A RISK MANAGEMENT FRAMEWORK FOR ANTIBIOTIC RESISTANCE IN INTEGRATED WATER-AGRI SYSTEMS

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Abstract

The transition toward circular water-agriculture systems is vital for achieving SDG 6 (Clean Water) and SDG 12 (Responsible Production), but it creates a "biological liability": the spread of antibiotic-resistant "superbugs" through recycled waste. This paper proposes a Risk Management Framework (RMF) that moves beyond basic testing to a proactive "One Health" strategy. By treating the agricultural supply chain as an integrated system, the framework identifies Critical Control Points—such as wastewater plants and manure storage—where managers can apply specific interventions to stop resistance from reaching the food supply.

By aligning these safety protocols with SDG 3 (Good Health and Well-being), this framework provides a practical roadmap for balancing sustainability with public health. It integrates advanced monitoring into standard business operations, helping stakeholders manage the trade-off between resource recovery and consumer safety. Ultimately, this systematic approach transforms circular agriculture from a high-risk experiment into a resilient, ESG-compliant (Environmental, Social, and Governance) solution for global food security.

Keywords*: Resistome, Biological Liability, Superbugs, One Health.*

Introduction

Modern farming is trying to be more "circular" by recycling wastewater and manure to save water and nutrients. This helps hit global goals like SDG 6 (Clean Water) and SDG 12 (Sustainable Production). However, this recycling "loop" has a hidden danger: antibiotic-resistant superbugs (the "resistome"). If we aren't careful, these germs move from our waste into our soil and onto our dinner plates, creating a major health risk.

To fix this, we need a Risk Management Framework. Think of this as a "safety GPS" for farm managers. Instead of just reacting when things go wrong, this plan identifies Critical Control Points—the specific moments, like water treatment or fertilizing, where the risk is highest. By adding "safety barriers" at these spots (like better filters or waiting longer before harvesting), we protect SDG 3 (Good Health). This turns a risky recycling project into a smart, safe business model that protects both the planet and the people eating the food.

Review of Literature

The latest research shows that while recycling water and waste for farming is great for the planet, it creates a hidden "biological liability." Experts like Beriberi (2023) and Gigliucci (2025) have found that wastewater and manure—the main ingredients in circular farming—often carry "superbug DNA" (the resistome). This creates a supply chain risk where dangerous, drug-resistant germs can travel from recycled waste into the soil, onto our crops, and eventually to the consumer's plate. For a manager, this means that a "green" initiative could accidentally become a major health safety issue if not monitored correctly.

The second major finding in recent studies is an "Operational Gap." Researchers such as Liguori (2022) and Kaur (2025) highlight that most current water treatment plants are outdated; they were built to catch chemicals, not tiny pieces of antibiotic-resistant genetic material. This creates a massive compliance risk. It means a farm could follow all current laws and use "approved" recycled water, yet still be spreading superbugs because the standard cleaning tools aren't strong enough yet.

To fix this, global organizations like the OECD (2025) and the World Bank suggest moving toward a "One Health" Management Strategy. This approach treats the farm, the water company, and the hospital as one connected team. Instead of just hoping for the best, managers are encouraged to use Critical Control Points—specific checkpoints in the farming process where they can test for risks and stop them. By doing this, businesses protect their "Bottom Line." As the International Water Management Institute (2024) warns, ignoring these superbugs could lead to a $100 trillion global economic loss by 2050. For any future manager, treating the "resistome" as a core part of ESG (Environmental and Social Governance) is no longer optional—it is a requirement for a safe and profitable business.

Statement of the Problem

Circular agriculture aims to solve water scarcity by recycling wastewater and manure (SDG 6 & 12), but this "green" loop accidentally acts as a highway for antibiotic-resistant superbugs (the resistome). The core problem is that farm managers are currently "flying blind" because they lack a practical way to manage this biological risk. Standard water treatments aren't designed to stop these germs, and the high-tech testing required to find them is too expensive for most farms. Without a clear Risk Management Framework, farmers cannot make safe decisions about when to water or harvest, creating a "biological liability" that threatens global food safety, public health (SDG 3), and the farm's own financial future

Research Gap

- The "Action" Gap: Most studies tell us that wastewater treatment plants are failing, but they don't provide a step-by-step decision matrix for a farm manager to follow when the water arrives at the gate. There is no clear "Standard Operating Procedure" (SOP) for resistome management.
- The "Incentive" Gap: Literature focuses on the $100 trillion global loss, but it doesn't explain how a single small-to-medium enterprise (SME) can afford to implement these high-tech monitoring systems. We need research on cost-effective management models for smaller players in the circular economy.
- The "Measurement" Gap: While scientists use metagenomics (expensive DNA testing), managers need "Proxy Indicators"—simple, cheaper things they can measure (like basic water quality or soil pH) that might predict if the resistome risk is high

Objectives

- **Find the Danger Zones**: To identify the exact spots in the farming process where "superbugs" are most likely to enter.
- **Create a "How-To" Guide**: To build a step-by-step manual that tells farm managers exactly how to handle recycled water safely.
- **Find Cheap Warning Signs**: To look for simple, low-cost ways to test for risks so farms don't have to spend a fortune on lab tests.
- **Help Small Businesses**: To make sure this safety plan is affordable and easy enough for small farms to use.
- **Meet Global Goals**: To make sure farming stays "green" and sustainable

while keeping the food safe for people to eat.

Research Methodology

To build this Risk Management Framework (RMF), the research uses a Secondary Research Methodology. This means instead of doing new experiments in a lab, we are analyzing existing data, scientific reports, and business guidelines to create a new "Safety Manual" for managers.

Collecting Information: We look at existing "science papers" to understand the germs and "business reports" from groups like the World Health Organization to understand the health risks.

Finding the "Holes": We use Gap Analysis. This is just a fancy way of looking at what scientists recommend (which is usually expensive) and comparing it to what a normal farmer can actually afford to do.

Findings

- The "Clean Water" Illusion: Water that meets government standards for "cleanliness" can still be packed with antibiotic-resistant genes. This means a manager can be legally compliant but biologically dangerous.
- The Invisible Harvest: Superbugs have been found inside the tissues of vegetables (like lettuce and carrots). You cannot "wash away" this risk because the resistance is inside the plant's cells, not just on the surface.
- The "Silent Highway": Reclaimed wastewater acts as a permanent "loop." Even if a farm stops using antibiotics on animals, the recycled water from nearby cities keeps bringing new superbugs back into the soil every single day.
- The Regulatory Vacuum: There are currently no global "speed limits" or laws specifically for the resistome in agriculture. This creates a massive legal risk for businesses if a health crisis is traced back to their "sustainable" farm.
- The Economic Crash: Research warns that if these superbugs aren't managed, the "Circular Economy" model will fail because consumers will stop trusting recycled food products, leading to a total loss of market value.

Suggestions

1. Establish a **"Three-Barrier"** System: Instead of relying only on the treatment plant, managers should use three on-farm barriers:
    - Sedimentation: Letting water sit in a holding pond to allow heavier particles (which often carry superbugs) to sink.

- Filtration: Using sand or charcoal filters at the farm gate.
- UV Exposure: Maximizing natural sunlight exposure for irrigation water, as UV rays help break down resistant DNA.
- Create "Safe Harvest Windows": Implement a strict rule where irrigation with recycled water must stop 14 to 30 days before harvest. This gives the environment time to naturally degrade superbugs before the food reaches the consumer.

2. Cost-Effective Monitoring (The "Proxy Indicators")

Use "Indicator Testing" Instead of DNA Labs: Since DNA testing is too expensive; suggest that managers monitor Turbidity (cloudiness) and pH levels. Research shows that high cloudiness often correlates with high microbial loads. If the water is cloudy, the risk of superbugs is higher—stops irrigation immediately.

Monitor "Bio-Indicators": Regularly check for common bacteria like E. coli. While E. coli itself might not be a superbug, its presence is a "proxy" warning that the water treatment has failed and more dangerous genes could be present.

3. Strategic Management (The "One Health" Approach)

Form a "Water-User Group": Managers should not work in isolation. Form a committee with the local wastewater plant and neighboring farms to share test results. If one farm sees a spike in germs, everyone is alerted.

Implement "Resistome Stewardship": Just as farms have "pesticide logs," suggest they keep "Recycled Input Logs." Record the source, the date, and the "proxy" test results for every batch of water used. This builds a data trail for ESG compliance and legal protection.

4. Infrastructure & Technology

Invest in Precision Irrigation: Move away from "spray" or "overhead" irrigation which puts water directly on the leaves. Suggest Drip Irrigation, which delivers water directly to the soil. This minimizes the chance of superbugs "sticking" to the edible parts of the plant.

Adopt "Digital Health" Tools: Even for small farms, simple IoT sensors that track water flow and quality can provide real-time data to a smartphone, allowing for "smart" shutdowns if water quality drops.

Conclusion

The shift toward a circular agricultural model is a powerful tool for environmental sustainability, but it introduces a

"biological liability" that current management systems are not equipped to handle. Research confirms that while recycling wastewater and organic waste supports global goals for water and production, it also creates a direct pathway for antibiotic-resistant "superbugs" to move from urban waste into our food supply. Because standard treatment plants often fail to remove these resistant genes, and most farms lack the expensive technology to detect them, the industry is currently "flying blind." This gap between legal compliance and actual biological safety puts public health at risk and threatens the long-term economic value of the circular economy.

To bridge this gap, managers must move beyond simple compliance and adopt a proactive One Health Risk Management Framework. By identifying "Critical Control Points"—such as using on-farm sand filters and setting strict "harvest windows" to allow germs to die off naturally—farms can block superbugs before they reach the consumer. This framework also offers a cost-effective solution for smaller farms by using simple "proxy indicators," like water cloudiness, to predict risk without needing a laboratory. Ultimately, this approach transforms a high-risk recycling loop into a resilient, ESG-compliant business model that protects both the planet and the people who eat the food

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