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THE ROLE OF SYNTHETIC CHEMICALS IN DRIVING ANTIMICROBIAL RESISTANCE IN THE ENVIRONMENT: A PERSPECTIVE

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Abstract

Antimicrobial resistance (AMR) is widely recognized as a consequence of antibiotic overuse, but a growing body of evidence implicates a broader class of synthetic chemicals—including biocides, heavy metals, pesticides, surfactants, and industrial by-products—as co-selectors and drivers of resistance in environmental settings. This perspective synthesizes current understanding of how non-antibiotic synthetic chemicals contribute to the emergence, maintenance, and dissemination of AMR through mechanisms such as co-selection, cross-resistance, horizontal gene transfer, and oxidative stress-induced mutagenesis. We review evidence from wastewater treatment plants, agricultural runoff, industrial effluents, and urban water systems where complex chemical mixtures create selective pressures at sub-inhibitory concentrations. Comparative information about minimum selective concentrations, co-occurrence of resistance genes and chemical contaminants, and regional monitoring studies is provided in tabular format. Existing regulations, which are mainly antibiotic-centric, are not sufficient to address this ubiquitous, although soft, selection pressure. Lastly, the paper identifies gaps in the research, including the need for standardised risk assessment procedures for co-selective chemicals, and policy recommendations for the incorporation of chemical pollution management into the One Health approach to AMR mitigation. Knowledge of these findings highlights the need for environmental chemical management strategies to be considered alongside antibiotic stewardship, in global efforts to contain AMR.

Keywords: Antimicrobial Resistance, Synthetic Chemicals, Co-Selection, Environmental Pollution, Heavy Metals, Biocides, Horizontal Gene Transfer, One Health

1. Introduction

Antimicrobial resistance (AMR) has been characterized by the World Health Organization as one of the top ten global public health threats facing humanity (World Health Organization, 2021). Historically, the discourse on AMR emergence has centered almost exclusively on the therapeutic and agricultural overuse of antibiotics. However, an expanding body of research over the past decade has drawn attention to a parallel and often underappreciated driver: the release of non-antibiotic synthetic chemicals into the environment (Wright, 2010; Bengtsson-Palme & Larsson, 2016).

Chemicals in the agricultural soil, surface waters, wastewater treatment systems and sediments are everywhere, such as in the form of quaternary ammonium compounds (biocides), heavy metals (e.g., copper, zinc, silver), pesticides, pharmaceuticals (apart from antibiotics), ingredients of personal care products and components from industrial effluent (Wales & Davies, 2015). A few of these compounds also have "chemical co-selection" effects (Pal et al., 2015), whereby their sub-inhibitory concentrations create selective pressures on the population of bacteria. Resistance to metals, biocides and antibiotics is often found on the same plasmid, integron or transposon, such that selection for resistance to one category can lead to selection for resistance against the other (Baker-Austin et al., 2006; Seiler & Berendonk, 2012).

The relevant environmental compartments are the effluents from wastewater treatment plants (WWTP), the use of pesticides or manure residues in agriculture, the discharge of industrial effluents (especially pharmaceutical manufacturing), and aquatic sediments (long-term reservoirs of resistance genes) (Larsson & Flach, 2022). In most cases, these environments consist of a mix of chemicals, not a single contaminant, and the overall selective pressure of these mixtures is not predictable based on only single chemical toxicological data (Bengtsson-Palme et al., 2018).

This perspective paper aims to (1) synthesize current mechanistic understanding of how synthetic chemicals other than antibiotics contribute to AMR selection and dissemination in the environment; (2) present comparative data from published environmental monitoring studies illustrating co-occurrence patterns between chemical contaminants and

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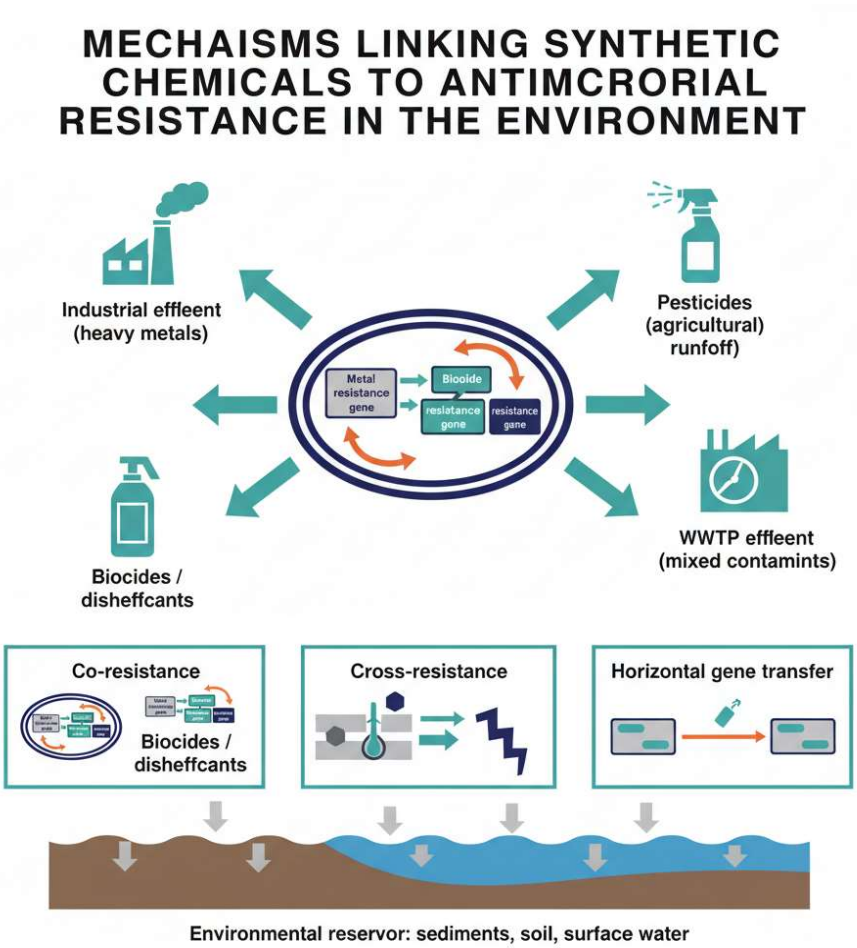
resistance genes; (3) critically evaluate current regulatory and risk-assessment frameworks; and (4) propose research and policy directions consistent with the One Health framework. Given the pace of publication in this field, we restrict our review of empirical studies to work published through mid-2023, while drawing on foundational conceptual literature published earlier.

2. Mechanistic Pathways Linking Synthetic Chemicals to AMR

Figure 1 provides a schematic overview of the principal sources of synthetic chemical exposure (industrial effluent, agricultural runoff, biocide use, and wastewater discharge) and the five mechanistic pathways—co-resistance, cross-resistance, stress-response induction, sub-inhibitory selection, and horizontal gene transfer—through which these chemicals converge to drive antimicrobial resistance in environmental bacterial populations. Each pathway is detailed in the subsections below.

Figure 1. *Conceptual pathways linking synthetic chemical exposure sources to mechanisms of antimicrobial resistance selection and dissemination in the environment.*

Figure 1: Synthetic chemicals and AMR mechanisms diagram



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2.1 Co-selection via Co-resistance

Co-resistance occurs when genes conferring resistance to unrelated chemical classes—for example, a heavy metal and an antibiotic—are physically linked on the same genetic element. Selection pressure from the metal therefore indirectly selects for the antibiotic resistance gene, even in the complete absence of antibiotic exposure (Baker-Austin et al., 2006). It has been well established that the resistance genes for mercury are often associated with the resistance genes for antibiotics on conjugative plasmids in Gram-negative bacteria (Seiler & Berendonk, 2012).

2.2 Cross-resistance

Cross-resistance occurs when one mechanism (like an efflux pump) provides resistance to a number of structurally unrelated compounds, such as biocides and antibiotics. Multidrug efflux pumps, like AcrAB-TolC in Escherichia coli, for example, can be overexpressed and cause decreased susceptibility to fluoroquinolones and other drugs when the bacteria are exposed to biocides like triclosan (Webber et al., 2008; Wales & Davies, 2015).

2.3 Co-regulation and Stress Response Induction

Even low levels of synthetic chemicals such as heavy metals and some pesticides can trigger the bacterial SOS response and cause the rise of reactive oxygen species, which may lead to an increase in mutation rates and enhance horizontal gene transfer (HGT) of resistance genes through transformation, transduction, and conjugation (Jutkina et al., 2018). Kohanski et al. (2010) demonstrated that even sub-inhibitory concentrations of bactericidal antibiotics increase mutagenesis through reactive oxygen species; subsequent work extended this logic to non-antibiotic stressors, including certain metals and biocides (Zhang et al., 2018).

2.4 Selection at Sub-Inhibitory Concentrations

Gullberg et al. (2011) provided pivotal experimental evidence that antibiotic resistance can be selected at concentrations far below the minimal inhibitory concentration (MIC), a finding subsequently extended conceptually to other chemical classes. This has motivated the concept of the "minimal selective concentration" (MSC) as opposed to the MIC as the relevant threshold for environmental risk assessment (Bengtsson-Palme & Larsson, 2016).

2.5 Horizontal Gene Transfer Facilitation

Some environmental chemicals, such as certain pesticides, certain surfactants, and disinfection by-products, have been shown to enhance the environmental spread of multidrug resistance plasmids between bacteria beyond the rate of selection alone (Jutkina et al., 2018).

3. Environmental Reservoir and Chemical Classes of Concern

3.1 Heavy Metals

Copper and zinc are commonly used as growth promoters and therapeutic agents in livestock production as well as ingredients in antifouling paints and industrial effluents, and are closely linked to co-selection of genes conferring antibiotic resistance in agricultural soils and aquatic sediments (Zhu et al., 2013; Pal et al., 2015). Silver nanoparticles are also a class of nanoparticles that are highly prevalent in consumer products and medical devices, and have been shown to co-select for antibiotic resistance both in the laboratory and under field conditions (Graves et al., 2015).

3.2 Biocides and Disinfectants

Antibiotic resistance that occurs through efflux-pump selection is cross-resistant to quaternary ammonium compounds and triclosan, which are widely used in household and hospital disinfectants (Webber et al., 2008). As the use of these

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biocides rose during the COVID-19 pandemic, interest in the potential for their role in selection of AMR in wastewater systems has grown (Nadimpalli et al., 2020).

3.3 Pesticides and Agrochemicals

Some herbicides (glyphosate, dicamba) and fungicides have also been found to cause changes in antibiotic resistance patterns in soil and gut bacteria, with some via efflux system induction and others via changes in membrane permeability (Kurenbach et al., 2015).

3.4 Pharmaceutical Manufacturing Effluents

The introduction of surface water discharges from pharmaceutical production processes, especially in areas where a large proportion of generic pharmaceutical products are manufactured, has led to some of the highest levels of antibiotic and chemical residues recorded in surface waters, which subsequently results in "hotspots" for selection and dissemination of resistance (Larsson, 2014; Bengtsson-Palme et al., 2018).

3.5 Wastewater Treatment Plants

Although some contaminants are removed from the water during treatment, WWTPs are a known hotspot for the enrichment of resistance genes and accumulation of a variety of chemical stressors, all of which are carried in by the mixed influents of domestic, hospital, and industrial sources, and are likely to contain high densities of bacteria that can facilitate the spread of HGT (Rizzo et al., 2013).

4. Data Synthesis: Comparative Evidence from Environmental Monitoring Studies

This section brings together three complementary strands of evidence—chemical classification, dose-response thresholds, and field-level co-occurrence data—to illustrate how synthetic chemicals interact with antimicrobial resistance genes across different environmental settings. Each table addresses a distinct analytical question and is discussed in turn below.

Table 1. Chemical Classes Implicated in Co-selection of Antimicrobial Resistance

Chemical Class	Example Compounds	Primary Mechanism	Key Reference
Heavy metals	Copper, zinc, silver, mercury	Co-resistance (shared mobile genetic elements)	Baker-Austin et al. (2006); Pal et al. (2015)
Biocides	Triclosan, quaternary ammonium compounds	Cross-resistance (efflux pump induction)	Webber et al. (2008); Wales & Davies (2015)
Pesticides	Glyphosate, dicamba, 2,4-D	Altered membrane permeability, efflux induction	Kurenbach et al. (2015)
Pharmaceutical residues (non-antibiotic)	NSAIDs, antidepressants	Stress-response induction, HGT facilitation	Wang et al. (2020)
Disinfection by-products	Chlorinated compounds	Oxidative stress, mutagenesis	Jutkina et al. (2018)
Nanoparticles	Silver nanoparticles, TiO2	Co-selection, membrane stress	Graves et al. (2015)

Note: Data compiled from cited primary and review literature; concentrations vary by site and are not directly comparable across studies due to differing analytical methods.

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Table 1 organizes the principal non-antibiotic chemical classes documented in the literature as contributors to AMR selection, alongside the dominant mechanism through which each class exerts its effect and a representative primary reference. The table highlights that co-selection pathways are mechanistically diverse: heavy metals and biocides operate largely through genetic linkage and efflux-pump induction, respectively, whereas pesticides and disinfection by-products act more indirectly through membrane and oxidative-stress pathways. This mechanistic heterogeneity is important because it implies that no single regulatory threshold or mitigation strategy can address all chemical classes simultaneously; risk assessment must instead be tailored to the specific mode of action of each contaminant group.

Table 2. Reported Minimal Selective Concentrations (MSC) Relative to Minimum Inhibitory Concentrations (MIC)

Compound Type	MSC/MIC Ratio (Approximate)	Study System	Reference
Tetracycline	1/230	Competitive fitness assay, *E. coli*	Gullberg et al. (2011)
Ciprofloxacin	1/4300	Competitive fitness assay, *E. coli*	Gullberg et al. (2011)
Copper sulfate	Sub-MIC selection observed	Soil microcosm	Berg et al. (2010)
Triclosan	Sub-MIC cross-resistance observed	*Salmonella enterica*	Webber et al. (2008)

Note: Data compiled from cited primary and review literature; concentrations vary by site and are not directly comparable across studies due to differing analytical methods.

Table 2 presents empirical evidence that resistance selection can occur at concentrations far below the minimum inhibitory concentration (MIC) traditionally used to define microbial susceptibility. The Gullberg et al. (2011) data are particularly striking: ciprofloxacin selected for resistant *E. coli* strains at concentrations roughly 4,300 times lower than its MIC, while tetracycline showed selective effects at approximately 1/230th of its MIC. Comparable sub-MIC selection has been reported for copper sulfate in soil microcosms and for triclosan-driven cross-resistance in *Salmonella enterica*. Collectively, these findings justify the proposed shift from MIC-based to minimal selective concentration (MSC)-based thresholds in environmental risk assessment, since MIC values substantially underestimate the true concentration range over which selective pressure operates in the environment.

Table 3. Environmental Compartments and Reported Co-occurrence of Chemical Contaminants with Resistance Genes

Environmental Compartment	Chemical Contaminants Detected	Associated Resistance Genes	Reference
Pharmaceutical manufacturing effluent (India)	Multiple antibiotics, solvents	*sul1, sul2, qnrS, blaNDM-1*	Bengtsson-Palme et al. (2018); Kristiansson et al. (2011)
Agricultural soil (manure-amended)	Copper, zinc, tetracyclines	*tetA, tetM,* metal resistance genes	Zhu et al. (2013)
Urban WWTP effluent	Biocides, heavy metals, residual antibiotics	Integron class 1 (*intI1*), multiple ARGs	Rizzo et al. (2013)
River sediment downstream of industrial discharge	Mixed heavy metals	Broad-host-range resistance plasmids	Seiler & Berendonk (2012)

Note: Data compiled from cited primary and review literature; concentrations vary by site and are not directly comparable across studies due to differing analytical methods.

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Table 3 provides a change of perspective from laboratory-derived thresholds to field-based monitoring and documents specific environmental compartments where the presence of chemical contaminants and resistance genes have been found to co-occur. Pharmaceutical manufacturing effluent in India is an extreme case, as multiple antibiotic classes, solvents and clinically significant resistance genes, such as blaNDM-1, have been found to co-occur in the effluents (Kristiansson et al. 2011; Bengtsson-Palme et al. 2018). Agricultural soils that have been amended with manure and effluents from urban wastewater treatment plants exhibit a patchier, but geographically extensive distribution, with metals and biocides present along with mobile elements like class 1 integrons. As a whole, the table shows that co-occurrence does not exclusively happen in agriculture, but is also present in the municipal and industrial pathways, which further highlights the importance of cross-sectoral monitoring and intervention instead of focused efforts on the source.

5. Gaps in regulatory and risk assessment

The present environmental risk assessment systems for chemicals, such as REACH (EU) and similar systems in other countries, are based mainly on ecotoxicological endpoints (e.g., acute and chronic toxicity to aquatic organisms) and lack resistance selection potential as a routine assessment criterion (Bengtsson-Palme & Larsson, 2016). Likewise, the effects of co-selective chemicals found in the same discharge stream as an antibiotic have not been considered in antibiotic environmental risk assessments to date (Ashbolt et al., 2013).

Although there is scientific evidence highlighting the relevance of environmental pollution and chemical pollution management, its mention is underrepresented when it comes to the Global Action Plan on AMR (2015) by the WHO and national action plans (Larsson & Flach, 2022). A regulatory gap was explicitly highlighted in the UN Environment Programme 2023 report on the environmental dimensions of AMR, where controls on chemical pollution (including pharmaceuticals, biocides and metals) were added to AMR containment strategies.

6. Discussion: Integrated One Health perspective

The evidence presented here reinforces a paradigm shift in which AMR is no longer just a result of inappropriate use of antibiotics, but a consequence of complex chemical pollution in the shared human, animal and environmental environment that is at the core of the One Health approach (World Health Organization, Food and Agriculture Organization, & World Organisation for Animal Health, 2019). Effective action to tackle AMR will need:

- Increased environmental monitoring with tracking of co-occurrence of chemical contaminants and resistance determinants, not just of antibiotics.
- New risk assessment procedures that include very limited selective concentration data for biocides, metals and other synthetic compounds, rather than MIC-based thresholds.
- Source control at manufacturing and municipal level, especially for pharmaceutical production effluents that have been identified as high-risk hotspots (Larsson, 2014).
- Policy co-ordination across sectors, interrelating AMR national action plans with chemical safety regulation (REACH-type policies).

There are several limitations of the current evidence: studies vary in design, it can be challenging to draw causal conclusions on the relationship between specific chemical exposure and proliferation of resistance genes in more complex field situations, and there is limited long-term monitoring data from LMC countries where pharmaceutical manufacturing and agricultural chemical use are often concentrated (Bengtsson-Palme et al., 2018).

7. Conclusion

Synthetic chemicals beyond antibiotics—including heavy metals, biocides, pesticides, and industrial effluent components—play a substantive and likely underappreciated role in driving the emergence and environmental dissemination of antimicrobial resistance. Mechanisms including co-resistance, cross-resistance, and chemically induced

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horizontal gene transfer operate at chemical concentrations well below those traditionally considered biologically significant, complicating conventional risk assessment approaches centered on inhibitory concentrations. Addressing AMR as a genuinely One Health challenge requires that environmental chemical management be elevated to a status comparable with antibiotic stewardship within national and global AMR action plans. Future research priorities include standardizing minimal selective concentration testing across chemical classes, expanding environmental surveillance in low- and middle-income regions, and developing regulatory mechanisms that account for chemical mixture effects rather than single-substance thresholds.

References

1. Ashbolt, N. J., Amézquita, A., Backhaus, T., Borriello, P., Brandt, K. K., Collignon, P., Coors, A., Finley, R., Gaze, W. H., Heberer, T., Lawrence, J. R., Larsson, D. G. J., McEwen, S. A., Ryan, J. J., Schönfeld, J., Silley, P., Snape, J. R., Van den Eede, C., & Topp, E. (2013). Human health risk assessment (HHRA) for environmental development and transfer of antibiotic resistance. *Environmental Health Perspectives, 121*(9), 993–1001. https://doi.org/10.1289/ehp.1206316
2. Baker-Austin, C., Wright, M. S., Stepanauskas, R., & McArthur, J. V. (2006). Co-selection of antibiotic and metal resistance. *Trends in Microbiology, 14*(4), 176–182. https://doi.org/10.1016/j.tim.2006.02.006
3. Bengtsson-Palme, J., Kristiansson, E., & Larsson, D. G. J. (2018). Environmental factors influencing the development and spread of antibiotic resistance. *FEMS Microbiology Reviews, 42*(1), fux053. https://doi.org/10.1093/femsre/fux053
4. Bengtsson-Palme, J., & Larsson, D. G. J. (2016). Concentrations of antibiotics predicted to select for resistant bacteria: Proposed limits for environmental regulation. *Environment International, 86*, 140–149. https://doi.org/10.1016/j.envint.2015.10.010
5. Berg, J., Tom-Petersen, A., & Nybroe, O. (2010). Copper amendment of agricultural soil selects for bacterial antibiotic resistance in the field. *Letters in Applied Microbiology, 40*(2), 146–151. https://doi.org/10.1111/j.1472-765X.2004.01650.x
6. Graves, J. L., Tajkarimi, M., Cunningham, Q., Campbell, A., Nonga, H., Harrison, S. H., & Barrick, J. E. (2015). Rapid evolution of silver nanoparticle resistance in *Escherichia coli*. *Frontiers in Genetics, 6*, 42. https://doi.org/10.3389/fgene.2015.00042
7. Gullberg, E., Cao, S., Berg, O. G., Ilbäck, C., Sandegren, L., Hughes, D., & Andersson, D. I. (2011). Selection of resistant bacteria at very low antibiotic concentrations. *PLoS Pathogens, 7*(7), e1002158. https://doi.org/10.1371/journal.ppat.1002158
8. Jutkina, J., Rutgersson, C., Flach, C. F., & Larsson, D. G. J. (2018). An assay for determining minimal concentrations of antibiotics that drive horizontal transfer of resistance. *Science of the Total Environment, 548–549*, 131–138. https://doi.org/10.1016/j.scitotenv.2016.01.044
9. Kohanski, M. A., DePristo, M. A., & Collins, J. J. (2010). Sublethal antibiotic treatment leads to multidrug resistance via radical-induced mutagenesis. *Molecular Cell, 37*(3), 311–320. https://doi.org/10.1016/j.molcel.2010.01.003
10. Kristiansson, E., Fick, J., Janzon, A., Grabic, R., Rutgersson, C., Weijdegård, B., Söderström, H., & Larsson, D. G. J. (2011). Pyrosequencing of antibiotic-contaminated river sediments reveals high levels of resistance genes and mobile genetic elements. *PLoS ONE, 6*(2), e17038. https://doi.org/10.1371/journal.pone.0017038
11. Kurenbach, B., Marjoshi, D., Amábile-Cuevas, C. F., Ferguson, G. C., Godsoe, W., Gibson, P., & Heinemann, J. A. (2015). Sublethal exposure to commercial formulations of the herbicides dicamba, 2,4-dichlorophenoxyacetic acid, and glyphosate causes changes in antibiotic susceptibility in *Escherichia coli* and *Salmonella enterica*. *mBio, 6*(2), e00009-15. https://doi.org/10.1128/mBio.00009-15
12. Larsson, D. G. J. (2014). Pollution from drug manufacturing: Review and perspectives. *Philosophical Transactions of the Royal Society B, 369*(1656), 20130571. https://doi.org/10.1098/rstb.2013.0571
13. Larsson, D. G. J., & Flach, C. F. (2022). Antibiotic resistance in the environment. *Nature Reviews Microbiology, 20*(5), 257–269. https://doi.org/10.1038/s41579-021-00649-x

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Publication Date:30th July 2023
Publisher: Sucharitha Publication, India
Digital Certificate of Publication: www.ijmer.in/pdf/e-CertificateofPublication-IJMER.pdf

14. Nadimpalli, M. L., Marks, S. J., Montealegre, M. C., Gilman, R. H., Pajuelo, M. J., Saito, M., Tsukayama, P., Njenga, S. M., Kiiru, J., Swarthout, J., Islam, M. A., Julian, T. R., & Pickering, A. J. (2020). Urban informal settlements as hotspots of antimicrobial resistance and the need to curb environmental transmission. *Nature Microbiology, 5*(6), 787–795. https://doi.org/10.1038/s41564-020-0722-0
15. Pal, C., Bengtsson-Palme, J., Kristiansson, E., & Larsson, D. G. J. (2015). Co-occurrence of resistance genes to antibiotics, biocides and metals as indicative of the selective pressure of anthropogenic activities. *BMC Genomics, 16*, 964. https://doi.org/10.1186/s12864-015-2153-5
16. Rizzo, L., Manaia, C., Merlin, C., Schwartz, T., Dagot, C., Ploy, M. C., Michael, I., & Fatta-Kassinos, D. (2013). Urban wastewater treatment plants as hotspots for antibiotic-resistant bacteria and genes spread into the environment: A review. *Science of the Total Environment, 447*, 345–360. https://doi.org/10.1016/j.scitotenv.2013.01.032
17. Seiler, C., & Berendonk, T. U. (2012). Heavy metal-driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture. *Frontiers in Microbiology, 3*, 399. https://doi.org/10.3389/fmicb.2012.00399
18. United Nations Environment Programme. (2023). *Bracing for superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance*. UNEP.
19. Wales, A. D., & Davies, R. H. (2015). Co-selection of resistance to antibiotics, biocides and heavy metals, and its relevance to foodborne pathogens. *Antibiotics, 4*(4), 567–604. https://doi.org/10.3390/antibiotics4040567
20. Wang, Y., Lu, J., Mao, L., Li, J., Yuan, Z., Bond, P. L., & Guo, J. (2020). Antiepileptic drug carbamazepine promotes horizontal transfer of plasmid-borne multi-antibiotic resistance genes within and across bacterial genera. *ISME Journal, 13*(2), 509–522. https://doi.org/10.1038/s41396-018-0275-x
21. Webber, M. A., Randall, L. P., Cooles, S., Woodward, M. J., & Piddock, L. J. V. (2008). Triclosan resistance in *Salmonella enterica* serovar Typhimurium. *Journal of Antimicrobial Chemotherapy, 62*(1), 83–91. https://doi.org/10.1093/jac/dkn137
22. World Health Organization. (2015). *Global action plan on antimicrobial resistance*. WHO.
23. World Health Organization. (2021). *Antimicrobial resistance: Fact sheet*. WHO.
24. World Health Organization, Food and Agriculture Organization, & World Organisation for Animal Health. (2019). *Monitoring global progress on antimicrobial resistance: Tripartite AMR country self-assessment survey*. WHO.
25. Wright, G. D. (2010). Antibiotic resistance in the environment: A link to the clinic? *Current Opinion in Microbiology, 13*(5), 589–594. https://doi.org/10.1016/j.mib.2010.08.005
26. Zhang, S., Song, J., Gu, P., Zhao, S., Ecker, D. J., Xia, X., & Kim, K. S. (2018). Trace mercury contributes to antibiotic resistance selection and horizontal gene transfer. *Environmental Pollution, 233*, 431–439. https://doi.org/10.1016/j.envpol.2017.10.084
27. Zhu, Y. G., Johnson, T. A., Su, J. Q., Qiao, M., Guo, G. X., Stedtfeld, R. D., Hashsham, S. A., & Tiedje, J. M. (2013). Diverse and abundant antibiotic resistance genes in Chinese swine farms. *Proceedings of the National Academy of Sciences, 110*(9), 3435–3440. https://doi.org/10.1073/pnas.1222743110