Laboratory Assessment of Alkaline Contaminant Leaching through a Simulated Soil Column: Implications for Pharmaceutical, Nutraceutical and Veterinary Waste Management

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Abstract
Pharmaceutical, veterinary and selected nutraceutical-associated chemicals can reach groundwater through manufacturing discharges, sewage infiltration, disposal of unused products, manure application and agricultural runoff. Their transport through the unsaturated soil zone is controlled by ionisation, sorption, mineral interactions, biodegradation and preferential flow. This preliminary laboratory study examined whether a simple packed-soil column could support an initial assessment of contaminant migration and areal mass flux. Sodium hydroxide was used as an alkaline challenge substance rather than as a representative pharmaceutical. Following an 11-day contact/leaching period, the collected leachate was screened with phenolphthalein and red litmus paper and quantified by titration against 0.1 N hydrochloric acid. A 50 mL aliquot required 2.0 mL acid to reach the phenolphthalein endpoint. The resulting titratable alkalinity was 0.004 N, equivalent to 0.16 g L−1 as NaOH. Assuming the analysed 50 mL represented the cumulative recovered leachate, the recovered alkaline mass was 0.008 g. Using the reported column area of 7.065 cm² and an 11-day period, the apparent flux was 1.03 × 10−4 g cm−2 day−1 (0.103 mg cm−2 day−1). The study is therefore best interpreted as a proof-of-concept screening experiment that identifies the methodological steps needed for defensible assessment of emerging-contaminant leaching to groundwater.

Keywords: Emerging Contaminants ; Groundwater ; Pharmaceutical Residues ; Soil Column ; Leaching ; Titratable Alkalinity

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1. Introduction

Groundwater is a strategically important source of drinking water, irrigation water and industrial supply, yet it is vulnerable to long-lived contamination because recharge, dilution and natural attenuation are often slow. The term “emerging contaminants” encompasses chemicals that are not consistently included in routine monitoring programmes but are increasingly detected as analytical sensitivity improves. Pharmaceuticals, personal-care ingredients, hormones, lifestyle chemicals and veterinary medicines have received particular attention because they are biologically active by design and may occur as complex mixtures at low concentrations (Lapworth et al. 2012; Stuart et al. 2012). Once these compounds reach an aquifer, remediation is technically difficult and costly; prevention and source control are therefore more rational than relying on downstream treatment.

The major pathways are well established. Human pharmaceuticals enter wastewater after excretion, direct disposal and hospital use, while industrial production can generate locally severe discharges

when waste streams are poorly controlled. High concentrations of active pharmaceutical ingredients have been documented in surface water, groundwater and drinking-water sources near pharmaceutical manufacturing areas (Larsson, de Pedro, and Paxeus 2007; Fick et al. 2009). At the global scale, a coordinated survey of 258 rivers in 104 countries showed that pharmaceutical contamination is geographically widespread and is greatest where wastewater and waste-management infrastructure are inadequate (Wilkinson et al. 2022). In India, investigations around Patna and the middle Gangetic Plain have demonstrated the vulnerability of shallow groundwater and river systems to urban wastewater-derived chemicals, including lifestyle and pharmaceutical markers (Richards et al. 2021, 2023).

Veterinary medicines follow partly different pathways. Antibiotics, antiparasitic agents and hormones may be excreted by treated animals and subsequently enter soil through manure storage, land application, grazing, aquaculture or runoff. Their environmental mobility depends on molecular charge, hydrophobicity, binding to clay and organic matter, and transformation in manure and soil (Boxall et al. 2004; Tolls 2001). The consequences include direct ecotoxicity and, for antimicrobials, selection pressure that can contribute to antimicrobial resistance. Nutraceutical waste is less clearly defined. It can include vitamins, minerals, plant-derived bioactives, formulation excipients and high-organic-load manufacturing effluent. These materials should not automatically be treated as equivalent to pharmaceuticals: some are readily biodegradable or naturally occurring, whereas others may be persistent, metal-rich or biologically active. Their environmental evaluation therefore requires compound-specific evidence rather than category-level assumptions.

Transport through the soil profile is governed by coupled physical, chemical and biological processes. Ionisable compounds may change charge state with pH, which alters their sorption to mineral surfaces and soil organic matter. Cation exchange, anion exclusion, hydrophobic partitioning, complexation, microbial degradation, colloid-facilitated transport and preferential flow can all change breakthrough time and recovered mass. Reviews of pharmaceutical sorption show that distribution coefficients vary by orders of magnitude among compounds and soils, making generic predictions unreliable (Chefetz, Mualem, and Ben-Ari 2008; Alhalabi et al. 2024). This variability is why standardised soil-column tests, supported by batch sorption data and compound-specific analysis, remain useful for assessing leaching potential.

International guidance increasingly connects environmental monitoring with product stewardship and waste management. WHO has concluded that pharmaceuticals in drinking water should be managed within a broader water-safety framework and has recently issued specific guidance for antibiotic-manufacturing wastewater and solid waste. The European Medicines Agency requires environmental risk assessment for human medicinal products, while VICH GL6 and GL38 provide a phased framework for veterinary medicinal products. OECD Test Guideline 312 describes controlled leaching studies using replicate columns, characterised soil, artificial rain, fractionated leachate and mass balance. These frameworks establish a much higher evidentiary standard than qualitative colour tests alone.

The project from which this paper was developed used sodium hydroxide (NaOH) as a visible and analytically simple alkaline challenge in a packed-soil column. NaOH is not a pharmaceutical, nutraceutical or veterinary active ingredient, and it does not reproduce the sorption, degradation or trace-level behaviour of such compounds. Its value is limited to demonstrating hydraulic passage, pH/alkalinity transfer and basic flux calculation. The study was therefore reframed as a preliminary proof-of-concept rather than direct evidence of pharmaceutical contamination.

1.1 Study objectives

1. To document a laboratory-scale packed-soil column as a preliminary screening system for chemical migration.
2. To estimate titratable alkalinity, recovered alkaline mass and apparent areal flux in collected leachate.
3. To define a defensible protocol for subsequent compound-specific groundwater-contamination studies.

Table-1 : Representative Sources, Pathways and Concerns Associated with the Waste Categories Considered in This Study

Category	Representative constituents	Dominant source/pathway	Key soil–water controls	Potential concern

Category	Representative constituents	Dominant source/pathway	Key soil–water controls	Potential concern
Human pharmaceuticals	Antibiotics, analgesics, antiepileptics, hormones, antidepressants	Excretion to sewage; hospital wastewater; manufacturing effluent; disposal of unused medicines	Ionisation, sorption, biodegradation, wastewater infiltration	Ecotoxicity, mixture effects, resistance selection, drinking-water exposure
Veterinary medicines	Antibiotics, antiparasitics, coccidiostats, steroidal agents	Manure application; grazing; aquaculture; farm runoff; disposal	Manure binding, soil organic carbon, pH, clay content, rainfall intensity	Soil and aquatic toxicity, resistance selection, food-chain transfer
Nutraceutical-associated waste	Vitamins, minerals, botanical extracts, excipients, cleaning chemicals	Manufacturing effluent; discarded supplements; wash water	Compound-specific persistence; biodegradability; metal content; organic load	Oxygen demand, colour, toxicity of specific bioactives or metals
Healthcare and household mixtures	Parent compounds, metabolites, disinfectants and formulation chemicals	Sewer leakage, septic systems, landfill leachate	Mixture interactions, variable redox conditions, preferential flow	Chronic low-level exposure and uncertain mixture risks

Table-2 : Selected International Technical and Regulatory Frameworks Relevant to Pharmaceutical and Veterinary Residues in Water and Soil

Organisation/ jurisdiction	Instrument	Primary emphasis	Relevance to future work
World Health Organization	Pharmaceuticals in drinking-water (2012); antibiotic-manufacturing waste guidance (2024)	Risk-based water safety; source control; discharge targets for antibiotic manufacturing	Prioritise source reduction, wastewater control and risk-based monitoring rather than assuming universal drinking-water limits

Organisation/ jurisdiction	Instrument	Primary emphasis	Relevance to future work
European Medicines Agency	Guideline on environmental risk assessment of medicinal products for human use, Revision 1 (effective 2024)	Phased exposure, fate and ecotoxicity assessment for marketing authorisation	Links predicted environmental exposure with persistence, bioaccumulation, toxicity and risk characterisation
VICH	GL6 Phase I and GL38 Phase II environmental impact assessment for veterinary medicinal products	Stepwise screening followed by environmental fate and effects testing where exposure warrants it	Provides a suitable framework for veterinary-antibiotic and antiparasitic test selection
OECD	Test Guideline 312: Leaching in Soil Columns	Replicate columns, characterised soil, artificial rain, leachate fractions and mass balance	Benchmark for redesigning the present proof-of-concept into a standardised mobility experiment
United States EPA	Methods 1694 and 1698 for PPCPs, steroids and hormones	Compound-specific instrumental analysis in water, soil, sediment and biosolids	Useful analytical templates; these methods are screening methods and are not blanket regulatory limits
European Union	Surface-water watch-list mechanism under the Water Framework Directive	Union-wide monitoring of selected emerging pollutants, including pharmaceutical substances	Illustrates adaptive monitoring where evidence is insufficient for permanent environmental-quality standards
India	CPCB effluent standards and biomedical/ healthcare-waste management requirements	Control of conventional effluent parameters and safe segregation/disposal of waste streams	Compound-specific pharmaceutical monitoring remains a gap; facility-level source control and validated surveillance are needed

2. Materials and methods

2.1 Study design and evidentiary scope

The study was conducted as a preliminary laboratory demonstration of solute passage through a packed soil profile. The experiment did not use an active pharmaceutical ingredient, veterinary medicine or nutraceutical constituent. Sodium hydroxide was selected as an alkaline challenge because its passage could be screened rapidly using acid–base indicators and titration. The experimental record was reviewed and calculations were independently reconstructed. Wherever the project record lacked information, the absence is reported rather than replaced by an assumption.

2.2 Soil-column apparatus

A vertical cylindrical column was mounted on a laboratory stand and packed with soil to simulate the unsaturated zone (Figure 1). The reported internal cross-sectional area was 7.065 cm², corresponding to an internal diameter of approximately 3.0 cm. The photograph confirms a narrow vertical column with a lower outlet and stopcock.

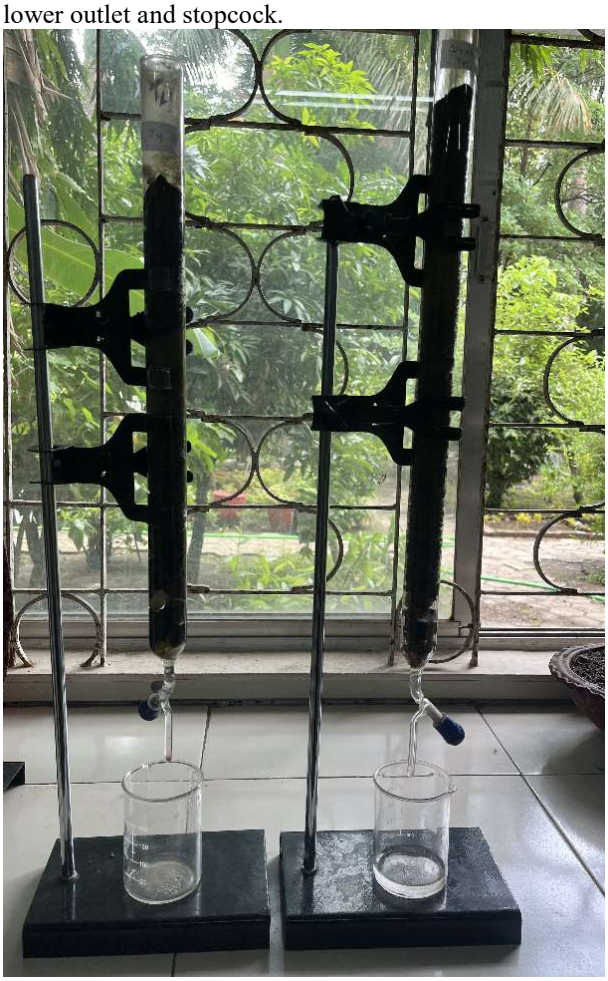

Figure 1. Laboratory Soil-Column Apparatus used for the Preliminary Alkaline Leaching Experiment. The Column was Vertically Mounted and Discharged through a Lower Outlet

2.3 Alkaline challenge and leachate collection

The project record states that the NaOH challenge was added on 1 May 2026 and that the column was checked through 11 May 2026, giving an 11-day test period. A 50 mL leachate sample was used for quantitative titration. For the mass and flux calculations below, this 50 mL volume was treated as the cumulative recovered leachate because that is the interpretation used in the source calculation.

2.4 Qualitative Alkalinity Tests

For the phenolphthalein test, approximately 5 mL of leachate was transferred to a test tube and 2–3 drops of phenolphthalein indicator were added. Development of a pink colour was recorded as evidence that the sample pH exceeded the indicator transition range. In a separate test, red litmus paper was contacted with the leachate and a red-to-blue colour change was recorded.

2.5 Quantitative titration

A 50 mL leachate sample was transferred to a conical flask and 2–3 drops of phenolphthalein were added. The sample was titrated with 0.1 N hydrochloric acid (HCl) until the pink colour disappeared. The recorded HCl consumption was 2.0 mL. The neutralisation reaction was represented as:

$NaOH + HCl \rightarrow NaCl + H_2O$

Because soil contact can introduce carbonate, bicarbonate and other proton-accepting species, the titration result is reported as titratable alkalinity and as a NaOH-equivalent concentration, not as compound-specific confirmation of NaOH.

2.6 Calculations

The equivalent relationship used for the acid–base titration was:

$N_{HCl}V_{HCl} = N_{alk}V_{sample}$

Substitution of the measured volumes gives:

$N_{alk} = (0.1\ N \times 2.0\ mL) / 50\ mL = 0.004\ N$

The NaOH-equivalent concentration was calculated from equivalent weight:

$C_{NaOH\text{-}eq} = 0.004\ eq\ L^{-1} \times 40\ g\ eq^{-1} = 0.16\ g\ L^{-1}$

Recovered alkaline mass and apparent areal flux were calculated as:

$M = C \times V = 0.16\ g\ L^{-1} \times 0.05\ L = 0.008\ g$

$J = M/(A \times t) = 0.008\ g/(7.065\ cm^2 \times 11\ day) = 1.03 \times 10^{-4}\ g\ cm^{-2}\ day^{-1}$

3. Results

3.1 Qualitative Response

Addition of phenolphthalein produced an immediate pink colour, and red litmus paper changed to blue. Both observations confirmed that the collected leachate was alkaline.

Control

3.2 Titratable Alkalinity and NaOH-equivalent Concentration

The 50 mL leachate sample consumed 2.0 mL of 0.1 N HCl at the phenolphthalein endpoint. The calculated alkalinity was 0.004 N. When expressed as NaOH equivalent, the concentration was 0.16 g L−1, or 160 mg L−1.

3.3 Recovered mass and Apparent Flux

Assuming the 50 mL sample represented the cumulative recovered leachate, the corresponding alkaline mass was 0.008 g. Normalisation by the reported 7.065 cm² cross-sectional area and 11-day test duration produced an apparent areal flux of 1.03 × 10−4 g cm−2 day−1, equivalent to 0.103 mg cm−2 day−1.

4. Discussion

The central observation is straightforward: alkalinity introduced at the top of the packed soil system was detected in water collected from the outlet after the test period. The apparatus therefore provided hydraulic connectivity through the packed profile and can function as a teaching-scale screening column. The reconstructed calculation is arithmetically correct if the reported area, 11-day duration and 50 mL cumulative volume are correct. The result is useful for demonstrating the concepts of concentration, recovered mass and areal flux.

OECD Test Guideline 312 is an appropriate benchmark for improving the experiment. It specifies at least duplicate columns packed with air-dried and sieved soil, pre-equilibration, controlled artificial rain, a defined test-substance dose, collection of leachate fractions, sectioning of the soil after leaching and accounting for parent compound, transformation products and non-extractable residues.

WHO's assessment of pharmaceuticals in drinking water does not support alarmist interpretation of every trace detection. It recommends prioritising microbial hazards and other established risks while using water-safety planning, source protection and targeted investigation for pharmaceutical residues. The more recent WHO guidance on antibiotic manufacturing is stricter at the source because concentrated discharges can create ecological effects and resistance-selection pressure before dilution. This distinction is important: low-level residues in finished drinking water and high-concentration manufacturing waste are different risk-management problems.

The revised EMA environmental-risk guideline and the VICH veterinary framework formalise a phased approach in which expected exposure determines the depth of fate and effects testing. Such frameworks are more suitable than applying one generic concentration limit to all compounds. In India, conventional effluent standards remain essential for pH, biochemical oxygen demand, chemical oxygen demand and other parameters, but these do not replace compound-specific surveillance where pharmaceutical manufacturing, hospitals, landfills or intensive livestock production create plausible sources. A realistic regulatory strategy would combine general effluent compliance, site-specific target analysis, safe return/disposal of unused products, antibiotic stewardship and publicly auditable monitoring near high-risk facilities.

The most effective intervention is to prevent concentrated waste from entering sewage, soil and recharge zones. Manufacturing facilities should segregate high-strength streams, quantify active ingredients in wastewater and sludge, and use treatment trains designed around the compounds present. Hospitals, pharmacies and households need accessible take-back systems so that unused medicines are not flushed or discarded with mixed waste. Livestock systems require veterinary oversight, restricted non-therapeutic antimicrobial use, manure-management plans and setback distances from wells and recharge areas.

Conventional activated-sludge treatment can remove readily biodegradable compounds but performs inconsistently for persistent micropollutants (Verlicchi, Al Aukidy, and Zambello 2012; Luo et al. 2014). Activated carbon, ozonation, advanced oxidation, membrane processes and properly designed hybrid systems can improve removal, although they increase cost, energy use and residual-management requirements. Treatment should therefore follow source reduction and should be validated using parent compounds, transformation products and toxicity endpoints rather than disappearance of colour or bulk organic matter alone.

5. Conclusions

A packed-soil column was successfully used to demonstrate passage of alkalinity through a simulated soil profile. The leachate showed a titratable alkalinity of 0.004 N, equivalent to 0.16 g L−1 as NaOH. Under the stated assumption that 50 mL was the cumulative recovered volume, the alkaline mass was 0.008 g and the apparent areal flux was 1.03 × 10−4 g cm−2 day−1. These values are internally consistent with the reported titration data.

The correct scientific interpretation is therefore a preliminary screening demonstration that exposes the requirements for a stronger study. Future work

should follow standardised column-testing principles, use defined pharmaceutical and veterinary marker compounds, incorporate replicate and blank columns, collect time-resolved fractions, apply validated LC–MS/MS methods and close the mass balance.

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Author Contributions

Conceptualisation, methodology, investigation, formal analysis, writing original draft, writing—review and editing: Teena Patidar ; supervision: Dr.Kuldeep Ganju

Ethics Statement

The study involved no human participants, identifiable personal data or experimental animals. Institutional chemical-safety and waste-disposal requirements remain applicable.

References

1. Alhalabi, A. M., M. A. Meetani, A. Shabib, et al. 2024. "Sorption of Pharmaceutically Active Compounds to Soils: A Review." Environmental Sciences Europe 36: 161. https://doi.org/10.1186/s12302-024-00984-9.
2. Aus der Beek, T., F.-A. Weber, A. Bergmann, S. Hickmann, I. Ebert, A. Hein, and A. Küster. 2016. "Pharmaceuticals in the Environment—Global Occurrences and Perspectives." Environmental Toxicology and Chemistry 35 (4): 823–835. https://doi.org/10.1002/etc.3339.
3. Boxall, A. B. A., L. A. Fogg, P. A. Blackwell, P. Kay, E. J. Pemberton, and A. Croxford. 2004. "Veterinary Medicines in the Environment." Reviews of Environmental Contamination and Toxicology 180: 1–91. https://doi.org/10.1007/0-387-21729-0_1.
4. Chefetz, B., T. Mualem, and J. Ben-Ari. 2008. "Sorption and Mobility of Pharmaceutical Compounds in Soil Irrigated with Reclaimed Wastewater." Chemosphere 73 (8): 1335–1343. https://doi.org/10.1016/j.chemosphere.2008.06.070.
5. Central Pollution Control Board (CPCB). n.d. "Effluent and Emission Standards." Government of India. Accessed July 1, 2026. https://cpcb.nic.in/effluent-emission/.
6. European Medicines Agency (EMA). 2024. Guideline on the Environmental Risk Assessment of Medicinal Products for Human Use, Revision 1. EMEA/CHMP/SWP/4447/00 Rev. 1. Amsterdam: EMA.
7. European Union. 2025. "Commission Implementing Decision (EU) 2025/439 Establishing a Watch List of Substances for Union-Wide Monitoring in the Field of Water Policy." Official Journal of the European Union.
8. Fick, J., H. Söderström, R. H. Lindberg, C. Phan, M. Tysklind, and D. G. J. Larsson. 2009. "Contamination of Surface, Ground, and Drinking Water from Pharmaceutical Production." Environmental Toxicology and Chemistry 28 (12): 2522–2527. https://doi.org/10.1897/09-073.1.
9. Kümmerer, K. 2009. "The Presence of Pharmaceuticals in the Environment Due to Human Use—Present Knowledge and Future Challenges." Journal of Environmental Management 90 (8): 2354–2366. https://doi.org/10.1016/j.jenvman.2009.01.023.
10. Lapworth, D. J., N. Baran, M. E. Stuart, and R. S. Ward. 2012. "Emerging Organic Contaminants in Groundwater: A Review of Sources, Fate and Occurrence." Environmental Pollution 163: 287–303. https://doi.org/10.1016/j.envpol.2011.12.034.
11. Larsson, D. G. J. 2014. "Pollution from Drug Manufacturing: Review and Perspectives." Philosophical Transactions of the Royal Society B 369: 20130571. https://doi.org/10.1098/rstb.2013.0571.
12. Larsson, D. G. J., C. de Pedro, and N. Paxeus. 2007. "Effluent from Drug Manufactures Contains Extremely High Levels of Pharmaceuticals." Journal of Hazardous Materials 148 (3): 751–755. https://doi.org/10.1016/j.jhazmat.2007.07.008.
13. Loos, R., G. Locoro, S. Comero, et al. 2010. "Pan-European Survey on the Occurrence of Selected Polar Organic Persistent Pollutants in Ground Water." Water Research 44 (14): 4115–4126. https://doi.org/10.1016/j.watres.2010.05.032.
14. Luo, Y., W. Guo, H. H. Ngo, et al. 2014. "A Review on the Occurrence of Micropollutants in the Aquatic Environment and Their Fate and Removal during Wastewater Treatment."

Science of the Total Environment 473–474: 619–641. https://doi.org/10.1016/j.scitotenv.2013.12.065.

15. OECD. 2004. Test No. 312: Leaching in Soil Columns. OECD Guidelines for the Testing of Chemicals, Section 3. Paris: OECD Publishing. https://doi.org/10.1787/9789264070561-en.
16. Richards, L. A., R. Kumari, D. White, et al. 2021. "Emerging Organic Contaminants in Groundwater under a Rapidly Developing City (Patna) in Northern India Dominated by High Concentrations of Lifestyle Chemicals." Environmental Pollution 268: 115765. https://doi.org/10.1016/j.envpol.2020.115765.
17. Richards, L. A., S. Guo, D. J. Lapworth, et al. 2023. "Emerging Organic Contaminants in the River Ganga and Key Tributaries in the Middle Gangetic Plain, India: Characterization, Distribution and Controls." Environmental Pollution 327: 121626. https://doi.org/10.1016/j.envpol.2023.121626.
18. Stuart, M. E., D. J. Lapworth, E. Crane, and A. Hart. 2012. "Review of Risk from Potential Emerging Contaminants in UK Groundwater." Science of the Total Environment 416: 1–21. https://doi.org/10.1016/j.scitotenv.2011.11.072.
19. Tolls, J. 2001. "Sorption of Veterinary Pharmaceuticals in Soils: A Review." Environmental Science & Technology 35 (17): 3397–3406. https://doi.org/10.1021/es0003021.
20. United States Environmental Protection Agency (US EPA). 2007a. Method 1694: Pharmaceuticals and Personal Care Products in Water, Soil, Sediment, and Biosolids by HPLC/MS/MS. EPA-821-R-08-002. Washington, DC: US EPA.
21. United States Environmental Protection Agency (US EPA). 2007b. Method 1698: Steroids and Hormones in Water, Soil, Sediment, and Biosolids by HRGC/HRMS. EPA-821-R-08-003. Washington, DC: US EPA.
22. Verlicchi, P., M. Al Aukidy, and E. Zambello. 2012. "Occurrence of Pharmaceutical Compounds in Urban Wastewater: Removal, Mass Load and Environmental Risk after Secondary Treatment—A Review." Science of the Total Environment 429: 123–155. https://doi.org/10.1016/j.scitotenv.2012.04.028.
23. VICH. 2000. Environmental Impact Assessment for Veterinary Medicinal Products—Phase I. VICH GL6. Brussels: International Cooperation on Harmonisation of Technical Requirements for Registration of Veterinary Medicinal Products.
24. VICH. 2004. Environmental Impact Assessment for Veterinary Medicinal Products—Phase II. VICH GL38. Brussels: International Cooperation on Harmonisation of Technical Requirements for Registration of Veterinary Medicinal Products.
25. Wilkinson, J. L., A. B. A. Boxall, D. W. Kolpin, et al. 2022. "Pharmaceutical Pollution of the World's Rivers." Proceedings of the National Academy of Sciences 119 (8): e2113947119. https://doi.org/10.1073/pnas.2113947119.
26. World Health Organization (WHO). 2012. Pharmaceuticals in Drinking-Water. Geneva: WHO. ISBN 978-92-4-150208-5.
27. World Health Organization (WHO). 2022. Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First and Second Addenda. Geneva: WHO.
28. World Health Organization (WHO). 2024. Guidance on Wastewater and Solid Waste Management for Manufacturing of Antibiotics. Geneva: WHO. ISBN 978-92-4-009725-4.