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DISSEMINATION AND ECOLOGICAL IMPACT OF PHARMACEUTICAL SUBSTANCES IN THE ENVIRONMENT

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ნანა შაშიაშვილი

ფარმაცევტული ნივთიერებების გარემოში გავრცელება და მათი ეკოლოგიური ზემოქმედება

თსსუ, სოციალური და კლინიკური ფარმაციის დეპარტამენტი

რეზიუმე

თანამედროვე მედიცინაში სამკურნალო საშუალებების ფართო გამოყენება თანმდევ გამოწვევებთან არის დაკავშირებული. ერთ-ერთი მნიშვნელოვანი პრობლემაა ფარმაცევტული პროდუქტის ბუნებრივ გარემოში მოხვედრა და მათი ეკოლოგიური ზემოქმედება. სამკურნალო ნივთიერებები გარემოში ხვდება სხვადასხვა გზით: ადამიანის და ცხოველის ორგანიზმიდან გამოყოფით, გამოუყენებელი მედიკამენტების არასწორი განადგურებით, სამედიცინო დაწესებულებებისა და ფარმაცევტული საწარმოების წყლის სისტემით, ასევე სოფლის მეურნეობაში მათი გამოყენების გზით. გრძელვადიან პერსპექტივაში, ეს პროცესები საფრთხეს უქმნის ბიომრავალფეროვნებას, ეკოსისტემის სტაბილურობას და ცოცხალი ორგანიზმების ჯანმრთელობას. შესაბამისად, საკითხი მოითხოვს ინტერდისციპლინურ მიდგომას, რაც გულისხმობს ფარმაცევტული ნარჩენების მართვის სისტემის გაუმჯობესებას, საზოგადოების ცნობიერების ამაღლებას და რეგულაციების გამკაცრებას გარემოს მდგრადობის უზრუნველსაყოფად.

Relevance of the Topic. The release of pharmaceutical substances into the natural environment has become an escalating ecological concern, affecting ecosystem stability, biodiversity, and potentially human health as well [1]. Although pharmaceutical compounds and drug formulations are developed with therapeutic intent, even trace amounts that enter the environment can cause unpredictable and sometimes harmful effects.

Research Objective. The aim of this study is to conduct a systematic assessment of the mechanisms by which pharmaceutical substances enter the environment and to evaluate their ecological impact. This includes analyzing their chemical and biological transformation processes, as well as the effects they exert on living organisms and ecological balance.

Methodology. The study is based on a comprehensive review of scientific literature. It draws on publications from various academic journals that document instances of pharmaceutical pollution in the environment and explore the underlying mechanisms of their impact.

Results. Pharmaceutical products are essential tools for improving human health; however, their improper use and production can often lead to significant ecological consequences. Residues of medicinal substances and healthcare-related products frequently enter the environment - particularly water resources - posing emerging environmental risks. These contaminants originate from pharmaceutical manufacturing waste, human excretion of drug metabolites following treatment, and the improper storage or disposal of unused medications. Once in the environment, these substances act as biologically active agents that disrupt the balance of aquatic systems, soil composition, and living organisms.

According to the World Health Organization, by 2050, deaths caused by antimicrobial resistance are projected to surpass those from cancer. In addition to the rising mortality rate, treatment inefficacy leads to increased healthcare costs, longer hospital stays, and overall worsening of patient outcomes. The continual presence of antibiotics in the environment, even at low concentrations, exerts evolutionary

pressure on bacteria, promoting the development of resistance. This resistance not only affects microbial ecosystems but also poses a direct threat to human health through reduced treatment options and the persistence of drug-resistant infections.

The primary sources through which pharmaceutical substances enter the environment can be categorized into several major groups:

- Excretion from humans and animals: After therapeutic use, many drugs or their metabolites are not completely broken down in the body and are naturally excreted via urine or feces. These compounds often resist degradation in wastewater treatment plants and end up in rivers, lakes, and groundwater. Trace amounts of paracetamol, ibuprofen, and carvedilol have been detected in the tissues of fish and aquatic plants in several European countries [2,3], indicating the inefficiency of current water purification systems in removing such contaminants.
- Improper disposal of medical waste: Expired or unused medications are frequently discarded along with regular household waste, reducing the chance for proper neutralization and increasing the likelihood of pharmaceutical residues entering water systems. According to the U.S. Food and Drug Administration (FDA), over 20% of discarded medications are flushed into domestic sewage systems, which is considered a significant pathway for pharmaceutical contamination of water bodies [4,5].
- Pharmaceutical manufacturing: The production of medicinal products often involves the release of substantial amounts of active pharmaceutical ingredients (APIs). Manufacturing facilities frequently lack adequate filtration systems or fail to comply with environmental regulations. A study conducted near a pharmaceutical plant in Hyderabad, India, revealed ciprofloxacin concentrations in the river reaching 31 mg/L—exceeding safe limits by more than a thousand-fold [6].
- Animal husbandry: Veterinary drugs are widely used to promote animal growth, treat infections, or prevent diseases. These substances are excreted and subsequently enter soil and water systems. In certain European regions, hormone pollutants like ethinylestradiol, originating from hospital waste, have caused genetic changes in fish populations such as carp [7].

Once in the environment, pharmaceuticals may act as novel and potentially harmful pollutants. Many remain pharmacologically active even after disposal. For instance, ethinylestradiol, even in nanogram-per-liter concentrations, can disrupt endocrine systems in animals, affecting reproductive functions and sexual development. In Sweden, the presence of just 5 ng/L of ethinylestradiol in river water was enough to cause feminization in female roach, significantly impairing their reproductive capabilities over several generations - and in some cases, leading to total infertility. Similar patterns have been observed in amphibians, including hermaphroditism and reproductive dysfunction in frogs, raising the threat of species extinction. Disruption of reproductive cycles and eventual decline or local extinction of species destabilize entire ecosystems. For example, declining fish populations reduce prey availability for predators, triggering their migration and ultimately leading to biodiversity loss in ecologically rich regions. Long-term disruption of ecosystems may also affect human food and water security. In many developing countries, reduced fish stocks threaten local fisheries and food sources [7,8].

Antibiotic residues also frequently enter agricultural areas due to inefficient filtration or water treatment systems. Sometimes, animal waste used as fertilizer contains antibiotics, leading to the presence of resistant bacteria in soil and water. Studies have shown that such bacteria can be transmitted to livestock and eventually to humans through food or water. The spread of resistant bacteria is recognized as one of the most pressing global public health threats [9,10,11].

Various drugs, including antidepressants, antifungals, and anticancer agents, can impair plant growth when they enter the soil via irrigation or fertilization. In soils treated with compost derived from

patients' excreta, corn and tomatoes exhibited suppressed root growth and underdeveloped foliage. In the long term, such impacts may jeopardize global food security, leading to higher food prices and shortages. Contaminated soil harms agricultural biodiversity and disrupts microbial balance, reducing soil regenerative capacity.

Pharmaceuticals such as antibiotics, antifungals, and antidepressants also disturb the microbial equilibrium in aquatic ecosystems. They alter the composition and function of bacteria, algae, and other microorganisms. A study conducted on a European river's microbiome revealed a decline in oxygen-producing bacteria in response to increased antibiotic concentrations. This reduction negatively affected dissolved oxygen levels in water, aquatic life quality, and ultimately influenced fisheries, biodiversity, and human food safety [12].

Conclusion. Pharmaceuticals enter the environment through various pathways: excretion from humans and animals, improper disposal of unused medications, discharge from medical facilities and pharmaceutical manufacturing plants, as well as use in agricultural practices. Compounds such as antibiotics, hormones, analgesics, and psychotropic drugs often retain their biological activity after release and can significantly affect aquatic ecosystems. These substances impact aquatic organisms, cause hormonal imbalances, disrupt reproductive functions, and increase the risk of spreading bacterial resistance.

The release of pharmaceutical products into the environment is a growing global challenge linked to the extensive use of medications in both human and veterinary medicine. The life cycle of a drug often does not end with its intended therapeutic action—residual substances can escape into the natural environment at various stages. These pharmaceutical residues may serve as significant sources of ecotoxicity, affecting the balance of water, soil, and living organisms. Their accumulation and transformation often go unnoticed, yet they are associated with long-term and difficult-to-reverse environmental consequences.

These substances pose substantial risks to aquatic ecosystems, influencing the health and behavior of aquatic life, causing harmful changes in reproductive processes, inducing hormonal disturbances, fostering the development of bacterial resistance to antibiotics, and affecting the microbial communities of soil. In doing so, they have the potential to alter broader ecological dynamics and stability [13].

The impact of pharmaceutical substances on ecosystems poses an escalating threat that requires proactive monitoring, interdisciplinary analysis, and decisive action to safeguard both the environment and public health. Moreover, raising public awareness on this issue is essential to encourage responsible practices regarding pharmaceutical use and disposal, and to foster broader societal engagement in environmental protection efforts.

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SUMMARY

The widespread use of medicinal substances in modern medicine is associated with accompanying challenges. One of the most significant concerns is the release of these substances into the natural environment and their ecological impact. Pharmaceuticals enter the environment through various pathways: excretion from humans and animals, improper disposal of unused medications, discharges from medical institutions and pharmaceutical manufacturing facilities, as well as through their use in agriculture. In the long term, these processes pose a threat to biodiversity, ecosystem stability, and the health of living organisms. Therefore, this issue requires an interdisciplinary approach, including improvements in pharmaceutical waste management systems, increased public awareness, and stricter regulations to ensure environmental sustainability.

Keywords: Pharmaceuticals, Environmental impact, Medical waste, Drug residues