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Impact of U.S. Pesticides and Chemical Discharges Regulations on Environmental Sustainability

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Abstract

The policy approach and strategy of the United States on the regulation of pesticides and toxic chemical discharges presents significant implications on environmental sustainability and public health. This research paper focuses on the harmful impacts of indiscriminate toxic discharges into the environment, the intricacies of the United States' regulatory policies, examining their effectiveness in reducing the debilitating environmental effects of pesticide use and chemical discharges. This study assesses the impact of U.S. pesticide and toxic chemical discharge regulations on environmental sustainability and public health, with a focus on the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and Clean Water Act (CWA). Furthermore, through a comprehensive literature review and policy analysis, we identify regulatory gaps, enforcement challenges, and persistent toxic residues affecting vulnerable populations. The research findings show that while the policies of the United States have evolved to incorporate stricter controls and safety assessments, tremendous challenges remain in confronting the cumulative and long-term effects of chemical exposure on both human health and the environment. The study concludes with recommendations for strengthening biopesticide use, enhancing enforcement, and aligning policy reforms with environmental justice principles to promote long-term ecological sustainability. By strengthening these areas, the United States can better safeguard its ecosystems and public health, paving the way for a more sustainable and resilient future.

Keywords: Environmental Sustainability, Environmental Protection, Pesticides, Chemical Discharge, Pollution, Toxic Residues, Biopesticides, Regulatory Framework.

INTRODUCTION

Environmental protection is crucial for sustaining vital resources such as clean air, water and soil, supporting biodiversity, and promoting resilience against global challenges like climate change. The need for this protection cannot be underestimated, as it guarantees the option of a sustainable planet and favorable for a desired climatic condition (Belluck *et al*., 2006; Omoyajowo *et al*., 2023). The rise of industrialization and evolution having significantly increased has resulted into the degradation of the environment, as caused by anthropogenic activities (Akas *et al*., 2017; Omoyajowo *et al*., 2017; Farinmade *et al*., 2019; Raimi *et al*., 2019; Makengo, 2020; Swim *et al*., 2011; Omoyajowo *et al*., 2023). Consequent upon this, the continuous use and disposition of chemical discharges and pesticides have raised serious concerns as it directly speaks to prolonged harm to ecosystems, wildlife, and human health (Miraglia *et al*., 2009; Tudi *et al*., 2021; Sylvester *et al*., 2023; Jacob *et al*., 2023; Omoyajowo *et al*, 2024 a, b).

This has invariably led to the contamination of air, soil, food, and water sources, disrupting natural ecosystems, harming aquatic life, and degrading soil quality, thereby impacting plant growth and biodiversity. (Kawahara *et al*., 2005; Castillo *et al*., 2006; Gouin *et al*., 2008; Tuncel *et al*., 2008; Jayaraj *et al*., 2016; Kim *et al*., 2017; Oshatunberu *et al*., 2023) Moreover, they pose serious health risks to humans by entering the food chain and accumulating in food products (Aktar *et al*., 2009; Sylvester *et al*., 2023; Jacob *et al*., 2023), potentially causing cancer, reproductive problems, neurological disorders and cardio-vascular diseases (Omoyajowo *et al*., 2024a). Chemical discharges also pollute water bodies, harming aquatic ecosystems and compromising water quality (Bashir *et al*., 2020). The United States Geological Survey (USGS) found several pesticides in more than 90% of water and fish samples collected from US streams (Rose *et al*., 2018).

Additionally, they degrade soil quality, leading to erosion, loss of arable land, and decreased agricultural productivity. Furthermore, pesticides and chemical discharges disrupt ecological balance by killing non-target organisms (Mingo *et al*., 2017; Rajak *et al*., 2023), such as beneficial insects and pollinators, leading to imbalances in predator-prey relationships and nutrient cycling. Overall, addressing these concerns is crucial for safeguarding environmental health and ensuring sustainable ecosystems.

Environmental Impact and Concerns

Pesticide disperses through multiple pathways including air (via wind), water (via runoff or leaching), and biological vectors (affecting plants, animals and humans) (Singh, 2012; Fang *et al*., 2017).

Ecological Impacts of Pesticide Use

Pesticides and chemical discharges can severely impact various ecosystems, primarily through water pollution, soil contamination, and air pollution (Nguyen *et al*., 2008; Aktar *et al*., 2009; Rajak *et al*., 2023). Depending on the environmental conditions and the pesticide's chemical characteristics (Wu *et al*., 2018), degradation may take from hours to days or even years (Tcaciuc *et al*., 2018). The degradation of pesticides leads to the production of residues (i.e. yields different metabolites) that persist and transform not only in aquatic ecosystems but also in terrestrial areas for years, posing a threat to the environment (Barron *et al*., 2017; Tariq and Nisar, 2018). These contaminants often originate from agricultural runoff, industrial processes, and urban areas (States of Jersey, 2007; Kader *et al*., 2023; Oshatunberu *et al*., 2023), leading to significant harm to aquatic life and disruptions in food chains (Liu *et al*., 2016; Arunakumara *et al*., 2013; Mishra *et al*., 2019; Rakib *et al*., 2022).

Additionally, soil contamination from pesticides can affect soil fertility and agricultural productivity (Joko *et al*., 2017; Silva *et al*., 2019; Rajak *et al*., 2023), while airborne pollutants contribute to air quality deterioration and pose health risks to humans and ecosystems (Straathof, 1986; Brammall and Higgins, 1988; Locke *et al*., 1995; Aktar *et al*., 2009; Dreistadt, 2016). These chemicals also disturb ecological balance, harming non-target organisms and reducing biodiversity. Wildlife faces health risks from exposure to these pollutants, leading to reproductive abnormalities, developmental disorders, and population declines (Khan *et al*., 2010; NCBI, 2024; Beyond Pesticides, 2024). Moreover, the bioaccumulation and biomagnification of toxins in the food chain elevate risks, especially for apex predators.

Exposure to pesticides can also alter an organism's behavior, impacting its ability to survive. (Beyond Pesticide, 2024; Oludoye *et al.*, 2023). Many deformations have been found after exposure to hormone-mimicking pesticides classified as endocrine disruptors. The impacts of these chemicals include hermaphroditic deformities in frogs, pseudo-hermaphrodite polar bears with penis-like stumps, panthers with atrophied testicles, and intersex fish in rivers throughout the United States. Reproductive abnormalities have been observed in mammals, birds, reptiles, fish, and mollusks at exposure levels considered "safe" by the U.S. Environmental Protection Agency (EPA) (Beyond Pesticide, 2024). Effective regulation, pollution prevention, and sustainable practices are crucial to mitigate these adverse environmental impacts.

Human Health Risks

Pesticide and harmful chemical exposure can occur in humans and animals through four routes: mouth, skin, inhalation into the lungs and the eyes (Alegrı´a *et al*., 2005; Desalu *et al*., 2014; Jallow *et al*., 2017). Previous exposure of people, especially farmers, to pesticides has been linked to a range of health effects, spanning from acute poisoning to chronic diseases. Symptoms generally include skin and eye irritation, headaches, dizziness, coughing, nausea, blurred vision, fatigue, respiratory disorders, abnormal semen, and chronic kidney disease (Sankoh *et al*., 2016; Elahi *et al*., 2019).

One specific example of environmental concern regarding pesticide pollution in the United States is the case of chlorpyrifos. Chlorpyrifos is an organophosphate pesticide commonly used in agriculture to control pests on crops such as fruits, vegetables, and nuts in the European Union (Wołejko *et al*., 2022). Studies have shown that chlorpyrifos can contaminate waterways through runoff from treated fields, leading to adverse effects on aquatic ecosystems and non-target organisms such as fish and amphibians (Mackay *et al*., 2014; Bernal-Rey *et al*., 2020). Additionally, chlorpyrifos exposure has been associated with neurological and developmental issues in humans, particularly in children and farmworkers (George *et al*., 2014; Tudi *et al*., 2022).

Another example is the contamination of water sources with atrazine, a widely used herbicide in the US. Atrazine has been detected in surface water and groundwater, posing risks to aquatic organisms and potentially contaminating drinking water supplies (Loos *et al*., 2010; Wirbisky-Hershberger *et al*., 2017; Yılmaz *et al*., 2017; He *et al*., 2019). According to the risk assessment report of US Environmental Protection Agency (EPA), atrazine could have some harmful impact on fish, terrestrial, and aquatic plants, and it might also adversely affect reptiles and amphibians (Bohn *et al*., 2011). Studies have linked atrazine exposure to endocrine, reproductive and developmental abnormalities in amphibians and other wildlife, as well as potential health concerns for humans (Mukherjee *et al*., 2019)

Regulatory Challenges

Overview of the United States Environmental Protection Policy

Core U. S. Regulatory Frameworks for Pesticide and Chemical Control

The regulation of pesticide and chemical discharges which is dire for protection of human health and environment from potential harm revolves around frameworks on pesticide and chemical discharges encompasses various laws, agencies, and policies aimed at controlling the sale, distribution, use, and disposal of these substances (FAO and WHO, 2020).

In the United States, the Environmental Protection Agency (EPA) is the key body that focuses on the regulation of pesticides under two distinctive legislations; being the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). The FIFRA, a legislation enacted in 1947 has undergone series of amendment, and this piece of legislation addresses the need for evaluation, registration and regulation of pesticide to ensure their safety for both the human health and the environment. This was achieved under the regulatory body- EPA and it is worth to mention that under the FIFRA, manufacturers of pesticide must ensure compliance with the submission of data and relevant information as it deals with the toxicity, environmental impact and efficacy before such product can be released into the public for sale. The EPA further establishes requirements on compliance monitoring and labeling. Further, the Clean Water Act and the Clean Air Act addresses discharge of chemicals into water bodies and the

atmosphere by drawing clear regulations, as it also ensures the need for protection of the water and air quality. The need for ensuring regulation of pesticide and certification of applicators is carried out by State governments, who work along with the available federal regulations to ensure proper oversight.

The U.S. Environmental Protection Agency (EPA) is tasked with protecting human health and the environment (USEPA, 2023). Their roles and responsibilities include:

- Ensuring clean air, land, and water for Americans.
- Basing national efforts to reduce environmental risks on the best available scientific information.
- Administering and enforcing federal laws that protect human health and the environment, ensuring they are applied fairly and effectively as intended by Congress.
- Integrating environmental stewardship into U.S. policies related to natural resources, human health, economic growth, energy, transportation, agriculture, industry, and international trade.
- Considering various factors when establishing environmental policy, including community needs, individual concerns, business interests, and the perspectives of state, local, and tribal governments.
- Providing accurate information to all segments of society, enabling effective participation in managing human health and environmental risks.
- Overseeing the cleanup and revitalization of contaminated lands and toxic sites by potentially responsible parties.
- Reviewing chemicals in the marketplace for safety to protect human health and the environment.

These responsibilities reflect EPA's commitment to safeguarding public health and the environment through regulatory oversight, scientific research, and collaborative efforts with stakeholders.

The United States' EPA accomplish this by developing and enforcing regulations, giving grants for projects and scientific studies aimed at protecting human health and the environment, addressing and studying environmental issues, partnering with sponsors (businesses, non-profit organizations, and state and local governments), teaching people about the environment (understanding the basic issues and how protecting the environment is everyone's responsibility) as well as publishing information through written materials and the US EPA website, to inform the public about their numerous activities (USEPA, 2023).

FIPRA is very clear on the requirements for manufacturers of insecticide to make submissions of extensive data to the EPA before a product can be registered for sale or distribution in the US. Requirements for data needed is inclusive of laboratory studies and field trials that assesses the effectiveness, toxicity and potential environmental impact of the product. It is imperative to mention that the approach, which is regulatory in nature ensures proper pre-market testing, in a bid to ensure that products meet with safety standards in relation to human health and consequential environmental effects. Notwithstanding these comprehensive testing, there are limitations to the pre-market registration process. The narrow scope of data coupled with testing focused on short terms effects and standardized conditions is a key limiting factor, and similarly, the failure of pre-market registration to adequately address the cumulative and synergistic effects of multiple chemicals. FIFPRA's present regulation does not address the continuous monitoring of pesticide once they are out there in the market, and this lack of monitoring in the long term may mean that emerging threats which are associated to pesticide are undiscovered for a longer period until irreversible damage is done to the environment in a significant manner. The focus of FIFRA on premarket registration, however good to show that compliance is followed on rigorous testing before approval does not fully account for; and apply to the long-term ecological impact that may come up once there is widespread usage of the product.

Regulation of Pesticides

United States Environmental Protection Agency defined pesticide as any substance or combination of substances with the purpose of preventing, destroying, repelling, or mitigating any pest. It may also be used as a plant regulator, defoliant, or desiccant (USEPA, 2025b). Pesticide products consist of both "active" and "inert" components: An "active ingredient" is responsible for preventing, destroying, repelling, or mitigating pests, or serves

as a plant regulator, defoliant, desiccant, or nitrogen stabilizer (USEPA, 2025a). All remaining ingredients are termed "inert ingredients" as per federal regulations. These inert ingredients play a crucial role in enhancing product performance and usability (USEPA, 2023).

There is the need to establish the fact that some inert components can still have environmental or health impacts, despite being categorized as non-active as this is measured by the following reasons *vis:* the toxicity of inert ingredients. There are some inert ingredients; solvents inclusive used to deliver the active ingredients and can result in health issues when ingested or having close contact with the skin. Further, the endocrine disruption is another inert ingredient in focus here, as interference with body hormonal system can affect human or wildlife health and thus create a disruption in reproductive and developmental process. Similarly, inert components can have synergistic effects, despite its classification. This is because inert ingredients enhance the toxicity of the active ingredients and interactions leads to hazardous by-products. The criteria for determining whether a product is considered a pesticide, subject to EPA registration, are based on four factors (USEPA, 2021, 2025a, b).

Firstly, if the product's labeling or marketing implies pesticidal use or contains active ingredients for pesticide manufacture, it falls under the pesticide category. It therefore follows that if a product is marketed or labeled as a pesticide, there is a possible implication of impacting the environment through runoff or direct application and the need to mention that products consisting of persistent active ingredients may pose risk of bioaccumulation if chemical accumulation in the food chain leads to ecological damage.

Secondly, if the product is primarily composed of active ingredients with no significant commercial use other than for pesticidal purposes or pesticide manufacturing, it is classified as a pesticide (Damalas and Eleftherohorinos, 2011). On the second criteria, the ecological impact is felt in how the active ingredients can cause a disruption in the ecosystem, thereby resulting into reduction of biodiversity, alteration of food chains or causing harm to beneficial species. The bioaccumulation risk is dependent on the chemical's stability and the ability to bind to fatty tissues which can allow persistence through multiple trophic levels.

Thirdly, if the distributor or seller has knowledge, whether explicit or implicit, that the substance will be used for pesticidal purposes, it meets the criteria for pesticide classification (USEPA, 2025a). This is impactful ecologically where the knowledge can lead to considerations for suitable and less harmful alternatives to be proffered and because there is intentional use for pesticide purpose, the likelihood of it entering the environment increases.

Lastly, if the product is considered a plant regulator (i.e. if it accelerates or retards growth, maturation, or alters plant behavior beyond simple nutrition, as defined by FIFRA) (FIFRA, 2012; USEPA, 2025a). There is the need to mention that plant regulators can alter plant growth and development, thereby leading to a different ecosystem and this can cause absorption of chemical nature into the plants, thereby affecting the food chain. This determination depends on the claimed plant response or mode of action and the product's composition, with substances like plant hormones typically classifying a product as a plant regulator. However, certain products, such as those containing plant nutrients, inoculants, or soil amendments, are exempt from being considered plant regulators under FIFRA if they meet specific criteria outlined in the regulation.

Legal and Enforcement Discussions

Discussions on the enforcement of the violations of FIFRA will show that the legislation is not without its challenges, reflective on the law's effectiveness in ensuring the protection of human health and the environment from unsafe pesticide use. A consideration of the challenges in enforcement will show, firstly the identification and detection of violations. In most instances, the violation of this legislation takes places in private settings, thus creating a difficulty in detection, as regulators from EPA is not present during the use of these pesticide. Resources limitation faced and encountered by enforcement agencies further create a setback in ensuring total compliance. Resources constraint creates limitation in terms of inspections, investigations and compliance, and as such causes delayed responses and the overall impact of enforcement. The nature of the complex system of regulations on pesticide labeling are obvious, and a

misapplication of these regulations can lead to violations. Limitations in international trade also constitute a threat in ensuring compliance.

Pesticide manufactured abroad might not comply with FIFRA and thus, not meet up with US Standards. Penalties for violations range from civil penalties which can be inclusive of the misuse, improper registration and failure to comply with labeling requirements. Criminal penalties coupled with injunctions and orders also constitute part of EPA's power. FIFRA penalties and enforcement mechanisms, whilst made to protect the public also have its effectiveness compromised by factors such as limited resources, difficulties in detection and application of penalties and punitive measures not consistent with violations.

Overview of the Registration Process for Pesticides, Including Evaluation of Safety and Efficacy. Discussion of labeling requirements and restrictions on pesticide use.

The process of registering a pesticide typically mandates the manufacturer (registrant) to undertake, analyze, and finance numerous scientific examinations. These evaluations encompass aspects such as product chemistry, potential risks to humans and domestic animals, the environmental behavior of the pesticide, and its effects on non-target organisms (Damalas and Eleftherohorinos, 2011). The data required to support an application for a registration should cover all relevant aspects of the product during its full life cycle. They should include the identity and physical and chemical properties of the active ingredient and formulated product, analytical methods, human and environmental toxicity, proposed label and uses, safety data sheets, efficacy for the intended use as well as residues resulting from the use of the pesticide product, application methods, and storage and disposal practices (FAO, 2002; WHO, 2010; Damalas and Eleftherohorinos, 2011).

Evaluating a registration application entails assessing potential human health and environmental effects associated with the pesticide's use, requiring data from studies conducted in compliance with EPA testing guidelines (Damalas and Eleftherohorinos, 2011; USEPA, 2025 a, b). Risk assessments are developed to evaluate potential harm to humans, wildlife, fish, plants (including endangered species and non-target organisms), and the contamination of surface and groundwater. Human health risks range from short-term toxicity to long-term effects such as cancer and reproductive system disorders (USEPA, 2024).

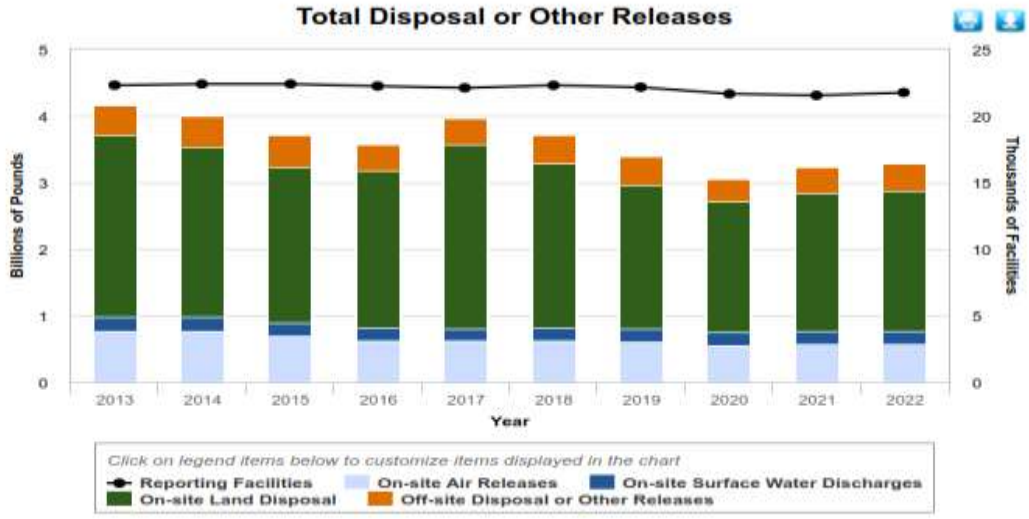
The evaluation process for pesticide registration and regulation involves assessing both human health and environmental risks (EPA, 2009; Damalas and Eleftherohorinos, 2011). Human health risks, including risks to sensitive groups like children and immune-suppressed individuals, are reviewed by examining data on aggregate, cumulative, and occupational exposures. Environmental risks are evaluated by considering potential groundwater contamination, impacts on endangered species, and the potential for endocrine-disruption effects (Adesina *et al.*, 2018). Comprehensive risk assessments are conducted based on scientific data, followed by peer review by scientific experts. Risk management decisions are made considering the results of the assessments and peer review, potential mitigation measures, and discussions with the applicant. If necessary, modifications to the product or labeling are required to mitigate risks before registration is granted, and new food tolerances may be established. The issuance of the registration is published in the Federal Register after completion of the process (USEPA, 2024). If the risk assessment indicates a high likelihood of hazard to wildlife or any phytotoxicity to non-target plants, the registration authority may require additional testing and extra data or require that the pesticide be applied only by certified individuals (i.e., restricted use). Alternatively, the registration authority may decide not to allow its use (Damalas and Eleftherohorinos, 2011).

The EPA regulates pesticide labeling by reviewing and approving all label language before a pesticide can be sold or distributed in the United States. The primary goal of the label is to provide clear directions for effective product performance while minimizing risks to human health and the environment. It is a violation of federal law to use a pesticide in a manner inconsistent with its labeling, as the label is considered a legal document by the courts. Following labeling instructions carefully and precisely is essential to ensure safe and effective use of pesticides (USEPA, 2024).

Compliance and enforcement of pesticide regulations require adherence to both federal and state laws. States typically have primary authority for monitoring compliance and enforcing regulations related to illegal pesticide use. This responsibility is commonly assigned to a state's department of agriculture, although other state agencies, such as environmental agencies, may also be involved in enforcement efforts (USEPA, 2024).

Regulation of Chemical Discharges

The release or disposal of Toxics Release Inventory (TRI) chemicals into the environment can occur through various means, including direct emission into the air or water, as well as disposal onto land. Facilities handling TRI chemicals must adhere to regulatory requirements and restrictions aimed at safeguarding human health and the environment (USEPA, 2024). These regulations necessitate reporting the quantities of TRI-listed chemicals released into the environment. Analyzing data from various reports, alongside other sources help, to identify potential community concerns, assess health impacts from those chemical discharges, and identify opportunities for engaging with facilities to implement pollution prevention measures (USEPA, 2024). It is important to understand that the quantity of chemical releases alone is not necessarily an indicator of human health outcomes or environmental impacts. Other important factors that contribute to potential harm and risks from releases of chemicals are chemical's relative toxicity, the potential for human exposure, route, frequency and duration of exposure, and the susceptibility of exposed individuals (Omoyajowo *et al.*, 2024a,b).



Source: https://www.epa.gov/trinationalanalysis/potential-risks-tri-chemicals

The graph illustrates the 10-year trend in total releases (or disposal) of chemicals. Various factors influence this trend, such as shifts in production rates, waste management techniques, raw material compositions, and pollution control technologies at facilities. Total releases of TRI chemicals saw a notable 21% decrease, primarily attributed to reduced disposal to land from metal mines. Air releases decreased by 26%, surface water discharges by 9%, on-site land disposal by 23%, and off-site disposal by 8%. Reductions in air releases from electric utilities were a significant contributor. However, the number of reporting facilities declined by 2%. In contrast, from 2021 to 2022, total releases increased by 1%, mainly due to heightened land disposal, driven by the natural gas processing sector's reporting expansion under TRI requirements (USEPA, 2024).

Enforcement and Compliance

Enforcing environmental laws is a key aspect of EPA's strategy to safeguard public health and the environment. The agency focuses on ensuring compliance with environmental regulations and takes civil or criminal enforcement action when necessary. Environmental justice is a top priority, with EPA integrating it into enforcement efforts by planning, identifying cases, and developing

solutions to address pollution in communities disproportionately affected by environmental hazards (USEPA, 2024).

Enforcement programs under environmental statutes encompass both civil and criminal measures to address pollution violations. The distinction between criminal and civil enforcement lies in the legal standard and intent. Civil liability arises from the mere existence of an environmental violation, irrespective of intent, while criminal liability requires some level of intent. Most EPA investigations focus on "knowing violations," where the responsible party is aware of the facts leading to the violation, typically categorized as felonies in federal environmental statutes. Examples of knowing violations include intentional disposal of pollutants without a permit or failure to install mandated pollution control devices (USEPA, 2024).

In civil cases involving environmental law violations, the burden of proof is based on "the preponderance of the evidence," meaning the evidence presented must be convincing and more likely to be true than not true, with a greater than 50 percent chance of being true. Defendants in civil suits can either be found liable after a trial or reach a settlement with the government, where they must meet the terms of the settlement without necessarily admitting guilt. In criminal cases, guilt must be established "beyond a reasonable doubt," a higher standard than civil liability, and if a defendant pleads guilty or is convicted, there is no question of legal wrongdoing, as they have committed the crime legally (USEPA, 2024).

In criminal prosecutions for environmental violations, individuals can face imprisonment consequently. Civil defendants found liable may incur monetary penalties, be subject to injunctive relief (such as installing pollution control equipment) or undertake actions to improve the environment. If a criminal defendant is convicted or pleads guilty, they may face fines or restitution to the U.S. Treasury for cleanup costs, compensation for harm caused, or even incarceration. Cleanup enforcement involves identifying responsible parties, negotiating cleanup efforts, or mandating cleanup actions, often involving payment for cleanup by the responsible parties or the EPA. Federal facilities enforcement ensures compliance with environmental regulations and statutes among federal facilities. (USEPA, 2024).

Enforcement actions taken could be in the form of civil administrative actions, civil judicial actions or criminal actions. Civil Administrative Actions are undertaken by EPA or state agencies outside of judicial court processes. These actions may involve issuing notices of violation, Superfund notices, or orders directing individuals or entities to comply or undertake cleanup efforts. Civil Judicial Actions involve formal lawsuits filed in court against parties that have failed to adhere to statutory or regulatory requirements, administrative orders, or obligations related to cleanup efforts. These cases are typically handled by the U.S. Department of Justice or State Attorneys General on behalf of states. Criminal Actions are pursued against companies or individuals for serious or willful violations. These actions can lead to fines or imprisonment and are typically reserved for the most severe violations (USEPA, 2024).

Civil enforcement actions aim to address violations of environmental laws through various measures. Settlements, often reached through consent agreements or decrees, provide agreed-upon resolutions to enforcement cases. Civil penalties, monetary assessments, serve as incentives for compliance and compensate for the severity of violations. Injunctive relief mandates actions to achieve compliance and may include mitigation measures to offset harm caused by violations. Additionally, Supplemental Environmental Projects (SEPs) are voluntary initiatives undertaken by violators to enhance the environment beyond required corrective actions. Together, these measures work to ensure accountability, deter future violations, and promote environmental protection and restoration (USEPA, 2024).
Criminal enforcement involves federal, state, or local fines imposed by a judge as part of sentencing. These penalties may include restitution to affected parties, such as covering the costs of responding to environmental incidents. Incarceration, or prison time, may also be ordered for individuals found guilty of serious violations (USEPA, 2024).

Enforcement and Compliance History Online (ECHO) is one of the EPA's enforcement and compliance assurance programs that uses data in

many areas, including managing the program and assessing performance. ECHO provides fast, integrated searches of EPA and state data for more than 800,000 regulated facilities. ECHO focuses on inspection, violation, and enforcement data for the Clean Air Act (CAA), Clean Water Act (CWA) and Resource Conservation and Recovery Act (RCRA) and includes Safe Drinking Water Act (SDWA) and Toxics Release Inventory (TRI) data (USEPA, 2024).

Future Directions and Challenges

The Environmental Protection Agency (EPA) is engaged in ongoing efforts to enhance environmental protection policies. This involves regular updates and revisions to regulations to address emerging environmental challenges and scientific advancements. Additionally, EPA promotes pollution prevention programs to minimize the release of harmful substances into the environment and encourages the adoption of cleaner technologies and practices. Enforcement and compliance activities play a crucial role in ensuring adherence to environmental laws and regulations, deterring pollution, and protecting public health and ecosystems. Environmental justice considerations are integrated into EPA's policies and programs to address disparities and promote equitable access to environmental benefits, particularly for marginalized communities. Collaboration and partnerships with various stakeholders, including governments, NGOs, industry, and academia, facilitate the implementation of effective environmental protection measures and solutions. Through these ongoing efforts, EPA strives to safeguard human health, preserve natural resources, and promote sustainable development nationwide.

The EPA faces key challenges and areas for improvement including environmental justice, climate change mitigation, pollution control, chemical safety, enforcement and compliance, and resource management. These challenges necessitate enhanced outreach to marginalized communities, strengthened regulations on greenhouse gas emissions, improved monitoring of pollution, and more effective enforcement of environmental laws. Adequate funding and collaboration with stakeholders are essential to address these challenges and fulfill the EPA's mission of protecting human health and the environment.

Potential future developments or changes in regulations may include stricter standards for air and water quality, increased focus on renewable energy and sustainability initiatives, enhanced regulation of hazardous chemicals and pesticides, and updated guidelines for waste management and pollution prevention. Additionally, there may be efforts to address emerging environmental issues such as microplastic pollution, biodiversity loss, and the impacts of emerging contaminants on ecosystems and human health. Collaboration with international organizations and adoption of innovative technologies could also shape future regulatory frameworks to address global environmental challenges more effectively.

Biopesticides as alternative to chemical pesticides

While there are many chemically derived pesticides, there is a group of pesticides referred to as Biopesticides. Biopesticides are pesticides made from natural sources like animals, plants, bacteria, and minerals. Examples include canola oil and baking soda. As of August 31, 2020, there were 390 registered biopesticide active ingredients. Biopesticides fall into three main classes: biochemical pesticides, microbial pesticides, and plant-incorporated protectants (PIPs). Biochemical pesticides use naturally occurring substances to control pests through non-toxic mechanisms, including interfering with mating or attracting pests to traps using plant extracts. Microbial pesticides contain microorganisms like bacteria, fungi, or viruses as the active ingredient, with each targeting specific pests. Bacillus thuringiensis (Bt) is a widely used microbial pesticide, with different strains targeting various insect larvae species. Plant-Incorporated-Protectants (PIPs) are substances produced by genetically modified plants, such as those containing Bt genes, which enable the plant to produce its own pesticide. These substances are also regulated by the EPA.

Biopesticides are typically less toxic than conventional pesticides and have a narrower spectrum of impact, targeting only the intended pest and closely related organisms. They are effective in small quantities and decompose quickly, minimizing exposure and pollution issues

associated with conventional pesticides. When integrated into Integrated Pest Management (IPM) strategies, biopesticides can significantly reduce reliance on conventional pesticides while maintaining high crop yields.

The EPA encourages the use of biopesticides by establishing dedicated divisions like the Biopesticides and Pollution Prevention Division, which facilitates the registration of biopesticides and promotes their integration into IPM programs. Compared to conventional pesticides, biopesticides require less data for registration, often taking less than a year for approval. However, the EPA conducts thorough reviews to ensure biopesticides' safety, requiring registrants to submit various studies and information on composition, toxicity, and degradation. Despite the expedited registration process, the EPA prioritizes the protection of human health and the environment when approving biopesticides.

CONCLUSION

Overall, the EPA's policies and regulations on pesticides and chemical discharges are aimed at protecting human health, safeguarding ecosystems, and promoting sustainable environmental management practices across the United States. These efforts require collaboration with stakeholders, including industry, academia, non-governmental organizations, and the public, to achieve effective pollution prevention and environmental stewardship.

Notwithstanding the progressive impacts of the current U.S. policies, many challenges remain unsolved, especially as it concerns regulatory enforcement and the perennial impacts of chemical use on the environment. The continued presence of pesticides residues in soil and water, coupled with the potential for bioaccumulation and biomagnification in food chains, heightens the dire need for comprehensive regulatory measures. Moreover, the existing policy frameworks do not adequately address the disproportionate impact of environmental pollution on marginalized communities, hence raising critical concerns about environmental justice. It is imperative that future policy reforms incorporate comprehensive risk assessments that account for these cumulative effects and prioritize the protection of vulnerable populations.

In prospects, the need to enhance enforcement and monitoring cannot be under-emphasized. This is achievable through enhanced funding for EPA and state agencies and adoption of modern technology to track chemical applications and run off. This could be applicable, in instance such as the perceived the Chesapeake Bay and Mississippi River pesticide runoff, watersheds and chemical emissions have led to serious environmental consequences. This will ultimately address the issue of insufficient resources available to tackle enforcement and help to identify and prevent the impact of harmful chemicals within the ecosystem. Stiffer penalties for violation if implemented for violators of FIFRA, and imposition of heavy fines will go a long way in checking the use of pesticides and chemical discharges. Pesticide poisoning in California is a perfect example as the incident exposed harmful practices as it relates to the use of the application of pesticide, and it is consequent upon these those stiffer penalties be made to ensure full compliance to FIFRA.

The call for public awareness and education is also imperative and cannot be jettisoned. There should be a massive launch for public awareness and campaign about the associated risks with the use of pesticide, as the misuse and misapplication of pesticide and chemical can result to a degrading environmental use, as this covers the knowledge gap among small scale businesses within the US and the public at large. Promotion and encouragement of research on friendly and environmentally friendly initiatives is also suggested. This could be achieved by funding research into bio-degradable, non-toxic means to ensure traditional and less harmful chemical pesticide, as this will address the gap of chemical innovations. The integration of innovative technologies and sustainable practices, such as the use of bio-pesticides, will be crucial in minimizing the reliance on harmful chemicals. Also, there is a dire need for consistent monitoring, transparent reporting, and continuous public engagements to ensure that policies remain adaptive to emerging environmental challenges. By strengthening these areas, the United States can lead the way in fostering a healthier, more resilient environment, ultimately achieving a balance between economic growth and environmental preservation.

In a bid to enhancing the extent of the US Pesticide and chemical discharge regulations on environmental sustainability, the following are research areas future and further research could concentrate on, *viz:*

i. The need for the investigation of the level of effectiveness, economic feasibility of bio-pesticides as alternatives to chemical pesticides, ensuring biopesticides viability. The essence of this research could focus on their prospects in reduction of chemical residues in soil and water and their role in integrated pest management strategies.
ii. An assessment and thorough evaluation of adjustments in EPA made recently is encouraged. This is necessary to determine the new position on requirements for labeling of pesticides, improved risk assessment models as this would aid in pointing out areas for further improvement and refine policy decisions.

Data Availability Statement

The data supporting the findings of this study are all publicly available.

Ethics Statement

This study adheres to ethical guidelines and best practices for environmental research. The analysis is based on publicly available environmental data, regulatory documents, and scientific literature.

Author Contributions

KO was responsible for conceptualization, methodology, data analysis, and writing the original draft. SU and BO were responsible for reviewing the literature and manuscript revision. All authors have approved the final manuscript and agree to be accountable for the content of the work.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest regarding the publication of this article. No financial or personal relationships influenced the content of this research.

Supplementary Material

Not applicable.

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