Review Article *Open Access*

Journal of Geoscience and Eco Agricultural Studies

ISSN: 3067-7297

Antimicrobial Resistance in Agriculture: Impacts on Soil, Water, Crops, Livestock, and Sustainability

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Citation: *Muhammad Mudassar, Momina Iftikhar, Areeg Fatima, Muhammad Shahzar, Maryam Khalid, et al. (2026) Antimicrobial Resistance in Agriculture: Impacts on Soil, Water, Crops, Livestock, and Sustainability. J. of Geo Eco Agr Studies 3(5): 1-13. WMJ/JGEAS-154*

Abstract

Antimicrobial resistance is an increasing agricultural and environmental challenge affecting livestock production, crop systems, soil quality, irrigation water, food safety, and sustainable farming. Agricultural environments can receive resistant bacteria and antimicrobial-resistance genes through manure, wastewater, contaminated irrigation water, biosolids, and inappropriate antimicrobial use. Once introduced into soil and water, resistant microorganisms may persist, interact with indigenous microbial communities, and potentially disseminate resistance determinants through horizontal gene transfer. The agricultural significance of environmental resistance is particularly important because food-producing systems connect environmental reservoirs with livestock, crops, farm workers, consumers, and downstream ecosystems. This review examines the major sources, environmental pathways, agricultural consequences, molecular surveillance approaches, and management strategies associated with antimicrobial resistance. Particular attention is given to β-lactamase-producing bacteria, agricultural water, soil–plant interactions, manure management, nanotechnology, and One Health surveillance. Sustainable antimicrobial stewardship, improved farm hygiene, responsible manure application, water-quality monitoring, and integrated molecular surveillance are essential for protecting agricultural productivity and food security.

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Submitted: 22.09.2026 **Accepted**: 28.09.2026 **Published**: 15.10.2026

Keywords: Agriculture, Antimicrobial Resistance, Soil, Irrigation Water, Livestock, Crops, β-Lactamase, Manure, Food Safety, One Health

Introduction

Agriculture is a complex biological system involving interactions among soil, water, crops, livestock, microorganisms, climate, and human management. Sustainable agriculture depends not only on maintaining productivity but also on protecting soil quality, water resources, biodiversity, food safety, and environmental health.

One emerging threat to these objectives is antimicrobial resistance (AMR). Antimicrobial-resistant microorganisms can enter agricultural environments through livestock manure, wastewater, contaminated irrigation water, biosolids, animal production facilities, and inappropriate antimicrobial use. The agricultural environment can consequently function as both a recipient and potential reservoir of resistant bacteria and antimicrobial-resistance genes.

The relationship between antimicrobial use and agricultural production is particularly important in livestock and poultry systems. Antibiotics may be used therapeutically, metaphylactically, or prophylactically under veterinary supervision. However, inappropriate or excessive use can exert selection pressure favoring resistant microorganisms. These microorganisms can subsequently be released through feces and manure.

Manure is commonly used as an organic fertilizer because it provides nitrogen, phosphorus, potassium, carbon, and other nutrients. However, untreated manure may also contain antibiotic residues, resistant bacteria, and resistance genes. When manure is applied to agricultural soil, these biological and chemical components may interact with indigenous soil microbial communities.

Water provides another important pathway. Rivers, canals, wastewater, groundwater, and agricultural drainage can transport resistant microorganisms across geographical boundaries. Guma et al. identified β-lactamase-associated genes in Klebsiella species isolated from the Euphrates River in Iraq, illustrating the importance of aquatic environments in environmental antimicrobial-resistance surveillance [1].

The agricultural importance of AMR extends beyond animal health. Resistant bacteria potentially interact with crops, soil microorganisms, farm workers, wildlife, and consumers. Consequently, agricultural AMR is appropriately considered within a One Health framework involving human, animal, plant, and environmental health.

This review evaluates the sources, pathways, consequences, detection, and management of AMR in agricultural systems, emphasizing soil, water, crops, livestock, manure, molecular surveillance, and sustainable agricultural practices.

Sources of Antimicrobial Resistance in Agricultural Systems

Several agricultural and environmental sources contribute to the dissemination of antimicrobial resistance.

Livestock Production

Livestock can receive antimicrobial treatment for bacterial diseases. Following administration, antimicrobial residues and resistant bacteria may be excreted in feces and urine. The gastrointestinal tract provides an environment where antimicrobial exposure can select resistant bacterial populations. Resistant organisms may subsequently contaminate animal housing, manure, soil, water, and farm equipment. Poultry production presents similar challenges because large numbers of animals may be housed in concentrated production systems. Poultry litter can contain bacteria, resistance genes, nutrients, and pharmaceutical residues.

Manure Application

Manure is an important component of sustainable nutrient management. However, its microbiological composition should be considered before application. The environmental fate of these contaminants depends on manure storage, composting, soil type, temperature, moisture, application rate, and agricultural management.

Wastewater

Treated and untreated wastewater can contain resistant bacteria and resistance genes. Agricultural reuse of wastewater may provide valuable irrigation resources in water-scarce areas, but inadequate treatment can

introduce microbiological hazards into soil and crops.
Wastewater management should therefore balance water conservation with microbial and chemical safety.

Irrigation Water

Surface water used for irrigation may receive contamination from municipal sewage, livestock facilities, agricultural runoff, and industrial activities.Once contaminated water is applied to agricultural fields, microorganisms can enter soil and potentially reach crop surfaces.

Environmental Pathways of Antimicrobial Resistance

AMR moves through agricultural systems via interconnected environmental pathways.

Table 1: Major agricultural sources and pathways of antimicrobial-resistance dissemination

Source	Principal material introduced	Agricultural pathway	Potential consequence
Livestock manure	Resistant bacteria and genes	Soil application	Soil microbial exposure
Poultry litter	Bacteria and residues	Crop fields	Crop and soil contamination
Wastewater	Resistant microorganisms	Irrigation	Soil and crop exposure
Surface water	Bacteria and resistance genes	Irrigation canals	Agricultural dissemination
Farm runoff	Microorganisms and residues	Rivers and groundwater	Environmental spread
Biosolids	Microbial communities and genes	Soil amendment	Persistence in soil
Animal housing	Resistant organisms	Dust, water, manure	Farm-wide dissemination
Slaughterhouse waste	Resistant bacteria	Wastewater and land	Environmental contamination
Agricultural drainage	Microorganisms	Downstream water	Watershed dissemination

The environmental behavior of resistance determinants depends on physical, chemical, and biological characteristics.Soil texture can influence microbial attachment and movement. Clay-rich soils may adsorb bacterial cells and extracellular DNA, whereas sandy soils may facilitate movement with percolating water. Organic matter provides carbon and energy for microbial communities but can also interact with antibiotics and resistance determinants.Soil pH, temperature, salinity, moisture, redox conditions, and nutrient availability may further influence microbial persistence.

Soil as an Agricultural Reservoir

Soil contains highly diverse microbial communities that perform essential functions, including decomposition, nutrient cycling, nitrogen fixation, organic-matter transformation, and plant growth promotion.The introduction of resistant bacteria into soil therefore occurs within a complex microbial ecosystem.Resistance genes may be present in bacterial chromosomes or mobile genetic elements. Plasmids, transposons, and integrons can facilitate gene movement between microorganisms.Agricultural soils should consequently be regarded as dynamic microbial environments rather than passive repositories of contaminants.

Plant–Soil–Microbe Interactions

Plants interact continuously with soil microorganisms through their roots. Root exudates containing sugars, amino acids, organic acids, and secondary metabolites influence rhizosphere microbial communities.The rhizosphere may

therefore provide favorable conditions for interactions between environmental bacteria.

Resistant bacteria introduced through irrigation water or manure can encounter plant-associated microorganisms. However, the presence of a resistance gene in agricultural soil does not automatically demonstrate transfer into crops or humans. This distinction is essential because molecular detection can identify DNA from nonviable microorganisms.

Agricultural Water and Crop Safety

Water quality is a fundamental component of agricultural production. The level of microbial exposure varies considerably between these methods. Overhead irrigation can directly deposit microorganisms onto leaves and fruits, whereas drip irrigation generally reduces direct contact between irrigation water and edible aerial plant tissues. Nevertheless, the choice of irrigation technology should be based on crop requirements, soil characteristics, water availability, economic feasibility, and environmental risk. Water-quality monitoring should include microbiological and physicochemical parameters where appropriate.

β-Lactamase-Producing Bacteria and Agriculture

β-lactam antibiotics represent a major antimicrobial class used in human and veterinary medicine. Bacteria can acquire resistance through production of β-lactamase enzymes capable of hydrolyzing β-lactam antibiotics.

Environmental β-lactamase genes may be found in bacteria inhabiting water, soil, wastewater, livestock environments, and other ecosystems. Guma et al. investigated two β-lactamase genes in Klebsiella species isolated from the Euphrates River in Iraq [1]. This study provides an important environmental example because rivers can interact directly with irrigation networks and agricultural landscapes. The study also demonstrates the value of molecular approaches in environmental surveillance. The agricultural significance of such findings lies not in assuming direct transmission to crops or humans, but in recognizing that aquatic environments may contain bacteria carrying clinically relevant resistance determinants.

Antimicrobial Use in Livestock

Antimicrobial stewardship is an important agricultural management principle. Antibiotics should be used when clinically justified and under appropriate veterinary guidance. Disease prevention through vaccination, biosecurity, adequate nutrition, clean water, appropriate housing, and good husbandry can reduce unnecessary antimicrobial use. Reducing unnecessary antimicrobial exposure can reduce selection pressure for resistance.

Manure Management

Manure management is central to both agricultural sustainability and environmental protection. Proper storage and treatment can reduce microbial hazards before land application. Composting may reduce viable pathogenic bacteria when appropriate temperatures and treatment durations are achieved. However, composting should be properly managed because incomplete treatment may allow resistant organisms or resistance genes to persist.

Antimicrobial Resistance and Agricultural Sustainability

Agricultural sustainability requires balancing productivity with environmental protection. Conversely, sustainable agricultural practices can contribute to AMR reduction. Integrated crop–livestock systems may recycle nutrients efficiently, but manure handling must be appropriately managed.Precision agriculture may help optimize fertilizer and water use, reducing unnecessary environmental transport. Geospatial technologies can identify contamination hotspots and support targeted monitoring.

Nanotechnology and Agricultural Applications

Nanotechnology has attracted attention in agriculture because nanoscale materials may be used for sensors, fertilizers, pesticides, antimicrobial surfaces, and controlled-release systems. Shallal et al. reviewed nanotechnology-based drug-delivery systems in bone tissue engineering, illustrating the potential of nanoscale technologies for controlled delivery [2]. Similar principles could be investigated in agriculture for controlled delivery of agricultural inputs or development of sensors capable of detecting microbial contamination.

However, the environmental safety of nanomaterials requires careful evaluation.Shallal and Owaid emphasized potential hazards and challenges associated with nanotechnology in agricultural environments [3]. Nanomaterials may interact with soil microorganisms, plants, water, minerals, and organic matter.

Molecular Surveillance in Agriculture

Traditional microbiological culture remains important because viable bacterial isolates can be recovered and tested for antimicrobial susceptibility.Molecular technologies provide additional capabilities.

Polymerase chain reaction can detect specific resistance genes, while quantitative PCR can estimate gene abundance.Metagenomics provides a broader view of resistance determinants within environmental microbial communities.

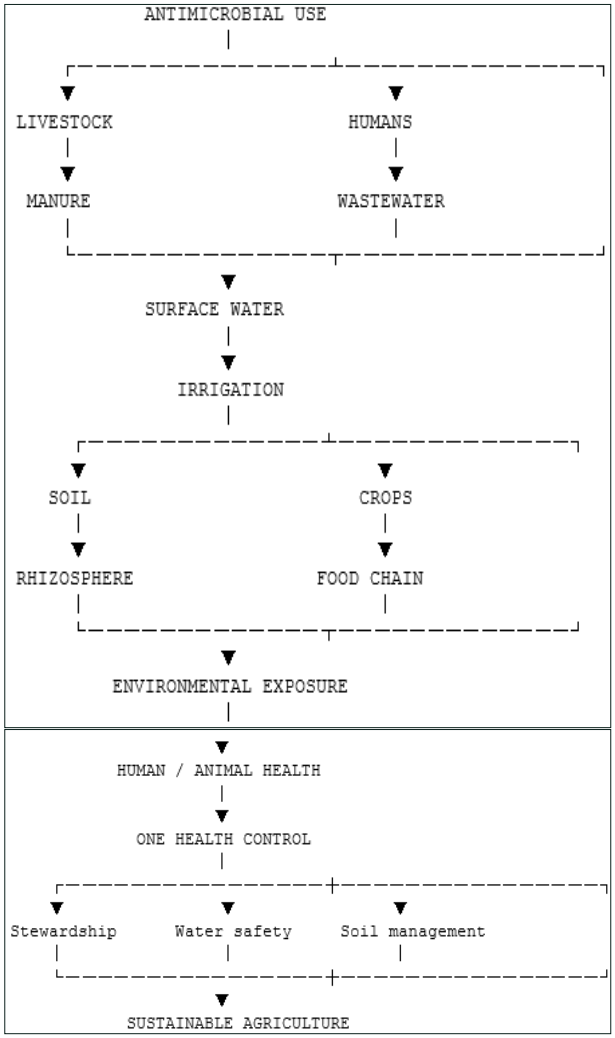


Figure 1: Integrated agricultural pathway of antimicrobial-resistance dissemination

One Health Approach

Agricultural AMR cannot be adequately addressed by focusing on farms alone.One Health agricultural surveillance program could collect samples from farms, irrigation water, soil, crops, livestock, wastewater, and nearby rivers.Results could then be combined with antimicrobial-use records and genomic information. Such integration may help identify environmental hotspots and improve prevention.

Agricultural Biomarkers and Environmental Health

Agricultural workers and livestock can experience multiple environmental exposures.Biomarkers can provide information concerning inflammatory and physiological responses, although they are rarely specific to a single exposure.Shallal reported changes in inflammatory and biochemical markers associated with smoking exposure [4]. This demonstrates the importance of interpreting biomarkers within broader exposure contexts.Similarly, research concerning immunomodulatory pathways in renal disease highlights the complexity of inflammatory signaling [5].Such research can inform agricultural environmental-health studies by encouraging comprehensive biomarker panels and appropriate control groups.

Environmental and Food Safety Implications

The presence of resistant bacteria in agricultural environments does not necessarily mean that food products are unsafe.Food safety therefore requires risk-based assessment rather than simple detection.Good Agricultural Practices, appropriate irrigation-water management, hygienic harvesting, washing, storage, and processing can reduce microbial risks [6-15].

Future Research Priorities

Future agricultural AMR research should focus on integrated environmental systems.More research is also needed to determine whether changes in environmental resistance gene abundance correspond to measurable changes in agricultural or human-health risk.

Table 2: Agricultural strategies for reducing antimicrobial-resistance dissemination

Strategy	Target	Expected benefit
Veterinary antimicrobial stewardship	Livestock	Reduce selection pressure
Vaccination	Animal disease prevention	Reduce antimicrobial demand
Manure composting	Farm waste	Reduce microbial hazards
Irrigation-water testing	Water resources	Detect contamination
Drip irrigation	Crop production	Reduce direct crop exposure
Soil monitoring	Agricultural fields	Detect environmental persistence
Wastewater treatment	Irrigation sources	Reduce resistant organisms
Farm biosecurity	Livestock facilities	Reduce disease transmission
Molecular surveillance	Resistance genes	Detect emerging resistance
GIS mapping	Agricultural landscapes	Identify contamination hotspots
Farmer education	Farm management	Improve preventive practices
Integrated One Health surveillance	Human–animal–environment interface	Improve coordinated control

Conclusion

Antimicrobial resistance represents a growing challenge for sustainable agriculture because resistant microorganisms and resistance genes can circulate among livestock, manure, wastewater, irrigation water, soil, crops, and surrounding ecosystems. Agricultural practices influence both the introduction and persistence of resistance determinants. Molecular evidence from environmental water, including β-lactamase detection in Klebsiella, demonstrates the importance of environmental surveillance. Effective management requires responsible antimicrobial use, vaccination, improved manure treatment, safe irrigation water, soil monitoring, molecular diagnostics, and farmer education. Nanotechnology and geospatial tools may strengthen future monitoring but require environmental safety assessment. A coordinated One Health strategy integrating agricultural, environmental, veterinary, and public-health surveillance offers the most promising pathway for reducing resistance while maintaining productive, safe, and sustainable agricultural systems.

References

1. Guma MA, Jubier OJ, Shallal AF, Nasser BM, Alisawi O (2026) Molecular identification and antibiotic resistance evaluation of two β-lactamase genes in Klebsiella species isolated from Euphrates River in Iraq. Egyptian Journal of Medical Microbiology https://doi.org/10.21608/ejmm.2026.476510.2277
2. Shallal AF, Owaid MN (2022) Challenges and hazards associated with nanotechnology in agriculture. In Advances in Nanotechnology-Based Drug Delivery Systems 399-414.
3. Shallal AF (2025) Immunomodulatory pathways of some biomarkers in individuals with renal failure. ARO—The Scientific Journal of Koya University 13: 326-333.
4. Shallal AF, Akram M, Muslim RF, Owaid MN, Yaseen OQ, et al. (2022) Bone tissue engineering using nanotechnology-based drug delivery system. In Advances in Nanotechnology-Based Drug Delivery Systems 177-196.
5. Shallal AF (2025) Modulation of immune pathway and biomarkers: Impacts of lifestyle, nutrition, and therapeutic interventions. Zenodo.
6. Bengtsson-Palme J, Larsson DGJ (2016) Concentrations of antibiotics predicted to select for resistant bacteria: Proposed limits for environmental regulation. Environment International 86: 140-149.
7. Berendonk TU, Manaia CM, Merlin C, Fatta-Kassinos D, Cytryn E, et al. (2015) Tackling antibiotic resistance: The environmental framework. Nature Reviews Microbiology 13: 310-317.
8. FAO, UNEP, WHO, & WOAH (2022). One Health Joint Plan of Action (2022–2026): Working together for the health of humans, animals, plants and the environment. Rome: Food and Agriculture Organization

of the United Nations.
9. Gatica J, Cytryn E (2013) Impact of treated wastewater irrigation on antibiotic resistance in the soil microbiome. Environmental Science & Technology 47: 12386-12393.
10. Graham DW, Bergeron G, Bourassa MW, Dickson J, Gomes MP, et al. (2019) Complexities in understanding antimicrobial resistance across domesticated animal, human, and environmental systems. Annals of the New York Academy of Sciences 1441: 17-30.
11. Karkman A, Do TT, Walsh F, Virta MPJ (2018) Antibiotic-resistance genes in waste water. Trends in Microbiology 26: 220-228.
12. Larsson DGJ, Flach CF (2022) Antibiotic resistance in the environment. Nature Reviews Microbiology 20: 257-269.
13. Manaia CM (2017) Assessing the risk of antibiotic resistance transmission from the environment to humans: Non-direct proportionality between abundance and risk. Trends in Microbiology 25: 173-181.
14. Shallal AF (2020) The changes in some inflammatory markers and biochemical aspects during smoking in males. Communities 1: 4.
15. Woolhouse M, Ward M, van Bunnik B, Farrar J (2015) Antimicrobial resistance in humans, livestock and the wider environment. Philosophical Transactions of the Royal Society B: Biological Sciences 370: 20140083.

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