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THE MANIFESTATION OF COMPREHENSIVE ANALYSIS OF KEY ISSUES ASPECTS OF PHARMACEUTICAL WASTE IN THE ENVIRONMENT: ECOLOGICAL CONSEQUENCES, PUBLIC HEALTH RISKS, COMPLEX INTERACTIONS, RISK ASSESSMENT, AND STRATEGIC MITIGATION APPROACHES

Nodar Sulashvili [1], Nana Gorgaslidze [2], Luiza Gabunia [3], Marina Giorgobiani [4], Igor Seniuk [5]

1. MD, PhD, Doctor of Pharmaceutical and Pharmacological Sciences in Medicine, Invited Lecturer (Invited Professor) of Scientific Research-Skills Center at Tbilisi State Medical University; Professor of Medical and Clinical Pharmacology of International School of Medicine at Alte University; Professor of Pharmacology of Faculty of Medicine at Georgian Teaching National University SEU; Associate Affiliated Professor of Medical Pharmacology of Faculty of Medicine at Sulkhan-Saba Orbeliani University; Associate Professor of Pharmacology of Pharmacy Program at Shota Meskhia Zugdidi State University; Associate Professor of Medical and Clinical Pharmacology at School of Medicine at David Aghmashenebeli University of Georgia; Associate Professor of Biochemistry and Pharmacology Direction at the University of Georgia, School of Health Sciences; Associate Professor of Pharmacology of Faculty of Medicine at East European University; Associate Professor of Pharmacology of Faculty of Dentistry and Pharmacy at Tbilisi Humanitarian Teaching University; Invited Professor of Pharmacology of Faculty of Medicine at Teaching University "Geomedi"; Invited Lecturer of Tbilisi State Medical University of Department of Clinical Pharmacology; Invited Professor of Pharmacology of Faculty of Medicine at European University; Tbilisi, Georgia; Researcher of Department of Pharmaceutical Management of Yerevan State Medical University After Mkhitar Heratsi, Yerevan, Armenia; https://orcid.org/0000-0002-9005-8577. E-mail: n.sulashvili@ug.edu.ge
2. MD, PhD, Doctor of Pharmaceutical Sciences, Academician, Professor of Tbilisi State Medical University, Head of The Department of Social and Clinical Pharmacy, Tbilisi, Georgia. https://orcid.org/0000-0002-4563-5224
3. MD, PhD, Doctor of Medical Sciences, Professor, Director of the Scientific Research-Skills Center at Tbilisi State Medical University, Professor, Head of the Department of Medical and Clinical Pharmacology at Tbilisi State Medical University, Clinical Pharmacologist of The First University Clinic of TSMU, Tbilisi, Georgia https://orcid.org/0000-0003-0856-2684
4. MD, PhD, Doctor of Medical Sciences, Academician, Professor of Tbilisi State Medical University, Faculty of Public Health; Department of Hygiene and Medical Ecology, Tbilisi, Georgia. https://orcid.org/0000-0003-0686-5227
5. PhD, Doctor of Pharmaceutical Sciences, Dean of faculty of Pharmacy at National University of Pharmacy of Ukraine, Associate Professor of Department Of Clinical Laboratory Diagnostics, Microbiology And Biological Chemistry at National University of Pharmacy of Ukraine, https://orcid.org/0000-0003-3819-733; Kharkiv, Ukraine.

Abstract. The ubiquitous dispersion of medicinal compounds throughout natural systems has become a pressing global problem, carrying profound implications for ecological stability and public welfare. This investigation probes the widespread pollution originating from these substances, analyzing their damaging influence on environmental equilibrium and species variety. It illuminates the intricate dynamics of drug-based chemicals within natural settings, which intensify their longevity and

harmful potential. The work highlights the considerable dangers presented to animal life and human communities, especially via biological accumulation and the impairment of hormonal functions. Additionally, the assessment scrutinizes existing approaches for determining ecological and health hazards, pointing out their shortcomings and the demand for more resilient analytical structures. To confront these issues, all-encompassing remedial measures are suggested, spanning from upgraded water purification methods to regulatory measures designed to curb drug-related waste generation. The conclusions emphasize the immediate requirement for strengthened hazard analysis procedures and international collaboration to alleviate the consequences for nature and societal health. Medicinal pollutants now represent a severe issue for natural systems, permeating aquatic, terrestrial, and atmospheric environments and causing extensive ecological damage and threats to human populations. These enduring chemical agents disturb marine and land-based ecosystems, diminishing biological diversity, transforming microorganism populations, and promoting drug-resistant pathogens. Their complicated behavior in environmental contexts complicates hazard estimation, calling for a more thorough grasp of their extended effects. This research investigates the complex routes by which drug remnants influence ecological networks and public welfare, underscoring the importance of integrated solution plans. Sophisticated water purification processes, more rigorous governance, and eco-conscious drug management are vital to reduce pollution. Furthermore, upgrading hazard assessment models with superior detection techniques and simulation tools is fundamental for protecting environmental and communal well-being. The frequent detection of medicinal chemicals in nature has provoked major alarm owing to their enduring characteristics and extensive repercussions. These pollutants, deriving from drug manufacturing, incorrect waste handling, and effluent release, penetrate water-based and land-based systems, harming wildlife, modifying natural cycles, and encouraging treatment-resistant bacteria. Their concentration in aquatic environments endangers marine life, builds up in food webs, and presents dangers to people via chronic contact. The complex relations between drug-derived compounds and natural processes hinder danger evaluation, creating a necessity for more evolved testing methods and forecasting frameworks. This analysis explores the broad consequences of drug-related pollution, reviewing the processes by which these agents impact ecological and human health. It stresses the critical need for comprehensive solutions, including the improvement of effluent management systems, the creation of environmentally-friendly medications, tighter legal controls, and educational initiatives. Moreover, a sophisticated hazard analysis methodology combining cross-disciplinary studies, novel surveillance techniques, and extensive

impact studies is crucial for successfully managing contamination threats. Resolving this growing challenge demands a unified worldwide initiative to maintain planetary health and safeguard the well-being of both human societies and the natural world.

Keywords: Drug, pharmaceuticals, medicine, ecology, environment, human health.

Introduction. The objective of this investigation was to examine the extensive environmental pollution resulting from medicinal compounds, analyzing their influence on ecological systems: associated hazards, intricate dynamics, and methods for hazard appraisal, holistic remediation approaches, and the necessity for improved evaluation protocols. The presence of medicinal compounds in natural settings has raised increasing alarm owing to their possible consequences for ecological stability and public welfare. These pollutants, frequently derived from human and animal therapeutics, are detected in aquatic, terrestrial, and atmospheric environments, presenting considerable dangers through their complicated interplay with other environmental contaminants. Although they are broadly distributed, prevailing ecological hazard evaluations commonly address single chemicals, possibly overlooking wider environmental repercussions. This research investigates the severe pollution caused by medicinal compounds, stressing their impact on water- and land-based ecosystems. It also addresses the threats linked to the buildup of these agents, their combined effects with other pollutants, and the possibility for synergistic or cumulative outcomes. Additionally, it underscores the pressing requirement for more resilient and all-encompassing hazard analysis frameworks, incorporating the examination of breakdown products, secondary consequences, and the prolonged effects of exposure to pharmaceutical substances [1-2].

The contamination of the environment by pharmaceutical residues presents a critical challenge to both ecosystem health and human well-being. The widespread presence of these substances in water, soil, and air underscores the need for a more comprehensive understanding of their environmental fate and effects. Current risk assessment approaches, which often examine individual compounds in isolation, are inadequate in addressing the complex interactions and cumulative risks posed by pharmaceutical pollutants, especially when combined with other environmental contaminants. Furthermore, the potential dangers of pharmaceutical transformation products, which may exhibit greater toxicity or persistence, remain underexplored. To address these concerns, a paradigm shift is required in environmental risk assessment, incorporating multi-substance interactions, long-term ecological impacts, and the effects of transformation products. The development of robust mitigation strategies– such as advanced waste treatment technologies, improved pharmaceutical disposal practices, and more stringent regulatory frameworks–must be prioritized. By adopting a more integrated, precautionary approach to pharmaceutical contamination, we can better protect ecosystems and human health from the growing threat posed by these persistent pollutants. Future research and policy initiatives should focus on improving our understanding of these substances, developing innovative solutions to reduce their environmental impact, and ensuring sustainable management practices for pharmaceuticals [3-5].

The presence of pharmaceutical residues in the environment has emerged as a significant global concern, as these substances increasingly contaminate water, soil, and air systems. The widespread use of pharmaceuticals in human and veterinary medicine, along with improper disposal practices, has led to the accumulation of pharmaceutical compounds in various environmental compartments. These residues, often detected in trace amounts, are not only persistent but can also have profound ecological and human health implications. The environmental impact of pharmaceuticals extends beyond direct toxicity, as they can disrupt ecosystems, alter microbial communities, and interfere with natural processes such as nutrient cycling and waste decomposition [7-9].

Current environmental risk assessments often focus on single substances, neglecting the combined effects of pharmaceuticals in the environment. This approach may overlook the potential for greater toxicity when multiple substances interact or the unanticipated consequences of transformation products, which can be more persistent or toxic than their parent compounds. For example, the breakdown products of some pharmaceuticals may persist in the environment for extended periods, increasing the long-term ecological risks. Moreover, the potential for these transformation products to migrate through the food chain and impact human health remains largely unexamined [11-13].

The lack of comprehensive understanding of pharmaceutical pollution in the environment is further compounded by inadequate data on the long-term effects of low-level, chronic exposure to these compounds. Despite significant advances in detecting pharmaceutical residues in environmental matrices, only a small fraction of the thousands of active pharmaceutical ingredients used globally have been adequately studied. This gap in knowledge makes it difficult to assess the full scope of the risks posed by pharmaceutical contamination [15-17].

To address this growing environmental challenge, there is an urgent need for an integrated, precautionary approach to risk assessment that considers the complex interactions between pharmaceuticals and other pollutants. A more nuanced understanding of how pharmaceuticals degrade in the environment, how they interact with other chemicals, and how these compounds affect ecological functions and biodiversity is essential. This requires an expansion of ecotoxicity testing to incorporate a broader range of subtle biological effects, such as behavioral changes, physiological disruptions, and alterations in biochemical processes. Advanced technologies, including genomics, proteomics, and high-throughput screening, could play a pivotal role in improving the assessment of pharmaceutical pollutants.

Moreover, effective mitigation strategies must be developed to reduce pharmaceutical releases into the environment. These strategies could include improved waste management practices, such as source control, better disposal systems for unused pharmaceuticals, and more advanced wastewater treatment technologies. Additionally, regulatory frameworks must be strengthened to ensure that pharmaceutical contaminants are adequately managed and that new drugs are evaluated for their environmental risks before they are widely used. Such efforts would require collaboration among scientists, policymakers, and the pharmaceutical industry to develop sustainable solutions that minimize the environmental impact of pharmaceutical residues [18-20].

The study advocates for the development of improved mitigation strategies, such as enhanced waste treatment technologies, better pharmaceutical disposal systems, and more effective regulatory frameworks. Ultimately, this research calls for a multidisciplinary approach to address the environmental challenges posed by pharmaceutical contamination, aiming to safeguard both ecological and human health in the face of growing global concerns. Pharmaceutical contamination of the environment is an increasingly significant concern that demands urgent attention. The presence of pharmaceutical residues in natural systems, primarily from human and veterinary drug use, leads to contamination of water, soil, and air, where their persistence can disrupt ecological balance and potentially harm human health. Current environmental assessments often fail to consider the complex interactions between pharmaceutical residues and other pollutants, leaving many potential risks overlooked. A key issue is the difficulty in predicting the cumulative effects of these contaminants, especially when pharmaceuticals are mixed with other toxic substances in the environment. The impacts are not limited to direct toxicity but may include indirect effects, such as changes to microbial communities and disruptions in ecological processes, like nutrient cycling. Moreover, the transformation products of pharmaceuticals, which may be more persistent or toxic than the original compounds, remain poorly understood and under-researched. Given these challenges, the existing risk assessment frameworks, which often focus on single-substance exposures, are insufficient. A more holistic approach is necessary to account for the interactions, transformations, and cumulative risks posed by pharmaceutical residues [21-23].

Effective mitigation strategies will require a combination of improved waste management practices, targeted regulatory policies, and advanced treatment technologies. Understanding the full scope of pharmaceutical contamination and its ecological and human health implications is essential for developing proactive, sustainable solutions. The uncontrolled release drugs into the environment may be wastewater and atmospheric emissions from enterprises producing finished drugs and pharmaceutical substances. the environmental safety of such production is usually regulated by law. However, accidental releases of drugs into the environment or those that violate existing norms and regulations that occur in industry, are nevertheless not systematic. Moreover, there is a general trend towards a reduction in the environmental load on the part of pharmaceutical production, primarily in developed countries of the world, due to a consistent increase in the technological effectiveness and organization of the production process, the introduction of increasing quality standards and environmental safety, and control by authorized government bodies . It is also necessary to take into account that pharmaceutical production is localized geographically, and if an accident occurs at the enterprise or there are violations of environmental legislation, then such emissions are exclusively local in nature and pose a danger only to specific regions. For all the reasons listed above, such sources are not the subject of analysis in this review, although they contribute to environmental pollution. Other sources of drugs that are practically uncontrollable and are formed mainly by people who use drugs for medical purposes, as well as in animals, pose a great danger to the environment [24-26].

This study aims to delve deeper into the environmental contamination caused by pharmaceutical residues, exploring their ecological impacts, the complexity of their interactions with other pollutants, and the urgent need for more comprehensive and integrated risk assessments. Furthermore, it will highlight the critical role of advanced mitigation strategies, innovative treatment technologies, and regulatory measures in addressing the growing environmental threat posed by pharmaceuticals. By fostering a greater understanding of pharmaceutical pollution, we can better protect ecosystems, safeguard human health, and mitigate the long-term risks associated with pharmaceutical contamination in the environment [27-29].

While some studies have identified individual pharmaceuticals in the environment, the complexity of interactions between multiple contaminants–such as pharmaceuticals, pesticides, and industrial chemicals–remains insufficiently understood. Current risk assessment frameworks primarily focus on single-substance exposure, which may fail to account for the cumulative or synergistic effects that arise when pharmaceuticals interact with other environmental pollutants. Additionally, the potential risks associated with transformation products, which may be more persistent or toxic than the parent compounds, have been largely overlooked [30-32].

The environmental contamination caused by pharmaceutical residues is an increasingly complex and critical issue that threatens the health of ecosystems and poses risks to human well-being. The widespread use of pharmaceuticals in both human and veterinary medicine, combined with inadequate disposal practices, has led to the persistence of these substances in various environmental media, including water, soil, and air. While pharmaceuticals are essential for human health, their unintended release into the environment raises concerns due to their potential ecological impacts. These compounds, often present in trace amounts, can accumulate over time and exhibit a range of adverse effects on aquatic and terrestrial organisms, including the disruption of microbial communities, alterations in biodiversity, and interference with critical ecosystem processes such as nutrient cycling and soil fertility [33-35].

Pharmaceutical residues in the environment are particularly concerning because they can have multiple modes of action, which can interfere with the natural functioning of ecosystems. Some pharmaceutical compounds, such as antibacterial, have been shown to affect soil microbes that play an essential role in processes like pesticide degradation and manure decomposition. The potential for synergistic or additive effects among pharmaceuticals and other environmental pollutants, such as pesticides, biocides, and industrial chemicals, adds further complexity to the issue. While individual pharmaceuticals have been studied in isolation, little is known about how they interact with other chemicals in the environment, which may lead to underestimated risks [36-39].

Given these concerns, there is a pressing need for a more integrated approach to the study and management of pharmaceutical residues in the environment. This includes the development of more robust risk assessment models that consider multiple substances, the environmental behavior of transformation products, and their potential long-term ecological impacts. Furthermore, effective mitigation strategies, including improved waste management, disposal practices, and regulatory measures, are essential to address the growing issue of pharmaceutical contamination. This paper aims to explore the environmental contamination caused by pharmaceutical residues, assess their risks and interactions, and highlight the need for improved frameworks to better understand and mitigate their impact on both ecosystems and human health [40-42].

The aim of the study. Aim of the research was to study and analyzed the deep environmental impact of medication waste, their effects on natural systems: public health threats, intricate relationships, risk analysis, holistic solutions, and the need for advanced hazard assessment.

Materials and Methods. The material of the article was the data from scientific publications, which were processed, analyzed, overviewed and reviewed by generalization and systematization. Research studies are based on a review/overview assessment of the development of critical visibility and overlook of the modern scientific literature. Use the following databases: (for extensive literature searches to identify the the deep environmental impact of medication waste, their effects on natural systems: public health threats, intricate relationships, risk analysis, holistic solutions, and the need for advanced hazard assessment.). PubMed, Medline, Web of Science, Scopus, Web of Knowledge, Clinical Key, Tomson Reuters, Google Scholar, Cochrane library, and Elsevier foundations, national and international policies and guidelines were also reviewed and as well as grey literature.

Results and Discussion. Pharmaceuticals have been entering the environment for decades, and researchers have only recently begun to quantify their levels in the environment. Using information from different countries and uses, several prioritization exercises have identified pharmaceutical products that are most likely to end up in the environment. Annual veterinary drug use was combined with information on routes of administration, metabolism and ecotoxicity to identify drugs that should be monitored under a national recognition programme. New analytical techniques such as liquid chromatography coupled with tandem mass spectrometry (LC-MS-MS) have provided a better understanding of the behaviour of drugs in the environment and have determined their concentrations in wastewater treatment plants, soil, surface water [43-45].

Once released into the environment, pharmaceuticals will be transported and distributed by air, water, soil or sediment. Their distribution will be influenced by a number of factors, such as the physicochemical properties of the compound and the characteristics of the receiving environment. The extent to which a pharmaceutical product is transported between different environmental media depends primarily on the sorption behavior of the substance in soils, sludge and wastewater systems, and wastewater treatment plants, which varies considerably between products. pharmaceuticals. Additionally, unlike other organic substances such as pesticides and industrial chemicals, the sorption behavior of many pharmaceuticals cannot be simply inferred from the hydrophobicity of the substance or the organic carbon content of the material. solid. Pharmaceutical substances can also be degraded by biological organisms in processing systems, water bodies and soils, as well as by abiotic reactions. Typically, these processes reduce the effectiveness of medications; however, some degradation products have the same toxicity as their original compounds. Additionally, degradation varies considerably depending on chemistry, biology and climatic conditions. For example, the half-life of the antiparasitic ivermectin is six times longer in winter than in summer, and the compound breaks down more quickly in sandy soils than in sandy loam soils. The natural estrogens 17β-estradiol and estrone are degraded in both aerobic and anoxic reservoirs of activated sludge systems, while 17α-ethinylestradiol is only degraded under aerobic conditions. All of this adds to the complexity of the problem and requires customized solutions for individual pharmaceuticals and applications[46-49].

In some studies have found low levels of a wide range of pharmaceuticals, including hormones, steroids, antibiotics and parasiticides, in soils, surface waters and waters. underground. Reported concentrations are generally low, but what is even more alarming is that many therapeutic substances have been found under a wide range of hydrological, climatic and land use conditions, and many substances have been detected throughout of the year. The study results raised questions about how this mixture of veterinary and medicinal drugs, abundant in soil and surface waters, affects beneficial organisms in the environment and human health [50-52].

Comparison of these data with information on therapeutic doses, drinking water restrictions, and health advisories shows that concentrations of therapeutic compounds in surface waters are well below levels of concern to human health. Therefore, indirect exposure to pharmaceuticals through the water supply is unlikely to pose a risk to humans. However, risks from other exposure routes, such as ingestion of crops through soil and biomagnification through the food chain, have not yet been quantified and cannot be completely excluded. Environmental health effects are more difficult to assess. Human and veterinary drugs are required by law to undergo an environmental risk assessment for their effects on aquatic and terrestrial organisms before a product can be marketed, and the EU has introduced similar requirements. These environmental impact studies examine the potential adverse effects of manure on fish, daphnia, algae, bacteria, earthworms, plants, and invertebrates. Most of the data are publicly available (many environmental assessments are posted on the FDA website) and provide a reasonable data set for further study. However, legitimate questions arise about the real value of these studies. Risk assessments typically use standard ecotoxicity tests, which are often short-term and focus primarily on mortality as an endpoint. In addition, aquatic tests typically focus on the aquatic environment and do not take into account pharmaceuticals present in sediment. In general, the effects observed in these studies occur at concentrations significantly higher than those measured in the environment. Less well known are the more subtle effects that therapeutically active substances may have on organisms in the environment, such as growth, fertility, or behavior. Pharmaceutical compounds are designed to be either highly active and receptorreactive in humans and animals, or toxic to many infectious organisms, including bacteria, fungi, and parasites. However, this does not mean that they affect only these life forms. Many lower animals have receptor systems similar to those of humans and animals used in agriculture. In addition, numerous groups of organisms that affect human and animal health, and to which pharmaceutical products are directed, play a critical role in the functioning of ecosystems. It is therefore possible that pharmaceuticals have subtle effects on aquatic and terrestrial organisms that are not detected in standard tests. And because human drugs are released almost continuously into the environment, wild organisms are exposed for much longer periods than those used in standard tests. Researchers have therefore begun to study some of the more subtle effects caused by long-term, low-dose exposure to pharmaceuticals. A wide range of subtle effects have been reported, including effects on oocyte and testis maturation, effects on insect physiology and behavior, effects on faecal decomposition, inhibition of growth or stimulation of aquatic plant and algal species, and the development of antibacterial resistance in soil. There is strong suspicion that steroids in contraceptives affect the fertility and development of fish, reptiles, and aquatic invertebrates. Similarly, human and veterinary antibiotics have effects on soil microbes and algae [53-55].

Medicines play an important role in the treatment and prevention of diseases in humans and animals. But it is due to the very nature of drugs that they can also have unintended effects on animals and micro-organisms present in the environment. Although side effects on human and animal health are typically studied in extensive safety and toxicology studies, the potential environmental impacts of drug manufacturing and use are less well understood and have only become recently a topic of research interest. Some of the effects of various compounds, including veterinary anthelmintics and antibacterial therapeutics, are already known, but there are many other substances that can affect organisms in the environment. The situation is further complicated by the fact that some pharmaceuticals can have effects on bacteria and animals well below the concentrations usually used in safety and effectiveness testing. Additionally, degradation products and the combination of different biologically active compounds can have unexpected effects on the environment. Although it is reasonable to assume that these substances do not significantly harm humans, we have only recently begun to investigate whether and how they affect a wide range of organisms in the environment and what this means for health environmental [5-57].

The scale of this potential problem should not be underestimated. More than several million women use oral contraceptives, which eventually end up in the environment. A wide range of human drugs are produced and used, including antibiotics, statins, and cytotoxins used to treat cancer, some of which are produced in quantities of several thousand tons per year. Information on the quantities of drugs used by humans is difficult to obtain, but recent data from Canada indicate that the most commonly used drugs include acetaminophen, aspirin, ibuprofen, naproxen, and carbamazepine. Large quantities of veterinary drugs, such as antibacterials, antifungals, and parasiticides, produced in aquaculture and agriculture can also contribute to environmental stress, especially because they are often found directly in soil and surface water, unlike human drugs, which typically pass through wastewater treatment plants first [58-59].

Human and veterinary drugs enter the environment through a variety of pathways. Residues generated during manufacturing may eventually end up in surface waters. After administration, human medications are absorbed, metabolized, and then discharged to sewers. They typically pass through wastewater treatment plants before ending up in water or on land through the application of sewage sludge. Antibacterial agents used to treat fish or shrimp in aquaculture end up directly in surface waters. Veterinary drugs used to treat grazing animals end up in soil or surface waters. When intensively treated livestock are treated, these drugs may end up indirectly in the environment through the application of slurry and manure as fertilizer. Other minor pathways include air emissions and disposal of unused medications and containers [60-61].

Macrocyclic lactones can affect invertebrate larvae in faeces at relatively low concentrations; earthworms appear sensitive to parasiticides used in veterinary medicine, and plants may be sensitive to many antibiotics. In addition, macrocyclic lactones have been shown to cause numerous sublethal responses in dung-feeding invertebrates, such as reduced feeding, water imbalance, decreased growth rate, inhibition of pupation, and impaired mating. Since livestock faeces contain a diverse fauna and provide a fruitful habitat for other species, macrocyclic lactones may therefore indirectly affect other species by depleting the quality and quantity of their food source. Sediment-related effects of pharmaceutical products have also been considered. Carbamazepine affects the emergence of chironomid midges [62-63].

Additionally, pharmaceuticals are not the only pollutants of environmental systems. Aquatic and terrestrial organisms are exposed to a mixture of drugs and other substances, including pesticides, biocides and common industrial chemicals. A recent study discovered the antibacterial agent lincomycin in combination with other additional chemicals. The study focused only on selected compounds, so many other synthetic substances could be present. Therefore, interactive effects are possible, such as the additivity of substances with similar modes of action and synergy. Because current environmental risk assessments focus on individual substances, it is possible that these assessments underestimate exposure. It is also possible that the environmental behavior of a substance changes in the presence of other substances. For example, antibacterials have been shown to affect soil microbes that play an important role in the breakdown of pesticides. For example, research shows that veterinary antibacterial medications can influence the reduction of sulfates in soil and inhibit the decomposition of manure. If an antibacterial veterinary drug was applied as a slurry to an agricultural field prior to pesticide application, it is possible that the environmental impact of the pesticide would be dramatically altered [64-65].

Because very little is known about the effects of pharmaceuticals on environmental health and the interactions of various compounds, some workers are taking a precautionary approach and developing methods to reduce releases of these substances into the environment. Various approaches have been proposed, including source control of pharmaceuticals, source separation, waste treatment to remove pharmaceutical compounds, implementation of breeding practices, and improvement of drug disposal systems. expired medicines and waste containers. Source control includes marking, controlled disposal and separation of urine. Separating sources of pharmaceuticals, such as hospital wastewater, which are likely to be heavily contaminated with pharmaceuticals and antibiotic-resistant bacteria, should allow treatment resources to be focused on the most contaminated waters [66-67].

Pharmaceuticals may be removed by treatment with physical processes such as sorption or volatilization, biodegradation, or chemical reactions such as ozone treatment. The significance of the different options is likely to be very specific to each substance. For example, the antibiotic ciprofloxacin is removed by strong sorption to suspended solids in sewage sludge, whereas diclofenac and 17α-ethinyl estradiol undergo significant biodegradation in aged activated sludge. A range of measures to reduce emissions is therefore likely to be required. Many treatment methods that eliminate pharmaceuticals may also produce transformation products that are more persistent and more mobile than the parent compounds, some of which may also have similar or increased toxicity. Little work has been done to assess the environmental impacts of these transformation products. Clearly, a wealth of data on the levels of pharmaceuticals in the environment and their effects on aquatic and terrestrial organisms has become available in recent years. However, many issues remain to be resolved before it can be determined whether residues in the environment pose a threat to human health and the environment. First, there are risks associated with substances that have not yet been studied. Due to resource limitations, only a small proportion of pharmaceuticals in use today have been studied, and there is an urgent need to understand how other substances affect the environment. Second, we can better assess ecotoxicity. Current standard ecotoxicity tests are likely inadequate to assess the effects of many pharmaceuticals. The use of more subtle parameters such as behavioral changes, physiology, and biochemistry is of particular interest. Further work is needed to identify these subtle effects. It is likely that many of the technologies currently used by molecular biologists, such as proteomics and genomics techniques or large-scale DNA or protein microarrays, can make a significant contribution to this task. Third, ecotoxicity data are relevant to the real world. Although many subtle effects have been demonstrated following exposure to pharmaceuticals at environmentally realistic concentrations, we need to establish the significance of these data in terms of ecological functioning. Fourth, there are risks associated with mixtures. Pharmaceuticals are unlikely to occur alone in the environment, so the current single-substance risk assessment approach may underestimate environmental impacts. This also includes potential indirect effects. Little has been done to determine the absorption of pharmaceuticals into organisms and throughout the food chain. Such studies are critical to determining the potential indirect impacts of environmental exposure on the ecology and human health. A related question is: should we be concerned about transformation products? Much of the work to date has focused on the parent compounds; however, we know that transformation products are produced in the environment and during processing. It is important that we begin to understand the potential impacts of these substances. Future work should therefore focus on understanding the biotic and abiotic processes underlying the release, fate, and environmental impacts of pharmaceuticals. Finally, certain environmental exposures lead to greater resistance to antibacterial drugs. A wide range of antibacterial agents have been found in water and soil, many of which persist for some time. It is possible that such exposures could lead to the development of resistant microbes that could pose a serious threat to human and animal health [68-70].

The future work should focus on understanding the biotic and abiotic processes underlying the release, environmental fate, and effects of pharmaceuticals. Such an understanding should ultimately enable the development of new modeling approaches. A comparative plasma concentration model linking mammalian and fish species, which could provide useful information on the likely effects of pharmaceuticals on fish. Other modeling approaches, such as quantitative structure-activity relationships, could help estimate the environmental impacts of pharmaceutical products based on their chemical structure. Read-across approaches, in which data from closely related compounds are used to determine the effects of an untested compound, can also help improve environmental assessment. Improved tools should provide a better understanding of the environmental impacts of pharmaceutical products. At the same time, we must strive to improve the way we use, handle and process medicines to minimize their release into the environmen [71-72].

The contamination of various components of the environment (water, soil and air) by pharmaceutical residues poses an environmental problem. Human consumption of medicines ranges from 50 to 150 g per person per year in the EU. Veterinary drugs are used in smaller quantities, but pets are a growing segment of the veterinary drug market. In most EU Member States, around 50% of unused human medicines (3-8% of total sales) are not collected [73-74].

The problem is that we do not have a comprehensive understanding of what happens when these drugs are released into the environment, and further characterization of possible pathways of human exposure is needed. Residues of different types of drugs (hormones, anti-cancer drugs, antidepressants, antibiotics, etc.) have been found in various environmental elements, raising the question of whether this poses a risk to exposed plants, animals and microbes or to the man [75-76].

This study characterizes the extent of the environmental impact of pharmaceutical products outside of personal care products. The aim was to identify non-legislative and legislative reasons for their presence in the environment and to suggest ways to adapt legislation to address this problem. 30 to 90% of an orally administered dose of the drug is generally excreted as active substance in the urine of animals and humans. A large proportion of medicines are flushed down sinks and toilets and end up in the environment. Inappropriate and excessive consumption can also lead to unnecessary emissions [77-78].

In the EU, the contribution of manufacturing facilities to emissions of medicines and/or their residues is generally considered negligible.

Once in the environment, drugs are transformed and transferred between its different parts (surface and groundwater, soil, air). Highly fat-soluble drugs also have the ability to accumulate in the fatty tissues of animals and can thus be introduced into the food chain. These products can be broken down either through digestion and metabolism by organisms or through physicochemical processes in soil and water. Some degradation products may persist even after wastewater treatment and cause concern [79-81].

For a number of pharmaceutical products, the environmental risks can be quite minor because they do not remain in the environment for long and are low in toxicity. However, it is increasingly clear that certain drugs, notably antiparasitics, antifungals, antibiotics and (xeno)estrogens, which can have ecotoxicological effects, in some cases present environmental risks. For example, the vulture population in the Indian subcontinent has declined due to poisoning with diclofenac, a painkiller found in the carcasses the vultures fed on. For humans, the possible consequences are less obvious than for the environment. Residue levels in drinking water or food are very low and are not considered to pose a risk to humans, but long-term exposure to low levels may occur through these routes [82-83].

There are currently no legal restrictions on human medicines potentially present in products of animal origin, this route of exposure being considered minor, even if it is currently not well characterized. For example, in Europe, only very low concentrations of veterinary antibiotics are found in dairy products [84-85].

Until 2005, the registration process for medicines did not include an environmental risk assessment (ERA), and therefore much relevant information was missing. Even for new products, the ERA was often incomplete. A number of regulatory frameworks for chemicals marketed and used in Europe now include an assessment of the potential for persistence, bioaccumulation and toxicity (PBT), but there is no specific guidance for veterinary and human medicinal products [86-87].

There are currently no European regulations covering the assessment of risks associated with contaminated soils and product residues transferred to animals, including fish, or present in wastewater sludge from wastewater treatment plants.

Key legislative steps to address these limitations include, among others, strengthening environmental risk assessments, which could also target “old” pharmaceuticals. The Water Framework Directive could explicitly take into account the results of the ERA for active pharmaceutical ingredients. Relevant legislative instruments could also establish a special label for the “green” pharmacy. The main non-legislative solutions focus on consumption and waste management through a better understanding of the ecotoxicity of medicines and encouraging the recruitment of ecotoxicology-trained staff to regulatory agencies. At the same time, training sections for doctors could be organized, a better match between consumer needs and packaging sizes could be considered, while increasing the role of pharmacists in collecting unused medicines and organizing public information campaigns. The main improvements in waste management could focus on more efficient collection systems for unused human and veterinary medicines and on monitoring their effectiveness [88-91].

Impact of climate change on the use of medicinal pharmaceuticals in the Northern Hemisphere. As climate change alters environmental conditions, the prevalence and global distribution of human diseases will change. Climate-related environmental changes are associated with an increase in chronic diseases already common in the Northern Hemisphere, such as cardiovascular disease and mental illness. The increase in these diseases is leading to an increase in the use of already widely used Western drugs. People with respiratory diseases may experience a worsening of symptoms due to changing environmental conditions, such as increased pollen counts, leading to an increase in the demand for drugs used to control these symptoms. Toxic substances and respiratory, waterborne, and foodborne infections, including vector-borne infections, may become more common in Western countries, Central and East Asia, and across North America. As new disease threats emerge, a significant increase in the use of pharmaceuticals seems inevitable, particularly for pharmaceuticals not currently in wide use (e.g., antiprotozoal drugs). This study found that the use of drugs to treat common symptoms, such as painkillers, may also increase. Understanding which diseases, and therefore which drugs, may be used in the future is important so that toxicologists, environmental scientists, policymakers and legislators can focus their efforts, implement mitigation measures and plan training, education and treatment [92-93].

The chemical pollutants such as pesticides, biocides or industrial chemicals, the release of pharmaceuticals into the environment must be regulated to ensure adequate information and transparency about the environmental impacts of pharmaceuticals; adequate and reliable assessment of environmental risks of pharmaceutical products; prevent pharmaceutical products from entering the environment throughout their entire life cycle and control releases of pharmaceuticals into the environment when prevention is not possible [94-96].

Consumption of medicinal products for human and veterinary purposes has impacts on terrestrial and marine environments and ecosystems. Increased environmental awareness regarding pharmaceutical activities has led to the development of policies and measures aimed at mitigating negative environmental impacts. Various measures have been taken to promote environmentally friendly production and practices, leading to the development of alternative methods and processes benefiting both the environment and industry. Distributors and pharmacists can make a difference by effectively managing daily operations, including improving inventory and rotation, consolidating supplies and reducing unused medications [97-98].

Pharmaceutical products are essential to human health, but they become an environmental problem when they enter the environment, which occurs when residues are excreted from the body after consumption or when unused pharmaceutical products are improperly disposed of. Although no method has been developed to detect all drugs entering an ecosystem, certain groups have been shown to have negative impacts on ecosystems, including increased mortality of aquatic species and changes in physiology, behavior, or reproduction. Particular attention is paid to these groups of drugs and their impact on the environment. In this review, the authors propose measures to reduce the amount of unused pharmaceutical products in the environment, with a focus on prevention. Various policy measures are recommended throughout the life cycle, including source-oriented, user-oriented and waste management measures, to prevent the generation of household pharmaceutical waste and ensure environmentally sound disposal of household pharmaceutical waste. Preventive measures include rational drug consumption, prescribing more environmentally friendly drugs or developing safe and easily biodegradable drugs, better disease prevention, personalized medicines, better packaging sizes and markets for the redistribution of unsafe drugs. The next step is to prevent inevitable waste from entering the environment. Therefore, it is extremely important to collect and properly dispose of unused medicines. Finally, education of healthcare professionals and the public, as well as partnerships between environmental scientists and clinicians, are essential at all stages of the pharmaceutical life cycle. Reducing drug levels in the environment will benefit human life [99-100].

Demographic, epidemiological and lifestyle changes, such as the aging of the population, the increase in chronic diseases, the availability of cheap generic treatments and easy access to a large number of over-the-counter medications, have become key factors in the growth of the pharmaceutical industry. The global increase in drug consumption has led to greater international awareness of the problem of unused pharmaceuticals (UPs) in households and the harmful environmental and health consequences of their improper disposal. Drugs in the environment are challenging because they are designed to interact with a living system and produce a pharmacological response at low doses, making them dangerous to the environment even at low concentrations. Secondly, drugs are designed to be stable in reaching and interacting with their target molecules, meaning that they degrade very slowly or that their continued use results in a constant, slower release into the environment, that is, as quickly like decomposition. In addition, conventional wastewater treatment plants are not designed to completely remove pharmaceuticals from wastewater [101-103].

Pharmaceutical products enter the environment through two main routes: excretion and insufficient elimination. In both cases, pharmaceuticals end up in sewage treatment plants, which are generally not designed to remove these pollutants from wastewater. Drugs have been found mainly in surface water, but also in groundwater, soil, manure and even drinking water. The presence of drugs in freshwater and terrestrial ecosystems can lead to the release of drugs into wildlife with the possibility of bioaccumulation. People are then exposed to drugs through drinking water and their residues in crops, fish, dairy products and meat. The effects of pharmaceuticals entering aquatic environments are of increasing concern, with impacts ranging from molecular changes to population-level effects [104-105].

The environment is everything that surrounds us: the air we breathe, the water we drink, and the land on which all living creatures live, the plants we use for food thrive. Development is what we do with these resources to improve lives. Our actions to make our lives more comfortable change the environment

One of the achievements of the United Nations in the field of environmental protection is the Kyoto Resolution on the Climate Change Convention (1997). In 2004, it passed into law, requiring countries to reduce emissions of dangerous greenhouse gases by 5.2% by 2012. The United Nations Convention on Biological Diversity (1992) obliges states to preserve the rich diversity of plants and animals necessary for human existence.

Environmental pollution leads to the increase of toxic substances in the human body and its environment – air, water, soil, animal and plant world – beyond the permissible norm, which is followed by a sharp increase in various chronic diseases [10, 19, 37].

The interaction between the organism and the environment takes place in two main directions. One of them refers to those biochemical changes in human organisms that are caused by the demands of environmental conditions or arise in the process of human impact on the environment. It is necessary to specify the impact processes of men, women, children and entire groups. The environment is that part of living and non-living nature that surrounds organisms and directly or indirectly affects their existence, development and reproduction [15, 41, 57].

Pharmaceutical and personal care products (PPCP) in the environment are a hot topic. Veterinary antibiotics, prescription drugs and cosmetic products are discarded from a variety of sources and regularly enter the environment, where they occur in small quantities in wastewater, surface and ground water, silt-laden agricultural soils, aquatic and terrestrial biota, and wet drinks Water. The public should become aware of this and is calling on the scientific and regulatory community to assess the potential risks to human health and the environment and take appropriate action if necessary [14, 27, 46].

Chemical pollutants are known to have specific effects on organisms, for example: Organotin compounds (used in anti-fouling paints on ships) affect marine life. However, there is another very diverse group of chemical compounds that can be harmful but have received relatively little attention as potential environmental pollutants. These include drugs, including drugs for humans and animals, as well as illegal (recreational) drugs.

Thousands of tons of pharmacologically active substances are used worldwide every year, but surprisingly little is known about the fate of most drugs after their intended use. Most of the administered dose is excreted unchanged from the body, and metabolites can be converted back into the active ingredient by bacteria. In addition, the public often throws unused medicines down the drain. Based on published prevalence data, it is likely that a significant portion of municipal wastewater is contaminated with narcotic compounds that vary only in the type and content of substances present [19, 42, 58].

Modern research has shown that many drugs are not completely eliminated from the body in wastewater treatment plants. The presence of drugs in surface systems, soil and even marine systems has been confirmed in concentrations ranging from high ng/liter to low mg/liter, which are similar to the concentrations of some pesticides. Pharmaceutical compounds discarded in household waste can end up in landfills and pose a risk to surface and ground water. Additionally, unlike more regulated contaminants, which often have a longer half-life in the environment, pharmaceuticals can become pseudopersistent due to prolonged exposure to wastewater, with unknown consequences for aquatic organisms that may be continuously exposed [19, 27, 39].

The potential consequences of the presence of pharmaceuticals in aquatic systems are unknown and have therefore received increasing attention as potential pollutants in recent years. The fact that an industrial chemical can end up in the environment is not surprising in itself. What's interesting about drug contamination is that it does not primarily arise from manufacturing, but rather from the widespread and ongoing use, isolation, and improper disposal of drugs for human and veterinary use [12, 25, 37].

Pharmaceuticals are potentially ubiquitous pollutants as they are present in all human environments. There is currently little evidence that pharmaceuticals are present in the environment in sufficient quantities to cause significant harm, although their use is expected to increase as the Human Genome Project is completed and the population ages. Drugs and their metabolites are increasingly being found in water bodies in areas adjacent to anthropogenic activities [39, 47, 54].

The biggest concern at the moment is that antibiotics in wastewater treatment plants may lead to increased resistance of natural bacterial populations. There are many isolates of microorganisms resistant to antibiotics in the environment, and although the issue remains controversial, the significant increase in the number of bacterial strains resistant to multiple antibiotics is often attributed to the misuse of antibiotics and the increase in their discharge into wastewater. Three known mechanisms of gene transfer (conjugation, transduction, and transformation) are thought to occur in aquatic environments; As a result, streams and rivers can become a source and reservoir of resistant genes, as well as a means of their dissemination. In addition, some non-target organisms (eg cyanobacteria) may be exposed to antibiotics, which may have indirect negative effects on the aquatic food [47, 58, 69].

The origin and possible effects of human and veterinary drugs on aquatic and terrestrial organisms are relatively new topics. However, in recent decades, a large number of studies have been published indicating the varied effects of drugs on organisms and the occurrence of drugs in different environmental areas on a global scale. It is now recognized that the environmental impact of pharmaceuticals is a global issue and not just a problem in developed countries. The general public, industry, research or regulatory authorities, do not want bioactive drugs to end up in the environment and therefore potentially in their drinking water. Therefore, the amount of pharmaceuticals in the environment needs to be minimized using all available strategies. Promising approaches such as ERA play an important role in minimizing problems before drugs enter the environment. These strategies need to be strengthened and adapted to minimize the amount of pharmaceuticals entering the environment [31, 39, 54].

The contamination of the environment by pharmaceutical residues presents a critical challenge to both ecosystem health and human well-being. The widespread presence of these substances in water, soil, and air underscores the need for a more comprehensive understanding of their environmental fate and effects. Current risk assessment approaches, which often examine individual compounds in isolation, are inadequate in addressing the complex interactions and cumulative risks posed by pharmaceutical pollutants, especially when combined with other environmental contaminants. Furthermore, the potential dangers of pharmaceutical transformation products, which may exhibit greater toxicity or persistence, remain underexplored. To address these concerns, a paradigm shift is required in environmental risk assessment, incorporating multi-substance interactions, long-term ecological impacts, and the effects of transformation products. The development of robust mitigation strategies– such as advanced waste treatment technologies, improved pharmaceutical disposal practices, and more stringent regulatory frameworks–must be prioritized. By adopting a more integrated, precautionary approach to pharmaceutical contamination, we can better protect ecosystems and human health from the growing threat posed by these persistent pollutants. Future research and policy initiatives should focus on improving our understanding of these substances, developing innovative solutions to reduce their environmental impact, and ensuring sustainable management practices for pharmaceuticals [28, 42, 46].

Regarding environmental risk assessment, (i) include the environment in the risk-benefit analysis of pharmaceutical products for human use, (ii) improve risk management capabilities, (iii) collect data on existing pharmaceutical products, and (iv) improve environmental availability risk These assessments represent some important next steps. The biological effects to environmental exposures promise interesting results, although very few studies have been conducted on wild animals or caged organisms, such as in the wild or in ecologically significant environments. This may be due to the lack of analytical method protocols as well as the variety of pharmaceutical structural features that are not easy to handle but need to be taken into account.

Various policies need to be implemented throughout the life cycle of pharmaceutical products, including source-oriented, consumer-oriented and waste management-oriented activities. The most effective solutions must be implemented at the source, before drugs enter the environment. These measures include rational drug consumption, prescribing more environmentally friendly drugs and developing harmless and easily biodegradable drugs. Improved disease prevention, personalized medicine, improved package sizes, and PC redistribution markets may go some way to avoiding drug waste. The next step is to prevent unavoidable waste from entering the environment. Therefore, correct collection and disposal of is critical and must be adapted to national and local conditions. Finally, education of health care professionals and the public, as well as partnerships between environmental scientists and clinicians, paharmacists are important at all stages of the pharmaceutical product life cycle. All joint efforts must be guided by a One Health approach to combat pharmaceutical waste and improve the health of people, animals and the environment, which are closely linked. To reduce contamination levels when consuming medicines should be: Creation of a system for collecting drug waste generated by the population; Conducting awareness-raising work with the population, employees of healthcare institutions and other target groups on the topic of environmental pollution by drug waste; Taking into account environmental factors when choosing and prescribing treatment. At the same time, there is no need to put environmental protection above the human need for treatment; Development and implementation of wastewater treatment systems. It should be taken into account that urban wastewater has an unstable composition in terms of names and concentrations of drugs. A higher priority is to prevent drug residues from entering the city sewer system [55, 57, 68].

The widespread contamination of the environment by pharmaceutical residues represents a significant and escalating global concern. These pollutants infiltrate water bodies, soil, and even air, leading to severe ecological disruptions, biodiversity loss, and potential long-term health risks for humans and wildlife. Their persistence, bioaccumulation, and role in fostering antimicrobial resistance further complicate their impact, demanding urgent and comprehensive intervention. Despite growing awareness, existing mitigation measures remain insufficient, necessitating a paradigm shift toward more sustainable pharmaceutical production, improved waste disposal, and enhanced regulatory frameworks.

To effectively address this crisis, a multi-pronged approach is essential. Advanced wastewater treatment technologies, such as membrane filtration, bioremediation, and oxidation processes, must be widely implemented to reduce pharmaceutical contaminants before they enter natural ecosystems. Strengthening regulations and global policies is critical to ensuring stricter controls on pharmaceutical manufacturing, prescription practices, and disposal methods. Additionally, promoting public awareness and responsible medication disposal can play a key role in minimizing environmental contamination at its source.

Risk assessment frameworks must also be refined to better understand the complex interactions of pharmaceutical residues within ecosystems. Integrating cutting-edge analytical techniques, predictive models, and interdisciplinary research will enable more accurate hazard evaluation and inform targeted mitigation strategies. Furthermore, the development of green pharmaceuticals – biodegradable drugs designed to minimize environmental impact – offers a promising long-term solution to this issue.

Addressing pharmaceutical pollution requires collective action from governments, researchers, healthcare providers, industries, and the general public. By adopting a proactive, science-driven approach, we can mitigate the adverse effects of pharmaceutical contamination, protect ecological integrity, and safeguard public health for future generations. The time to act is now–delaying intervention will only exacerbate the environmental and health consequences of unchecked pharmaceutical pollution.

The problem is further complicated by the fact that exposure to only one drug or toxic substance at a time is likely to be a rare event. Laboratory studies have shown that mixtures of just a few compounds have effects on ecosystems, but it is unknown what happens in the wider environment. Most organisms are constantly exposed to various substances, the concentrations of which vary little in time and space. Therefore, the limits of your tolerance depend on the duration of exposure to chemical and non-chemical stressors, many of which have the same mechanism of action and whose effects can result in additive effects. Thus, risk estimates that ignore possible cumulative drug effects will almost certainly lead to significant underestimation of risk [36, 39, 57].

Increasing demand for global water sources will likely lead to increased indirect and direct water reuse in the future. Drinking water is a direct route to the human body, including drugs and other contaminants that may be present there. Advanced water treatment technologies such as granular activated carbon (GAC) and reverse osmosis (RO) can remove drugs from drinking water until they are invisible, but these processes are not widely used. Due to the lack of appropriate technology and the need for significant economic investment, municipal wastewater is never treated in this way. In addition, large-scale monitoring programs to test these compounds would be extremely expensive and time-consuming due to the large number of different compounds and the diversity of their properties and effects [14, 28, 59].

Given that the extent and consequences of the presence of drugs in aquatic environments is largely unknown, more research is needed before a clear picture of the true nature and importance of the problem can be formed. Therefore, it would be unwise to claim that these compounds have significant environmental impacts until convincing evidence is available. To this end, future emphasis should be on adequate and sufficient scientific knowledge to determine occurrence, exposure, sensitivity and consequences in order to make informed decisions regarding human health and the environment [14, 19, 68].

When evaluating drugs, benefits to human health must take precedence over potential harm to the environment. Therefore, it may be beneficial to focus on reducing or eliminating problems at their source by developing clearer drug labeling and more effective guidelines for the disposal of pharmaceutical compounds by patients and healthcare professionals. The potential benefit of this approach would be improved consumer health (by minimizing the consumption of active substances) as well as reduced healthcare costs. Given the enormous importance of the pharmaceutical industry to both human health and the economy, any increased control could have serious economic and social consequences. If pharmaceuticals turn out to be problematic contaminants, collaboration between health professionals and environmentalists will be mutually beneficial, as much research remains to be done before the problem can be fully understood [13, 62, 76].

Ecology, which directly affects the health of society, is one of the most important factors in the modern era of civilization. Factors affecting population health are the biggest social problem. The health and illness of society are determined by the environment in which a living organism is located and develops. Man is a biosocial being. Environmental factors affect organisms in different ways. It can be irritating, limiting or determining the existence of the organism in specific conditions; the danger of disturbing the natural balance is associated with pollution of the atmosphere, water, soil and food products with nitrates, pesticides, radionuclides and other harmful substances. The environment is saturated with psychotoxins, chemical waste, biological damaging agents (drug-resistant bacteria, fungi, viruses, parasites resulting from mutations). causing death of plants and animals and illness in humans. Therefore, it is clear what a great danger an environmental disaster poses [39, 47, 56].

An environmental disaster has a direct impact on public health. Society and the environment are in constant relationship. Therefore, the health and illness of society are determined by the environment in which a living organism is located and develops. Factors affecting population health are the biggest social problem.

There is a danger of disturbing the natural balance. Pollution of the atmosphere, water, soil and food products with nitrates, pesticides, radionuclides and other harmful substances leads to the death of plants and animals and diseases of people. Therefore, it is clear what a great danger ecological disaster causes [34, 47, 82].

The most serious consequence of biosphere pollution is the manifestation of genetic disorders. As a result of increased radioactive background and chemical pollution of the environment, the number of pathologies, malignant tumors, mental disorders, etc. increases. number. Mutagens in the form of chemical compounds, ionizing radiation penetrate the cell and cause disruption of the genetic program, causing mutations in somatic cells [37, 46, 52].

Diseases and conditions caused by climate change will also impact demand in the healthcare system and pharmaceutical industry. The pharmaceutical industry may see a change or increase in demand for drugs. For example, an increase in temperature can trigger asthma due to increased pollen levels. This increase in asthma cases will, in turn, lead to an increase in demand for medications to control asthma. Changing demand for medicines could create opportunities for the pharmaceutical industry to make the most of climate change and incorporate green chemistry principles into the development of new medicines [65, 69, 78].

The production and consumption of pharmaceuticals results in the presence of active pharmaceutical ingredients (APIs) in the ecosystem. Active ingredients enter the marine and terrestrial environment through release from manufacturing facilities, into wastewater after consumption of the drug in question, or through improper disposal of expired or unused drugs. The use of medicinal products in veterinary medicine may also result in the release of active substances into the environment, for example through the use of wastewater for irrigation, agriculture, aquaculture or the disposal of animal carcasses treated with veterinary drugs. The presence of APIs in the ecosystem can have a number of side effects, such as: Bacterial resistance to antibiotics and changes in the activity of digestive glands in marine life, reproductive toxicity in amphibians and feminization of fish. Another striking example of the impact of APIs on the ecosystem is the sharp decline in vulture populations due to the presence of diclofenac residues in cattle carcasses [81, 89, 96].

Based on data from the World Health Organization, an analysis of the impact of environmental factors on human health was published, which revealed large differences between countries and showed that human health can be improved by reducing exposure to environmental factors such as: pollution, ultraviolet radiation, noise, climate, ecosystem change and dangerous work environment. More than 10% of deaths in 23 countries of the world are related to the environment with two risk factors: 1) polluted air and water; 2) low sanitary and hygienic indicators.

The industrial agriculture, municipal wastewater treatment, and the introduction of municipal sewage sludge (biosolids) as major sources of pharmaceuticals and personal care products in the environment. To compensate for this, indicators of veterinary antibiotic use are provided by both the agricultural industry and interested scientists. Personal care products are divided into fragrances and musks, cleansers and disinfectants [14, 42, 56].

Pharmaceutical products intended for human use are included in the UNESCO list of emerging pollutants. Their identification and elimination represent a decisive step towards achieving the goals of the Sustainable Development Program. Concentrations of drugs found in the environment are below therapeutic levels. In waters receiving treated wastewater, drugs are found at concentrations below 100 ng/L. These low concentrations make it difficult to assess their toxic effects on ecosystems and human health. The vast majority of pharmaceutical products have not been adequately studied regarding their long-term toxic effects, presence and fate in the environment. However, certain classes of drugs, such as beta blockers, antibiotics, anticancer drugs, and endocrine disruptors, have been shown to have devastating effects on the ecosystem, including increased mortality and disruption of the physiological and reproductive functions of aquatic species. Moreover, since it is impossible to separate humans from nature, this has devastating consequences for human health. However, the extent of the problem remains largely unknown due to the large number of drugs available and difficulties in assessing the risks associated with exposure to multiple compounds at low doses over long periods of time. The drugs on the market pose a potential risk to the environment. Although there is no established method for detecting all pharmaceuticals entering an ecosystem, some are widespread and have been shown to have negative impacts on ecosystems. These groups include hormones, antibiotics, antidepressants, anti-inflammatory and pain relievers, beta blockers and anti-cancer drugs [24, 29, 45].

Antibiotic resistance is a global public health problem, especially given the increased use of antibiotics during the COVID-19 pandemic, which has led to the exhaustion of the last line of antibiotics. It has been established that the use of antibiotics in medicine, veterinary medicine and agriculture is associated with pollution of various parts of the environment, which has contributed to increased antibiotic resistance and the occurrence of ecotoxicological effects. Failure to properly dispose of antibiotics through sewers by patients also poses a growing environmental threat to public health. Additionally, high levels of antibiotic contamination after long-term exposure can negatively impact human health, especially in patients with chronic diseases such as obesity, diabetes and asthma [36, 54, 87].

Antidepressant contamination has increased significantly worldwide during the COVID-19 pandemic. To this day, antidepressants can be found in urban and suburban water supplies. Many aquatic animal species bioaccumulate various antidepressants in their tissues, resulting in cytotoxicity, genotoxicity, impaired stress response, weight and length gain/loss, and liver and kidney damage. Because there is significant overlap between human and animal environments, exposure to antidepressants (sertraline, fluoxetine) in the environment also affects human neurological development and various mental illnesses. Although psychotropic drugs are usually present in wastewater at subtherapeutic levels, they can have biological effects at low doses, and combinations of multiple psychotropic drugs are often present, especially in the environment, increasing the risk of toxic effects [38, 45, 52].

Pharmaceutical compounds are used in modern society for various beneficial purposes, but at the same time, the pharmaceutical industry releases highly toxic pollutants into the environment either directly or after chemical modification. Additionally, pharmaceutical compounds can enter the environment through various routes such as treated wastewater discharge, seepage into landfills, sewer pipes, animal waste, etc. Although a number of physical and biological processes occur in an aquatic ecosystem, they can lead to depletion of many lead to pharmaceutical compounds. Traces of human and veterinary drugs and their metabolites were found in several bodies of water. Objects such as surface water, groundwater and drinking water sources. Several industries, including pharmaceuticals, chemicals, paints, etc., are rapidly developing in India, with wastewater being discharged into water bodies either directly or after partial treatment. Pharmaceutical compounds have been found to be released into the environment and may be considered environmental pollutants. Several pharmaceutical plants have been found to be sources of much higher concentrations in the environment than those resulting from drug use. Typically, the pharmaceutical industry generates a large amount of waste during production and service. Drugs have been found in sewage treatment plant wastewater and drinking water. Trace amounts of drugs in drinking water can have serious adverse effects on human health and aquatic life over long periods of time, even when drug concentrations in drinking water (in the nanogram per liter range) are orders of magnitude below the minimum therapeutic dose [15, 29, 47].

Pathways through which drugs may be exposed to the environment include manufacturing plants and hospital wastewater, land use (eg, biosolids and water reuse), etc. Wastewater treatment services are not always successful in removing active chemicals from wastewater. Therefore, drugs enter the aquatic environment, where they have a direct effect on aquatic organisms and can be absorbed into the food chain.

Higher concentrations of antibiotics can lead to changes in microbial community structure and ultimately affect food chains. Nonsteroidal anti-inflammatory drugs (NSAIDs), such as ibuprofen, naproxen and diclofenac, are widely used and therefore often found in wastewater systems, both surface and groundwater. Ibuprofen, ketoprofen, naproxen, indomethacin, diclofenac, acetylsalicylic acid and phenazone were detected in the surface water system. However, after clofibric acid, the most common drugs found in aquatic environments are diclofenac, ibuprofen and propyphenazone. Diclofenac has also been shown to be highly toxic to vultures and livestock. NSAIDs such as ibuprofen, naproxen, and aspirin are the most commonly used medications and are often found in effective amounts in municipal wastewater [19, 48, 57].

Many pharmaceutical companies are responsible for the generation of toxic wastewater during their operations. The wastewater generated from these facilities contains solids, biodegradable and non-degradable organic compounds, etc. Pharmaceutical wastewater provides basic information about the reliability of the aquatic environment of the rivers and streams into which it is discharged. An important indicator of industrial wastewater contamination is the oxygen content of chemical oxygen demand (COD) and biological oxygen demand (BOD), with nutritional status measured by the amount of nitrogen and phosphorus in the wastewater.

Long-term exposure of coastal biota to lower concentrations of complex drug mixtures can result in acute and chronic damage, behavioral changes, tissue accumulation, reproductive impairment, and inhibition of cell proliferation. Several studies have shown that fish exposed to sewage may experience reproductive problems. In addition, fish exposed to trace amounts of contraceptive drugs in the concentration range found in the environment show dramatic reductions in reproductive success, suggesting that population-level effects may be possible [42, 48, 84].

Around the world, the drug residues in the environment poses risks to humans, aquatic animals and wildlife and is becoming a major concern for both regulatory authorities and the pharmaceutical industry. Significant progress on this issue is simply not possible with the current limited knowledge about the transport, fate, and environmental impact of pharmaceuticals. It is necessary to take into account the possible potentiating effects of different drugs acting on the same receptors. Risk assessment of pharmaceutical chemicals involves identifying the hazards associated with each step and assessing the risks associated with those hazards.

Currently, pharmaceutical compounds are regularly released into the environment in extremely large quantities, and the current emission control system is unable to control untreated or partially treated pharmaceutical wastewater. The effects of drugs permeate and impact ecosystems, biota and humans. Adverse health effects on humans, aquatic animals and livestock should be investigated through careful toxicological and safety studies. Serious efforts are needed to reduce this problem, and appropriate regulations are needed to monitor and control it. Water quality guidelines in India should include analysis of the most commonly used pharmaceutical compounds in drinking water sources. In addition, pharmaceutical industrial wastewater treatment plants need to implement new corrective measures to prevent long-term environmental and health risks [7, 83, 102].

Water sources contaminated with pharmaceutical contaminants are found in agricultural lands, surface water, groundwater, and drinking water. Water flows to plants, which affects the quality of soil and crops grown using this contaminated water. Pharmaceutical contaminants are considered external environmental factors that affect crop quality. Drugs enter plants as pollutants, either through the soil or the air. Pollutants enter the plant from the soil through the roots and are transported through the stem. Plants also absorb pollutants from the air, and leaves can absorb pollutants from the atmosphere. Pharmaceutical contaminants such as B-lactams, aminoglycosides, macrolides, tetracyclines, sulfonamides, herbicides including sulfonylureas, triazines, imidazolinone, phenylurea and bisphenol (BPA) have been found to cause toxicity in plants. Polychlorinated biphenyls (PCBs) affect plant growth, reproduction and productivity [8, 39, 67].

Most pharmaceuticals we use are excreted via urine and feces in unchanged form or as metabolites and eventually end up in the drain. The pharmaceutical residues can then reach lakes, the sea and groundwater, despite passage through wastewater treatment plants, as the wastewater treatment plants are not built to clear pharmaceuticals. Pharmaceuticals affect biological processes. They are also often designed to withstand biodegradation and can therefore remain in the environment for a long time. There are reports of effects on fish, as well as that measured concentrations of antibiotics in wastewater treatment plants can select for antibiotic resistance.

Chemicals play an important role in healthcare as they can be used as disinfectants, cleaning agents, laboratory reagents, sterilants, pesticides, pharmaceuticals, and in medical devices and equipment. They also offer great animal welfare benefits. However, there is growing awareness and concern about the consequences of mishandling drugs and chemicals on human health and the environment [9, 47, 88].

Pharmaceuticals are also biologically active substances specifically designed to provide pharmacological effects on living organisms. They affect the health of wildlife and ecosystems if not managed in an environmentally sound manner.

Active pharmaceutical ingredients (APIs) are the biologically active components of a drug. These APIs are sold to pharmaceutical companies that manufacture end products for patients around the world. More than 5,000 active pharmaceutical ingredients are used in prescription, over-the-counter and veterinary products worldwide.From a chemical and waste management perspective, environmental and health issues in this sector are mainly related to the release of pharmaceuticals into the environment: Waste ends up in rivers, lakes and underground aquifers. In addition, when used in livestock production and when manure is used as fertilizer, veterinary drugs end up in the soil and environment. This leads to soil contamination and biomagnification due to leaching of drugs into food crops [12, 58, 79].

Sources of drug release into the environment include direct emissions from drug manufacturing, patient and animal feces, aquatic agriculture, and disposal of unused or expired drugs. Medicines designed to degrade slowly, or even non-degradate to resist chemical breakdown as they pass through the human or animal body, pose a particular risk if ingested, stored, or distributed into the environment. When released into the environment, the biological activity of persistent pharmaceutical pollutants in the environment can have direct negative effects on non-target organisms such as wildlife and have long-term impacts on the health and sustainability of ecosystems. The latter occurs through population-level reproductive effects that persist into future generations of non-target organisms. Pharmaceutical contaminants that are persistent in the environment are frequently and increasingly used in consumer products. However, significant gaps remain in knowledge about the environmental and health impacts of these pollutants [41, 48, 95].

Some pharmaceuticals have been found in low concentrations in drinking water, which is a warning sign that the current handling of pharmaceuticals may lead to health and environmental problems in the future.

Access to healthy water is a prerequisite for good health. Since society's use of chemicals, including pharmaceuticals, is continuously growing, the risk is also increasing that these chemicals will return to us in our food and water supply through nature's ecocycle.

There are little knowledge of the long term effects that continuously supplied trace quantities of pharmaceuticals and other chemicals could have on our development, our ability to resist disease and wellness in general. Therefore caution is advisable. The pharmaceuticals in nature can cause health problems. According to the precautionary principle, measures can be taken if there is reason to believe that a product or a method of production involves unacceptable risks to the health of human beings, animals, plants and the environment – even if there is no definitive scientific proof of such an effect [9, 65, 79].

Drug residues are found in various environmental components around the world, and there is growing concern about the harm they may cause to human health and the environment. In nature, drug residues were found in urban wastewater, rivers and lakes. Effective measures must be taken to prevent further contamination of the environment by drugs. First of all, it is necessary to create a system for collecting drug waste from the population. Undoubtedly, drugs enter the environment during the production process through wastewater from pharmaceutical plants, municipal wastewater through natural human excretion, wastewater and manure from the use of veterinary drugs and as a result of improper handling of drug waste [19, 36, 77].

The review defines each of these sources and steps that can be taken to reduce drugs' environmental impacts. In the European Union, since 2004, the obligation to organize a system for collecting drug waste from the population has been established. For the successful operation of such a system, information work with the population about how drugs affect the environment and how to properly dispose of them is important. Residents of all European countries can bring drug waste to a pharmacy or hazardous waste collection point. However, in some countries there is a lack of widespread awareness-raising, which leads to inefficient collection systems and most waste ends up in the trash or drained into sewers. In some countries, drug waste generated by medical and pharmaceutical organizations is neutralized in pharmacies, clinics, hospitals and manufacturers. At the same time, pharmacies and hospitals have the right to transfer expired medicines to the manufacturer [36, 57, 81].

In most countries where the system operates successfully, the costs of collecting and neutralizing drug waste are shared by pharmaceutical companies, drug manufacturers and local authorities. The main problem is the very existence of unused drugs. So, generally many patients buy more medicines than they need. The best way to reduce their number is seen in optimizing the practice of prescribing drugs, so that only the necessary amount of drugs is prescribed, giving preference to more environmentally friendly ones, as well as improving information interaction between doctors and patients. The pharmaceutical industry must also provide for the production of drug packaging adapted to various treatment regimens [10, 19, 64].

Every participant in the drug supply chain, from the pharmaceutical industry to the patient, plays an important role in reducing the environmental impact of pharmaceutical activities. The International Pharmaceutical Federation has highlighted the different roles that each person plays in the pharmaceutical supply chain to minimize the environmental impact of pharmaceutical products. The pharmaceutical industry plays an important role in the environmental impact of pharmaceutical products.

Educating pharmaceutical personnel and the public is an important aspect of helping to create a healthy environment and reduce activities that contribute to climate change. The implementation of green practices in the pharmaceutical sector is already included in the curricula of EU Countries countries universities. Pedagogical input helps to recognize the importance of such practice early in professional development.

Consumer education is also important as it plays an important role in reducing the amount of drugs in the environment. Consumers should be discouraged from storing medications to avoid wasting them when not in use. They should also be taught how to properly store and dispose of unused and expired medications that may end up down the drain [13, 28, 39].

The world's population is aging, which will lead to an increase in drug use. Various measures need to be taken to minimize the release of active pharmaceutical ingredients into the environment and reduce the carbon footprint of the pharmaceutical sector. Small contributions from many people can synergistically have a positive impact on the environment [7, 18, 48].

There are several sources of release of active pharmaceutical ingredients (APIs) into the environment. The main ones are: wastewater from cities, hospitals, pharmaceutical plants and landfills. The vast majority of the active pharmaceutical ingredients (API) of drugs taken orally is excreted in the urine of animals and humans. Some pollution comes from the use of veterinary drugs in livestock and fish farming. However, it is not yet possible to evaluate this contribution, because there is no control and accessible reporting of the use of veterinary drugs. The most vulnerable to the effects of active pharmaceutical ingredients (APIs) are amphibians, fish, some animals and birds [48, 54, 69].

The main source of drugs entering the environment is wastewater from pharmaceutical enterprises (from product washing, waste acidic and alkaline wastewater, wastewater from cleaning equipment and production facilities, etc.) and liquid waste that is allowed to be discharged into the sewer system. Currently monitored parameters in pharmaceutical wastewater are biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids, ammonia and ammonium ions, phosphates, chlorides, sulfates, petroleum products, iron, anionic surfactants and pH value. This list may include other chemical compounds, including active pharmaceutical ingredients (APIs), but their content is not regulated or controlled at this time. Currently, the countries of the European Union have prioritized the most environmentally stable active pharmaceutical ingredients (APIs) - diclofenac, hormonal drugs of the estrogen group (ethinyl estradiol), antibiotics of the macrolide class (erythromycin, clarithromycin, azithromycin) and etc [29, 57, 62].

Assessment of environmental risks of both original and generic drugs. In European countries, for some drugs such an assessment is carried out, as well as an assessment of the level of resistance, bioaccumulation potential and toxicity. Currently, providing information about environmental hazards when registering drugs in the countries of the European Union is voluntary. In some countries has been created an online database of drugs, which describes their environmental risks and expanding the responsibility of drug manufacturers throughout the entire cycle from production to neutralization [84, 88, 95].

After drugs enter the body, they are destroyed, neutralized, metabolized and converted into new compounds. However, some of them are excreted unchanged or in the form of metabolites, ending up in the sewer system. Municipal wastewater treatment does not involve removal of APIs. Some of them are concentrated in sewage sludge from treatment plants, which is stored in filtration fields, while the rest ends up in rivers. The Challenges in this matter are also hospitals, where there is a high level of drug consumption. In the absence of an established system for collecting drug waste generated by the population, it either ends up in the sewer or is thrown into the trash. From landfills, drugs can be carried by animals, birds, or migrate into the soil and groundwater.

To raise animals and fish on an industrial scale, hormonal drugs, antibiotics and other drugs can be used, which can be excreted from the animal's body naturally. Hormones can be used in veterinary medicine and animal husbandry to stimulate the development and growth of animals, improve fertility, digestibility of feed, accelerate puberty, regulate the timing of pregnancy, etc. According to studies in some countries, antibiotic residues were found in manure, in plants grown in fields fertilized with manure, in soils, and in small quantities in groundwater. The use of veterinary drugs in should be regulated by veterinary and sanitary rules for the use, sale and storage of veterinary drugs.

European experience in collecting hazardous waste from the population shows that waste collection is carried out effectively if such collection is organized by a company specializing in the collection of hazardous waste. The same practice works in our country. In the EU, pharmacies are considered only as an area for the installation of appropriate containers and containers for collecting hazardous waste from the population. The containers themselves are installed by specialized companies interested in collecting hazardous waste. It is inappropriate to oblige pharmacies, healthcare institutions or other trade organizations to organize the collection of drug waste from the population [47, 59, 76].

Pharmacies and medical institutions are places where consumers can obtain the most complete information about drug waste, since these organizations employ personnel with the relevant knowledge. In the country, many pharmacies themselves are located on the territory of various retail facilities, so there may not be places in pharmacies to install a special container for collecting drug waste. When determining places for collecting waste from the population, it is necessary to comply with the criterion of step-by-step accessibility of such places from the places of residence of citizens. In this regard, retail facilities should also be considered as places for installing special containers for collecting drug waste. The decision to organize collection points for drug waste from the population in pharmacies should be made by Health care institutions in every countries.

In the vast majority of countries, all drug waste collected from the population is sent for incineration. At the same time, pharmacies, for example, in Sweden and Lithuania, can only accept medications without packaging, because it belongs to secondary resources and must be sent for recycling. Low-temperature, medium-temperature (up to 850°C) and high-temperature (at least 1200°C) combustion is used for waste. Hazardous waste, which includes most drugs, cannot be burned at low temperatures. At medium temperatures it is possible in limited quantities and in the absence of high-temperature combustion technology. Cytostatic drugs for cancer treatment can only be burned at temperatures above 1200°C, but the generation of such waste in household use is unlikely. Currently, there is a steady trend towards a decrease in the number of thermal installations for the neutralization of pharmaceutical waste. Incineration of waste is contrary to three principles of international law: precaution, prevention and limitation of transboundary effects. In Europe, resistance to waste incineration manifests itself in the form of the introduction of alternative technologies. Any combustion method requires monitoring of pollutant emissions and the resulting ash. An alternative to conventional methods of thermal treatment of pharmaceutical waste are technologies that provide for the preliminary decomposition of the organic component of the waste in an oxygen-free atmosphere (pyrolysis). When carrying out microwave pyrolysis with heating using microwave waves, toxic gaseous products are converted into less dangerous ones.

In countries where there are no incineration plants or their use is limited geographically, drug waste is disposed of. The main disadvantage of this method is the high probability of soil and groundwater contamination. According recommendations of the World Health Organization, only non-hazardous drug waste (vitamins, herbal-based drugs, biodegradable drugs) can be sent to the landfill. Hazardous waste, including cytotoxic drugs, must be pre-sealed, i.e. placed in a metal capsule and filled with plaster and cement [46, 62, 85].

Liquid waste of drugs classified as non-hazardous (syrups, herbal preparations, solutions based on salts, amino acids, lipids or glucose) can be poured into the sewer after diluting with water. It is necessary to prevent the discharge of large quantities of disinfectants into the sewer system, because they can affect the quality of biological wastewater treatment. Discharge of drugs that are persistent in the environment, capable of biological accumulation and have toxic properties into the sewer system leads to environmental pollution with active pharmaceutical ingredients. According to studies conducted in many countries, existing wastewater treatment systems do not eliminate such pollution and drug residues are found in wastewater cleaning sludge, and to a greater extent in water after cleaning, which is discharged into natural watercourses.

Some drugs pass through the human body, exit unchanged or in the form of metabolites, while maintaining their stability in wastewater and the environment for a long time. In addition, improper disposal of medications and disposing of them down the drain increases the concentration of hazardous APIs in water. Wastewater from pharmaceutical plants is also discharged into the city sewer system after local treatment. The active pharmaceutical ingredients are present in municipal wastewater above detection limits. Traditional mechanical and biological wastewater cleaning methods are unable to neutralize the active pharmaceutical ingredients in water. The issue of purification efficiency, the formation of drug metabolites and their behavior, the interaction of some drugs with others is still under study. Among the methods being developed and implemented in the countries of the European Union one can highlight physicochemical methods, aerobic/anaerobic biological cleaning in membrane bioreactors. Effective technologies for purifying wastewater from medicinal components include oxidation with ozone or hydrogen peroxide and the use of carbon filters. However, such technologies are currently expensive to implement and use. At the same time, more and more attention is being paid to preventing the entry of drugs into wastewater, including during production. The main problem is the very existence of unused drugs [15, 19, 22, 58].

One of the most obvious sources of uncontrolled release of drugs into the environment may be wastewater and atmospheric emissions from enterprises producing finished drugs and pharmaceutical substances. The environmental safety of such production should be usually regulated by law. However, accidental releases of drugs into the environment or those that violate existing norms and rules that occur in industry, are nevertheless not systematic. Moreover, there is a general trend towards a reduction in the environmental load on the part of pharmaceutical production, primarily in developed countries of the world, due to a consistent increase in the technological effectiveness and organization of the production process, the introduction of increasing standards of quality and environmental safety, and control by authorized government agencies. It is also necessary to take into account that pharmaceutical production is localized geographically and if an accident occurs at the enterprise or there are violations of environmental legislation, then such emissions are exclusively local in nature and pose a danger only to specific regions. Other sources of drugs that are practically uncontrollable and are formed mainly by people who use drugs for medical purposes, as well as in animals, pose a great danger to the environment [55, 62, 84].

For the most part, drugs are xenobiotics, and many of them are metabolized in the human body. The task of metabolism, as a rule, is to impart polarity to lipophilic substances in order to facilitate subsequent excretion. Metabolic parameters are individual for each substance and depend on gender, race, age and physiological state of the human body. There are two phases of metabolism, the numbering of which does not necessarily reflect their actual sequence. In the first phase of metabolism, a redox or hydrolytic transformation of the molecule occurs, increasing its polarity. In the second phase of metabolism, the xenobiotic is conjugated with endogenous molecules that improve the transport properties of the metabolite. During metabolism, inactivation of the active substance often occurs, which can lead to its inability to further exert a biological effect. However, many drugs are either not subject to metabolism or are subject to it only to some extent. And this leads to the fact that the active molecule of the active substance is excreted unchanged either in the urine or in the feces and is capable of further exerting a biological effect. In addition, as research results show, glucuronide transport complexes of active molecules of some drugs, formed during the second phase of metabolism, are easily destroyed during sewage treatment processes and release unchanged active substance into the aqueous phase or sewer sludge. We can also mention the route of release of drugs into aquatic environments due to their transport through the skin or leaching of drugs for external use during swimming in open waters. But from the point of view of quantitative indicators, this path is of little significance [39, 49, 83].

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We can also mention the route of release of drugs into aquatic environments due to their transport through the skin or leaching of drugs for external use during swimming in open waters. But from the point of view of quantitative indicators, this path is of little significance.

The increasing the availability of drugs, for the general development of health care systems, the consumption of drugs for medical purposes increases and, as a result, their content in the environment increases. This process is poorly managed and poses a potential danger to human health and other biological organisms. Contamination of the environment with drug residues has a global character and is actively studied in the developed countries of the world. However, this problem remains insufficiently worldwide [26, 39, 57, 72].

The best ways to reduce their number are to optimize the practice of prescribing drugs, so that only the required amount of drugs is prescribed, giving preference to the least environmentally hazardous ones, as well as improving information interaction between doctors and patients. The pharmaceutical industry must also consider producing drug package sizes tailored to different treatment regimens. One key measure is to encourage the pharmaceutical industry to develop harmless drugs that quickly break down into harmless compounds in the environment. For example, currently in European countries, when registering a new drug, environmental characteristics such as ecotoxicity, biodegradability are indicated.

The comparing drugs that are equally safe and well suited for treating a patient, it is recommended to take into account, in addition to their pharmaceutical properties, their environmental impact. To do this, recommend using environmental drug classifiers.

Large quantities of nonsteroidal anti-inflammatory drugs, including acetaminophen, acetylsalicylic acid, ibuprofen, diclofenac, and naproxen, are significant contributors to environmental pollution, especially because they have been detected in nanogram and microgram quantities in soil, wastewater, surface water, and drinking water, groundwater. These drugs have chronic ecotoxic effects because their stable chemical structure makes them very resistant to biological changes in the environment. It is now known that they primarily damage the organs of invertebrate and vertebrate animals, cause oxidative stress and interfere with the activity of detoxification enzymes.

These drugs may also cause cardiovascular effects, hepatotoxicity and affect oocyte maturation through unknown mechanisms [5, 19, 42, 49].

Beta blockers are very long-acting drugs that are toxic to the environment. Although there is no data on their adsorption in the environment, these drugs are known to have moderately high water solubility and are present in surface waters at μg/L concentrations. These compounds are extremely resistant to hydrolysis, bioavailable and mobile in the environment. Therefore, its accumulation in the environment can have unexpected consequences for many living organisms. According to European Union Directive, metoprolol and propranolol are compounds harmful to aquatic organisms. This is evidenced by the results of tests with green algae.

Anticancer drugs interfere with cell growth and division, and when released into the environment, they disrupt the ecosystem, impair fertility and cause significant genetic changes in living organisms. Anticancer drugs are prescribed in smaller quantities, but their effects are destructive even at concentrations in the ng/L range and include mutagenic, carcinogenic and teratogenic effects on aquatic life. Cytostatics are frequently found in the pharmaceutical industry and hospital wastewater due to improper use and disposal. The detection rate of anti-cancer drugs in oncological hospitals wastewater is big amount and cisplatin is considered one of the most dangerous drugs. The presence of cisplatin in water, even at concentrations of ng/l, can have a toxic effect on aquatic flora and fauna [28, 47, 59, 74].

Environmental pollution caused by pharmaceuticals is a complex public health problem that is scientifically controversial and affects multiple stakeholders with different interests and at different organizational levels: governments, non-governmental organizations, academic institutions, manufacturers, industries and families.

In keeping with the idea of protecting the environment, the pharmaceutical industry must develop promising concepts to minimize secretions while still ensuring sufficient pharmacologically effective concentrations in the patient. The potential of developing new pharmaceutical products that are more biodegradable and less harmful to the environment. There are already some examples of the development of greener pharmaceuticals, such as glufosfamide and green drug delivery systems. Scientists are currently developing an effective and environmentally friendly version of the antibiotic ciprofloxacin, a very stable drug. Using computer modeling, an existing active ingredient is analyzed and theoretically modified to improve biodegradability and reduce toxicological effects. The most promising candidates have been synthesized and tested *in vitro* [37, 46, 81, 89].

Limited consumer awareness of best recycling practices weakens their influence on recycling practices in many countries. Information campaigns can increase awareness and use of environmentally friendly pharmaceutical waste disposal methods in households. A good example is the Meds disposal campaign, a European initiative jointly coordinated by several European health and supply chain organizations and supported by media campaigns in different languages. The aim of the initiative was to combat the negative impact of mishandling of pharmaceutical products on the environment, raising consumer awareness of correct disposal routes and collection systems in a number of European countries.

In addition, greater awareness and behavior change can be achieved through specific recycling instructions on the product's outer packaging or information leaflet, which are mandatory in EU countries. In addition, eco-labels that reflect the environmental impact of various pharmaceutical products can influence consumer choice and awareness, as well as help physicians make prescribing decisions. Instructions on how to properly dispose of medications should also accompany medication dispensing at regular intervals. Pharmacists can play a key role in educating their patients about proper medication disposal.

Human activity has the most negative impact by releasing pollutants. Pollutants are considered to be all those substances that enter the atmosphere, soil, natural waters and cause disruption of the biological, physical or chemical processes taking place there. Radiation and thermal radiation are also pollutants. As a result of human activities, carbon dioxide (CO_2), carbon dioxide (CO), sulfur dioxide (SO_2), methane (CH_4), nitrogen oxides NO_2, NO, N_2O are released into the atmosphere. As a result of aerosol use, chlorofluorocarbon enters the atmosphere, and hydrocarbons from transport emissions. Water bodies are polluted not only by waste from industrial production, but also by organic and mineral fertilizers and pesticides used in agriculture. In the same way, sea water is being polluted. Rivers carry millions of tons of chemical waste into the sea every year. Millions of tons of oil spill into the oceans every year as a result of tanker and oil rig accidents, killing marine animals. Burial of nuclear waste at the bottom of the sea, sunken ships with nuclear reactors and weapons also pose a danger [7, 19, 28].

Radioactive contamination of the soil creates a great danger, since radioactive substances from the soil enter plants, and from there into the body of humans and animals, where they accumulate and cause various diseases. Chemicals pose a particular danger, specifically, organic compounds used in agriculture to control weeds, pests and diseases.

The uncontrolled release drugs into the environment may be wastewater and atmospheric emissions from enterprises producing finished drugs and pharmaceutical substances. the environmental safety of such production is usually regulated by law.

However, accidental releases of drugs into the environment or those that violate existing norms and regulations that occur in industry, are nevertheless not systematic. Moreover, there is a general trend towards a reduction in the environmental load on the part of pharmaceutical production, primarily in developed countries of the world, due to a consistent increase in the technological effectiveness and organization of the production process, the introduction of increasing quality standards and environmental safety, and control by authorized government bodies . It is also necessary to take into account that pharmaceutical production is localized geographically, and if an accident occurs at the enterprise or there are violations of environmental legislation, then such emissions are exclusively local in nature and pose a danger only to specific regions. For all the reasons listed above, such sources are not the subject of analysis in this review, although they contribute to environmental pollution. Other sources of drugs that are practically uncontrollable and are formed mainly by people who use drugs for medical purposes, as well as in animals, pose a great danger to the environment [14, 55, 69].

For the most part, drugs are xenobiotics, and many of them are metabolized in the human body. The task of metabolism is generally to impart polarity to lipophilic substances in order to facilitate subsequent excretion. Metabolic parameters are individual for each substance and depend on gender, race, age and the physiological state of the human body. There are two phases of metabolism, the numbering of which does not necessarily reflect their actual sequence. In the first phase of metabolism, a redox or hydrolytic transformation of the molecule occurs, increasing its polarity. In the second phase of metabolism, the xenobiotic is conjugated with endogenous molecules that improve the transport properties of the metabolite [25, 29, 37].

The impact of pharmaceuticals on the ecology and human health. Currently, increasing attention is being paid to the presence and fate of active pharmaceutical ingredients, solvents, intermediates and raw materials that may be present in water and wastewater, including pharmaceutical wastewater. Traditional wastewater treatment methods, such as activated sludge, are insufficient to completely remove active pharmaceutical ingredients and other wastewater components from these waters. Pharmaceutical wastewater has direct and indirect impacts on the environment and health, especially near pharmaceutical industrial sites. Although pharmaceutical factories produce untreated or partially treated wastewater, drinking water sources are contaminated. Various classes of pharmaceutical compounds such as analgesics, antidepressants, antihypertensives, contraceptives, antibiotics, steroids, hormones, etc. To protect the environment and lifestyles from health risks, the concentration of pharmaceutical compounds in medical wastewater entering drinking water sources should be regularly monitored. This article highlights the toxicity, health risks, and environmental risk assessments associated with pharmaceutical contaminants. To reduce contamination levels when consuming medicines should be: Creation of a system for collecting drug waste generated by the population; Conducting awareness-raising work with the population, employees of healthcare institutions and other target groups on the topic of environmental pollution by drug waste; Taking into account environmental factors when choosing and prescribing treatment. At the same time, there is no need to put environmental protection above the human need for treatment; Development and implementation of wastewater treatment systems. It should be taken into account that urban wastewater has an unstable composition in terms of names and concentrations of drugs. A higher priority is to prevent drug residues from entering the city sewer system [45, 67, 95].

Incorporating green practices into the pharmacy curriculum provides future pharmacists with the skills and competencies needed in the field to reduce the environmental impact of processes and medications. A more environmentally conscious workforce in the pharmaceutical industry is creating the necessary ripple effect for the adoption and implementation of green principles across various pharmaceutical environments. Patients should also learn to avoid accumulating medications and disposing of them safely and correctly. Adopting environmentally friendly practices leads to a reduction in the use of chemicals and waste generation, which in turn leads to a reduction in the pollutants that contribute to climate change.

The increasing production and use of pharmaceutical and veterinary products has had an impact on the environment over time. Drug production processes have a significant impact on the environment, which affects the value of chemistry to society. The pharmaceutical industry impacts the environment through the carbon footprint generated during the production of pharmaceutical products and throughout the supply chain, which can lead to climate change. Climate change may alter the incidence of vector-borne diseases by altering the population of species that act as disease vectors. Another consequence of climate change is the emergence of infectious diseases caused by pathogens that would otherwise be dormant [33-35].

Currently, increasing attention is being paid to the presence and fate of active pharmaceutical ingredients, solvents, intermediates and raw materials that may be present in water and wastewater, including pharmaceutical wastewater. Traditional wastewater treatment methods, such as activated sludge, are insufficient to completely remove active pharmaceutical ingredients and other wastewater components from these waters. Pharmaceutical wastewater has direct and indirect impacts on the environment and health, especially near pharmaceutical industrial sites. Although pharmaceutical factories produce untreated or partially treated wastewater, drinking water sources are contaminated. Various classes of pharmaceutical compounds such as analgesics, antidepressants, antihypertensives, contraceptives, antibiotics, steroids, hormones, etc. were detected in water samples ranging from mg/L to μg/L. Although the quantities detected are very small, they are highly toxic to humans, animals and aquatic life. To protect the environment and lifestyles from health risks, the concentration of pharmaceutical compounds in medical wastewater entering drinking water sources should be regularly monitored. This article highlights the toxicity, health risks, and environmental risk assessments associated with pharmaceutical contaminantsm [36-38].

Residues of many pharmaceutical products can be found in drinking water, plants and fruits, as well as in the tissues of fish and shellfish. Thus, people are exposed to these residues when they drink contaminated water and eat contaminated food. Pharmaceuticals in the environment can also influence the provision of important ecosystem services and have indirect effects on human health and well-being. Found the evidence that drug residues in drinking water and food affect human health, as well as the indirect effects of drugs on human health. Available evidence suggests that the risks of direct toxicity are low, but there are scenarios in which indirect effects are possible. Much remains to be done regarding the wider range of drugs and exposure pathways, and the links between the presence of drugs in the environment and the provision of ecosystem services.

Human drugs, hormones, antibiotics, analgesics, antidepressants and anticancer drugs indicate environmental risks. When it comes to veterinary products, hormones, antibiotics and parasiticides are often considered environmentally sensitive. These results are consistent with findings from the open scientific literature on approaches to environmental drug prioritization. Promising approaches such as environmental risk assessment of pharmaceuticals play an important role in minimizing the problems caused by pharmaceuticals in the environment. However, the regulatory framework for environmental risk assessment can be improved by integrating the environment into the risk-benefit analysis of drugs for human use, (ii) improving risk management capabilities, collecting data on existing drugs, and improving the availability of data for environmental risk assessment. In addition, more general and integrative stages of regulation, legislation and research have been developed and presented in this article. To minimize the amount of pharmaceuticals in the environment, they should strive to improve existing pharmaceutical legislation, prioritize pharmaceuticals present in the environment, and (iii) improve the availability and collection of pharmaceutical data.So, the presence of pharmaceuticals in the environment has received increasing attention. Medicines are released into the environment and can have harmful effects [25,28,47].

It is clear that priority must be given to environmentally relevant pharmaceutical substances. Existing pharmaceutical substances for which environmental data are lacking, as well as substances being considered for monitoring campaigns, need to be given priority attention to identify and minimize their environmental risk. According to the World Health Organization, concentrations of pharmaceuticals in water systems are expected to increase as the use of pharmaceuticals is expected to increase as they become more accessible to a growing world population. To be proactive, it is necessary to identify and prioritize the most important substances for the environment, which has become a challenge in recent years. Depending on the chemical properties of the substances, different approaches have been proposed. Most often, a combination of exposure and exposure data is used to prioritize environmentally significant chemicals. Several approaches have proposed using toxicological data to predict adverse effects on aquatic organisms (comparisons of several, but not all, approaches are included). Most published approaches to prioritization indicate the high environmental potential of various drug classes. Human medicines are often a priority, with all attention paid to hormones, antibiotics, psychotropic, anti-inflammatory and cytostatic substances, as well as beta blockers. In addition to hormones, antibiotics and parasiticides have proven to be environmentally important in veterinary medicines.

Conclusions. The widespread infiltration of medicinal compounds into natural systems constitutes an escalating danger to ecological stability and community welfare. These chemical agents impair biological variety, modify environmental processes, and foster treatment-resistant pathogens, creating enduring hazards that demand immediate action. Owing to their durability and intricate behavior within ecosystems, traditional remediation methods are inadequate. Confronting this issue requires a multi-pronged approach combining sophisticated water purification systems, more rigorous governance, eco-conscious drug manufacturing, and conscientious waste management protocols. Moreover, refining hazard evaluation frameworks via enhanced detection capabilities, simulation tools, and cross-disciplinary studies is vital for precisely determining the threats presented by drug residues. Cooperative initiatives uniting regulators, researchers, medical practitioners, and citizens are fundamental for formulating and executing successful interventions. By emphasizing forward-looking environmental stewardship and reinforcing international regulatory standards, we can reduce the harmful consequences of pharmaceutical contamination and protect both planetary health and societal well-being for posterity.

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