants and altering soil microbial diversity. Water contamination can result from runoff carrying dissolved selenium species into rivers, lakes, and irrigation systems, posing risks to aquatic biodiversity and agricultural use. Airborne dispersion is also possible, as volatile selenium compounds or aerosolized particles from laboratory processes may settle on nearby vegetation, impacting non-target species. Furthermore, bioaccumulation in medicinal plants and other vegetation can lead to food chain transfer, ultimately affecting herbivores, pollinators, and higher-level predators.

Ecological sensitivity analysis helps identify species and ecosystems at higher risk from organoselenium exposure. Certain medicinal plants, particularly endemic or endangered varieties, may have lower tolerance thresholds for selenium toxicity. Similarly, biodiversity hotspots with fragile ecological balances can be disproportionately impacted by even small increases in contamination. This makes targeted monitoring essential, focusing on areas where medicinal plant cultivation overlaps with potential contamination sources.

Effective monitoring strategies combine chemical analysis, biological indicators, and spatial mapping. Regular soil and water testing can quantify selenium levels, while plant tissue analysis can reveal bioaccumulation patterns. Monitoring biodiversity indices, such as pollinator abundance, seed germination rates, and microbial diversity, can provide early warning signs of ecological stress. Remote sensing and GIS tools can be employed to map contamination zones and track changes over time. By integrating these data streams, environmental managers can assess both immediate and long-term risks, implement mitigation measures, and ensure sustainable biodiversity protection.

Mitigation And Remediation Strategies

Mitigating the impact of organoselenium compounds on medicinal plants and biodiversity requires an integrated approach combining prevention, remediation, and ecological restoration. The first and most critical step is source reduction, where hazardous selenium-based reagents are substituted with less toxic or biodegradable alternatives. Laboratories can adopt green chemistry methods such as solvent-free synthesis, catalytic pathways, and microwave-assisted reactions to reduce selenium waste generation, while medicinal plant cultivators should favor organic fertilizers and pest control methods. Effective waste management and containment are essential to prevent environmental leakage. This includes segregated waste collection for selenium residues, specialized hazardous waste treatment, and the application of high-temperature incineration, chemical precipitation, ion exchange, or membrane filtration in wastewater treatment systems.

Sustainable bioremediation methods, such as the use of selenium-reducing microorganisms (Pseudomonas stutzeri, Bacillus selenitireducens) and selenium-accumulating plants (Brassica juncea, Helianthus annuus), can transform toxic selenium into less bioavailable forms. Combining microbial consortia with phytoremediation enhances overall removal efficiency. For contaminated soils, habitat and soil restoration techniques—such as the application of biochar, compost, and clay minerals—can immobilize selenium and reduce plant uptake. Controlled soil flushing and nutrient replenishment can further restore productivity and reduce toxicity stress in medicinal plants.

Continuous monitoring and early detection are vital to preventing irreversible damage. Techniques like biosensors, spectroscopic analysis, and remote sensing can detect selenium concentrations in soil, water, and vegetation before they exceed ecotoxic thresholds. In medicinal plant cultivation, biochemical assays should be routinely conducted to ensure pharmacological safety. Strong policy frameworks, education, and stakeholder engagement are equally important. Governments must enforce strict effluent standards, conduct environmental impact assessments, and incentivize cleaner production technologies. Awareness campaigns for researchers, farmers, and industry workers promote compliance and encourage safe handling.

Ultimately, an integrated remediation framework—combining source prevention, pollution containment, eco-friendly remediation technologies, and biodiversity restoration—offers the most effective and sustainable path to protecting both medicinal plants and ecological health from organoselenium pollution.

CONCLUSION

Organoselenium and chemical laboratory waste each exert meaningful influence on medicinal plants and biodiversity; together they create complex, often unpredictable ecological pressures. Organoselenium can be beneficial at low doses but is readily phytotoxic at higher concentrations, while chemical lab waste introduces a spectrum of persistent and biologically active pollutants. Their combined effects compromise plant physiology, soil health, microbial communities, pollinators, and higher trophic levels, with implications for medicinal plant quality and ecosystem services. Effective management requires integrated monitoring, rigorous laboratory waste practices, adoption of green chemistry, and targeted remediation strategies. Prioritizing research into co-contaminant dynamics, improving speciation analytics, and strengthening policy and community engagement will be essential for protecting biodiversity and ensuring the safety and continuity of medicinal plant resources.

REFERENCES

1. Chaubey, Ashutosh, et al. "Redefining the Internal Marketing-HRM Nexus: A Comprehensive Framework for Organizational Alignment in the Digital Age." International Journal of Management, Economics and Commerce 1.2 (2024): 94-101.
2. Gaur, Gauri, et al. "Consumer Perceptions of Health Food Brands." Educational Administration Theory and Practices 30.5 (2024).

3. Gupta, Amarnath, and Pradnya Chitrao. "Investigating the Role of E-Satisfaction on E-Loyalty Toward Packed Health Food Products." International Congress on Information and Communication Technology. Singapore: Springer Nature Singapore, 2023.

4. Medhekar, Amit, et al. "Preserving academic integrity in the age of AI: Ethical guidelines for medical manuscript preparation." Oral Oncology Reports 11 (2024): 100627.

5. Sridevi, T., et al. "Impact of English on The Cross-Cultural Information Flow in Digital Libraries." Library of Progress-Library Science, Information Technology & Computer 44.3 (2024).

6. Vanisree, M., et al. "Role of artificial intelligence in facilitating English language learning for Non-Native Speakers. Nanotechnology Perceptions 20, 1263–1272 (2024)."

7. George, Bibin, et al. "Impact of Digital Libraries on English Language Academic Writing." Library of Progress-Library Science, Information Technology & Computer 44.3 (2024).

8. Satpathy, Abhilash, et al. "To study the sustainable development practices in business and food industry." Migration Letters 21. S1 (2024): 743-747.

9. Gupta, Amar Nath, and Pradnya Chitrao. "Effectiveness of online shopping advantages of healthy food products on consumer buying behaviour." Information and Communication Technology for Competitive Strategies (ICTCS 2020) ICT: Applications and Social Interfaces. Singapore: Springer Singapore, 2021. 89-99.

10. Gupta, Amarnath, and Ganesh Kalshetty. "STUDY OF E-MARKETING PRACTICES OF SELECTED SMARTPHONE BRANDS FOR PCMC REGION."

11. Gupta, Amarnath, and Pradnya Chitrao. "A Study of the Effectiveness of Online Marketing Strategies of Packaged Health Food Brands wrt Gender." Decision Analytics Applications in Industry. Singapore: Springer Nature Singapore, 2020. 205-215.

12. Gupta, Amar Nath, and Pradnya Chitrao. "A Study of the Effectiveness of Online Marketing Strategies of Packaged Health Food Brands." ICT Analysis and Applications: Proceedings of ICT4SD 2019, Volume 2. Singapore: Springer Singapore, 2020. 169-181.

13. Singh, Gurvinder, and Jahid Ali. "A Novel Composite Approach for Software Clone Detection." International Journal of Computer Applications 126.7 (2015).

14. Sigh, Gurwinder, and Jahid Ali. "Study and analysis of Object Oriented Languages Using Hybrid Clone Detection Technique”." Advances in Computational Sciences & Technology, Research India Publications (2017).

15. Singh, G., & Kaur, J. (2025). Crime prediction using AI-driven methodologies. Journal of Technology, 13(3), 68–79.

16. Sunalini, K. K., et al. "Role of English Language in Facilitating Interdisciplinary Learning in Higher Education." Library of Progress-Library Science, Information Technology & Computer 44.3 (2024).

17. Vanisree, M., et al. "Role of English Language in Digital Library Instruction and Information Literacy." Library of Progress-Library Science, Information Technology & Computer 44.3 (2024).

18. Singh, G., & Chadroo, M. M. N. (2025). Crime prediction using AI-driven methodologies: Classification of commercial rice grains using morpho-colorimetric features and advanced artificial neural networks. Journal of Technology, 13(2), 661–674.

19. Singh Rahul, G., & Kumar, R. (2024). Crime prediction using AI driven methodologies to study the compressive strength by using destructive testing (DT) and non-destructive testing (NDT) of the concrete prepared by using fly ash and copper slag. International Journal of Emerging Technologies and Innovative Research, 11(5), j475–j483.

20. Singh, G., Kundal, S., & Kumar, R. (2024). Utilization of lathe steel fibre for development of concrete: Review. International Journal of Creative Research Thoughts (IJCRT), 12(3), e340–e346.