Journal of Emerging Technologies and Industrial Applications
Vol. 4 No. 1 (2025) pp. 1-13
e-ISSN: 2948-507X

Journal homepage: https://jetia.mbot.org.my/index.php/jetia/index

Mini Review of Antimicrobial Resistance and River Health: A Dual Crisis and Sustainable Mitigation Strategies

Chee Loong Teo*

Department of Research and Development, Agri Season Sdn. Bhd. No 30, Lot 2718 Jalan Kejayaan 1, Batu 24, 81900 Kota Tinggi, Johor, MALAYSIA.

*Email: anthony1109@hotmail.my

Abstract: Antimicrobial resistance (AMR) and river contamination are interconnected global challenges that threaten public health, environmental sustainability, and water security. AMR, fueled by the overuse and misuse of antibiotics in healthcare, agriculture, and wastewater mismanagement, has led to the widespread emergence of antibiotic-resistant bacteria in natural ecosystems. Simultaneously, poor sanitation infrastructure, untreated wastewater discharge, and industrial pollution have contributed to the degradation of river systems, exacerbating the spread of AMR. This review consolidates insights from four major thematic areas: (1) AMR as a global health crisis and the urgent need for containment strategies, (2) the environmental spread of antibiotic-resistant bacteria and the role of pharmaceutical and personal care products in AMR contamination, (3) the evolution, surveillance, and mitigation of AMR in Malaysia's rivers, and (4) the relationship between poor sanitation and water pollution, with a focus on sustainable solutions such as the Eliminate, Reduce, Enhance, and Create (EREC) framework and constructed wetlands. By integrating scientific research, engineering innovations, policy enforcement, and community engagement, this review highlights actionable strategies to control AMR and restore river health, ensuring a future of clean water and effective antimicrobial treatments.

Received 10 February 2025; Accepted 20 May 2025; Available online 30 June 202

Keywords: Antimicrobial Resistance (AMR); Antibiotic-Resistant Bacteria (ARB); Environmental Contamination; Wastewater Management; Sustainable Sanitation

*Corresponding Author:

Chee Loong
Department of Research and Development,
Agri Season Sdn. Bhd. No 30,
Lot 2718 Jalan Kejayaan 1, Batu 24,
81900 Kota Tinggi, Johor, MALAYSIA
Email : anthony1109@hotmail.my

1.0 Introduction

Antimicrobial resistance (AMR) has become one of the most urgent global health threats, jeopardizing modern medicine and public health systems worldwide. As infections caused by drug-resistant bacteria become increasingly difficult to treat, routine medical procedures, such as surgeries and cancer therapies, face higher risks due to limited effective antimicrobial treatments [1]. The unregulated use of antibiotics in human medicine, animal agriculture, and aquaculture has accelerated the emergence of antibiotic-resistant bacteria [2]. If left unaddressed, AMR could result in 10 million deaths per year by 2050, causing severe economic and social consequences [3].

However, the AMR crisis extends beyond clinical settings. In recent years, the environmental dimension of AMR has gained increasing attention, particularly the role of rivers and water systems as reservoirs for antibiotic-resistant bacteria (ARBs) and antibiotic resistance genes (ARGs) [4]. Pharmaceutical residues, hospital waste, agricultural runoff, and untreated wastewater all contribute to the persistence and spread of resistant bacteria in water bodies [5]. Studies have shown that rivers receiving wastewater discharge contain significant levels of multidrug-resistant bacteria, amplifying the risk of AMR transmission to human populations through drinking water, irrigation, and aquaculture. While AMR surveillance programs have largely focused on healthcare and livestock, environmental AMR monitoring remains underdeveloped, limiting the ability to track the full extent of its spread in aquatic ecosystems [6].

Sanitation is an often overlooked but critical factor in the fight against AMR. Inadequate wastewater treatment, open defecation, and insufficient sanitation infrastructure have accelerated the spread of drug-resistant pathogens in many regions [7]. Poorly managed sanitation systems release untreated waste into rivers, where resistant bacteria can persist and proliferate [8]. In response to these growing concerns, governments and researchers are exploring sustainable sanitation strategies, including nature-based solutions like constructed wetlands, advanced wastewater treatment technologies, and policy-driven interventions [9].

This review synthesizes insights from global and regional perspectives on AMR and its intersection with river health, wastewater management, and sanitation challenges. It explores the origins and mechanisms of AMR, the role of sanitation in spreading drug-resistant pathogens, and innovative mitigation strategies such as the EREC framework (Eliminate, Reduce, Enhance, Create) for sustainable wastewater management. By integrating scientific research, engineering solutions, policy recommendations, and community-driven initiatives, this review highlights actionable strategies to reduce the burden of AMR and protect global water systems from further degradation.

2.0 Antimicrobial Resistance: A Global Threat and Strategies for Containment

Antimicrobial Resistance (AMR) has become one of the most pressing global health threats, as emphasized by the World Health Organization (WHO). The growing resistance of bacteria to antibiotics is pushing the world toward a "post-antibiotic era," where once-treatable infections could again become life-threatening. Recognizing the urgency of this issue, the WHO's Global Action Plan on Antimicrobial Resistance aims to curb the spread of resistant microorganisms and safeguard the effectiveness of antibiotics for future generations [1]. This chapter delves into the causes, consequences, historical development, alarming discoveries, and strategic measures required to mitigate the impact of AMR.

2.1 The Global Concern of Antimicrobial Resistance

The first global report on Antimicrobial Resistance (AMR) (2014) by the World Health Organization (WHO) highlighted antibiotic resistance as one of the greatest threats to human health. The overuse and misuse of antibiotics accelerate the resistance mechanisms in pathogens, making infections increasingly difficult to treat [1]. According to Margaret Chan (2015), key concerns include dangerously high antibiotic resistance levels worldwide, as documented in multi-country surveillance studies, the emergence of "superbugs", highly resistant bacteria that cause severe infections in hospitals and intensive care units (ICUs), and the looming post-antibiotic era, where once-treatable infections could become untreatable, leading to rising mortality rates [10]. A major contributor to AMR is the inappropriate use of antibiotics in human medicine, veterinary practices, and agriculture. This widespread misuse has accelerated bacterial evolution, rendering many previously effective drugs obsolete and increasing treatment failures worldwide.

2.2 Historical Development of Antimicrobial Resistance

Resistance to antibiotics is not a new phenomenon. Since the introduction of penicillin in 1941, bacteria have continuously evolved mechanisms to neutralize the effects of antibiotics. Key events in AMR history, as documented by Medscape (2009), show that with each new antibiotic introduced, bacteria rapidly adapted, demonstrating the swift evolution of resistance mechanisms. This ongoing cycle underscores the persistent challenge of antimicrobial resistance and the urgent need for innovative strategies to combat I [11].

Table 1: Timeline of Antibiotic Introduction and the Emergence of Resistance [11]

Year	Antibiotic Introduced	Year Resistance Documented
1941	Penicillin	1942 Resistance Documented
1956	Vancomycin	1997 Vancomycin Intermediate Resistance (VISA) 2002 Vancomycin high resistance (VRSA)

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

Year	Antibiotic Introduced	Year Resistance Documented
1959	Methicillin	1961 Methicillin-Resistant Staphylococcus Aureus (MRSA)
1999	Quinurpristin/dalfopristin	2000 Resistance Documented
2000	Linezolid	2001 Resistance Documented
2003	Daptomycin	2005 Resistance Documented
2005	Tigecyline	-

2.3 Alarm Bells: The Emergence of Pan-Drug Resistant Bacteria

A major breakthrough in Antimicrobial Resistance (AMR) research was the discovery of the mcr-1 gene, a plasmid-borne gene that grants resistance to colistin, one of the last-resort antibiotics. This gene enables bacteria to withstand treatment, even with the strongest antibiotics available, making infections increasingly difficult, if not impossible, to treat. A notable case in 2016 involved a 46-year-old patient infected with colistin-resistant E. coli, marking a significant milestone in the spread of untreatable infections [12]. Such alarming discoveries highlight the urgent need for global action to develop new antimicrobial treatments, strengthen infection control measures, and restrict the misuse of existing antibiotics to curb the growing threat of AMR.

2.4 Strategies to Contain AMR

To effectively combat Antimicrobial Resistance (AMR), several strategic approaches have been identified, focusing on rational drug use, infection prevention, surveillance, research, public awareness, and a comprehensive health approach that integrates human, veterinary, and agricultural sectors. Rational drug use and regulation involve enforcing strict guidelines for appropriate antibiotic prescriptions, reducing over-the-counter sales of antibiotics without prescriptions, and strengthening regulations on antibiotic use in agriculture to prevent resistance development in livestock. Infection prevention and control strategies emphasize promoting hand hygiene and sanitation in hospitals and communities, implementing stringent infection control measures in healthcare settings, and expanding vaccination programs to reduce reliance on antibiotics by preventing infections before they occur. Surveillance and research play a crucial role in addressing AMR by establishing global AMR monitoring programs, strengthening research on alternative therapies such as phage therapy and antimicrobial peptides, and expanding genomic surveillance to track resistant bacterial strains and their evolution.

Furthermore, public awareness and education are essential in ensuring responsible antibiotic use by educating healthcare professionals and the public on the dangers of AMR, encouraging behavioral changes to reduce self-medication and unnecessary antibiotic consumption, and promoting adherence to prescribed antibiotic courses to prevent incomplete treatment from fueling resistance. Lastly, a Health approach is necessary to address AMR holistically across human health, veterinary medicine, and agriculture. This includes reducing antibiotic use in livestock farming to prevent resistant bacterial strains from entering the food chain, ensuring clean animal husbandry, sustainable agriculture, and aquaculture practices to minimize AMR risks from environmental sources. By implementing these strategies collectively, the global community can slow down the spread of AMR and preserve the effectiveness of antimicrobial treatments for future generations.

2.5 Key Priority Areas and Strategic Objectives

To strengthen the global response to Antimicrobial Resistance (AMR), four key priority areas have been identified [13]. These strategies collectively aim to curb the spread of resistant pathogens and ensure the continued effectiveness of life-saving antibiotics. Public awareness and education play a crucial role in strengthening awareness and understanding of AMR by promoting responsible antibiotic use and fostering behavioral changes in both healthcare professionals and the public. Surveillance and research are essential in strengthening national and international AMR surveillance programs, advancing research on alternative therapies, and developing new antimicrobial agents. Infection prevention and control focus on reducing the transmission of infections and diseases through improved hygiene practices, vaccination programs, and strict infection control measures in healthcare and community settings. Lastly, the appropriate use of antimicrobials is critical to optimizing antibiotic use across various sectors, including human health, veterinary medicine, and agriculture, ensuring that antibiotics remain effective for future generations. By addressing these priority areas, a comprehensive and coordinated approach can be achieved in the fight against AMR.

Table 2: Key Priority Areas and Strategic Objectives for AMR Containment

Key Priority Areas	Strategic Objectives
Public Awareness and Education	Strengthen awareness and understanding of AMR.
Surveillance and Research	Strengthen national and global AMR surveillance and research efforts.

Key Priority Areas	Strategic Objectives
Infection Prevention and Control	Reduce transmission of infections and diseases.
Appropriate Use of Antimicrobials	Optimize antimicrobial use across relevant sectors.

Antimicrobial Resistance (AMR) poses a severe and escalating threat to global health, food security, and economic development. If left unchecked, drug-resistant infections could cause millions of deaths annually, leading to devastating socio-economic consequences and overwhelming healthcare systems worldwide. The rise of superbugs and the declining efficacy of existing antibiotics underscore the urgency of a coordinated global response to mitigate the AMR crisis. To effectively combat AMR, a multi-sectoral approach is essential, involving governments, healthcare professionals, researchers, policymakers, and the public in a collective effort. Key strategies include investing in new drug discovery to develop next-generation antibiotics, improving healthcare infrastructure to enhance infection prevention and control, and enforcing antimicrobial stewardship programs to regulate antibiotic use across human health, veterinary, and agricultural sectors. Strengthening AMR surveillance systems, promoting public awareness, and fostering global collaboration are also critical in slowing the spread of resistant pathogens. The world must act urgently to prevent a post-antibiotic apocalypse, where routine infections become untreatable and once-curable diseases regain their deadly potential. By prioritizing research, responsible antibiotic use, and sustainable healthcare practices, we can preserve the effectiveness of life-saving antibiotics for future generations and ensure a healthier, more resilient global population.

3.0 Antimicrobial Resistance: A Global Crisis and the Urgent Need for Action

Antimicrobial Resistance (AMR) has emerged as one of the most critical global health threats, as underscored by leading organizations such as the World Health Organization (WHO) and the United Nations Interagency Coordination Group (UN IACG). The misuse and overuse of antibiotics across various sectors—including healthcare, agriculture, and aquaculture—have accelerated the emergence of superbugs, making once-treatable infections increasingly fatal. If left unaddressed, AMR could lead to million deaths annually, with severe economic and public health consequences [3]. This chapter examines the global impact of AMR, the contributing factors fueling its rise, the regional challenges faced by different countries, and the strategic interventions needed to mitigate its devastating effects. Through a multi-sectoral approach involving governments, healthcare professionals, researchers, and the public, AMR can be effectively contained to safeguard global health and the future of modern medicine.

3.1 The Global Threat of AMR

According to the UN IACG Report (2019), antimicrobial resistance (AMR) is responsible for at least 700,000 deaths annually, with 230,000 deaths attributed to multidrug-resistant tuberculosis alone. Without urgent intervention, this figure could escalate to million nmubers of deaths annually, making AMR one of the leading causes of mortality worldwide. Even high-income countries are not immune, as they are projected to experience 2.4 million deaths between 2015 and 2050 due to AMR-related infections [3]. Key concerns associated with AMR include the widespread prevalence of superbugs in hospitals and intensive care units (ICUs), the escalation of multidrug-resistant tuberculosis and other bacterial infections, and the significant economic and healthcare burdens resulting from untreatable diseases. The urgency for global action is undeniable, as inaction could reverse decades of medical advancements, rendering once-common infections untreatable and significantly increasing mortality rates. Immediate, coordinated efforts are essential to curb the spread of AMR and ensure the continued efficacy of life-saving antibiotics [14].

3.2 AMR in Malaysia: A Growing Concern

AMR is not just a global crisis—it is an urgent and escalating threat to Malaysia as well. According to a report by Health Minister Dr. Dzulkefly Ahmad, Malaysia is projected to face 87,000 deaths due to AMR by 2030 if no immediate intervention is taken. This alarming statistic underscores the critical need for stronger regulations, enhanced public awareness, and improved surveillance systems to curb the spread of antibiotic-resistant bacteria [15]. Several key factors are driving the rise of AMR in Malaysia. Unregulated antibiotic use in healthcare and animal farming has contributed significantly to resistance development. Additionally, insufficient public awareness regarding the proper use of antibiotics has led to widespread misuse, further exacerbating the problem. The lack of strict policies to regulate over-the-counter antibiotic sales allows easy access to antibiotics without prescriptions, increasing the risk of resistance. Moreover, environmental contamination from pharmaceutical and agricultural waste has introduced antibiotic residues into water systems, promoting the spread of resistant bacteria. To mitigate the impact of AMR, Malaysia has launched MyAP-AMR 2022-2026, a national action plan aimed at strengthening awareness, research, surveillance, and antimicrobial stewardship [13]. This initiative focuses on a multi-sectoral approach, integrating human, veterinary, and environmental health to combat AMR effectively and ensure the long-term sustainability of antimicrobial treatments.

3.3 How AMR Spreads: The Environmental Connection

The phrase "What Goes Around, Comes Around" aptly illustrates the environmental impact of Antimicrobial Resistance (AMR). The widespread use of Pharmaceuticals and Personal Care Products (PPCPs), including antibiotics, has led to their infiltration into natural ecosystems, particularly water systems, through various pathways. Hospital and medical waste, improper disposal of medications, agricultural runoff from livestock treated with antibiotics, and discharge from wastewater treatment plants (WWTPs) all contribute to the accumulation of antibiotics and resistant bacteria in aquatic environments. Once in water systems, these pollutants accumulate in aquatic organisms, creating an AMR cycle where resistant bacteria spread back to humans through the consumption of contaminated seafood and exposure to polluted water sources. This continuous loop amplifies the risk of drug-resistant infections, making AMR not only a medical issue but also an urgent environmental challenge. Addressing this issue requires effective waste management, strict regulation of pharmaceutical pollutants, and the implementation of environmentally sustainable practices to break the cycle of AMR transmission.

3.4 AMR Surveillance and Research in Malaysia

To effectively combat Antimicrobial Resistance (AMR), intensive surveillance and research efforts are essential. The MyAP-AMR 2022-2026 outlines four key strategic objectives: strengthening awareness and understanding of AMR, enhancing national health surveillance and research efforts, reducing the transmission of infections and diseases, and optimizing the use of antimicrobials across relevant sectors. These strategies aim to mitigate the spread of resistant bacteria and preserve the efficacy of antibiotics in human, veterinary, and environmental health settings. Despite these structured initiatives, critical challenges remain. One major concern is the lack of public awareness, with studies showing that only 20% of the population is aware of AMR and its implications. Additionally, questions persist regarding the effectiveness of current surveillance and intervention measures in controlling the spread of resistance [16]. Addressing these gaps requires stronger collaboration between governments, healthcare institutions, researchers, and the public, ensuring that AMR strategies are effectively implemented and continuously improved. Malaysia's AMR surveillance efforts focus on three main sectors to monitor antibiotic contamination and resistance trends. Fishery surveillance monitors antibiotic levels in seafood to prevent resistant bacteria from entering the food chain. Food safety and quality surveillance ensures that antibiotic residues do not accumulate in consumer food products, while environmental health surveillance tracks antibiotic pollution in rivers, wastewater, and natural ecosystems to control environmental AMR transmission. This integrated surveillance approach aligns with the Health framework, addressing AMR across human, animal, and environmental health sectors to create a sustainable and coordinated response to this growing crisis.

3.5 Pharmaceutical and Personal Care Contributions to AMR

Pharmaceutical and personal care products (PPCPs) play a significant role in driving antimicrobial resistance (AMR) due to the widespread use of antibiotics and improper disposal of pharmaceutical waste. Studies have shown that 17% of pharmaceuticals in use are antibiotics, which can enter the environment through hospital wastewater, agricultural runoff, and improper drug disposal [16]. Additionally, other pharmaceutical compounds such as antifungal, anti-inflammatory, and endocrine-disruptive drugs have also been linked to AMR, as they can alter microbial ecosystems and promote resistance. Personal care products, including detergents, fragrances, and insecticides, may further contribute to microbial resistance by exposing bacteria to chemical stressors, encouraging adaptive resistance mechanisms. These findings emphasize the urgent need for stricter regulations on pharmaceutical waste disposal and responsible antibiotic use, ensuring that antibiotics and other PPCPs do not contaminate the environment and exacerbate AMR risks.

3.6 Quantification and Detection of Antibiotic-Resistant Bacteria

To assess Antimicrobial Resistance (AMR) levels, quantification methods are used to evaluate antibiotic resistance in bacterial strains. A recent study analyzed bacterial resistance to four commonly used antibiotics—Ampicillin (AMP), Ciprofloxacin (CIP), Erythromycin (ERY), and Sulfamethoxazole (SMX)—by testing various antibiotic concentrations [17]. The results indicated that Ampicillin and Ciprofloxacin exhibited higher antibiotic concentration levels, raising concerns about their long-term effectiveness and potential treatment failures. This finding underscores the importance of continuous monitoring of antibiotic resistance patterns and adjusting prescription guidelines to ensure optimal antibiotic efficacy while minimizing resistance development.

3.7 Antibiotic Contamination in Malaysia’s Marine Life

Recent studies have also detected antibiotic residues in marine species, raising concerns about the role of seafood consumption in AMR transmission. Research conducted in the Straits of Johor, Malaysia, analyzed antibiotic concentrations in green-lipped mussels (Perna viridis), revealing the presence of Ampicillin (AMP), Ciprofloxacin (CIP), Erythromycin (ERY), and Sulfamethoxazole (SMX) in varying concentrations [17]. The study found that Ampicillin levels ranged from 2.6 – 14.6 ng/g (wet weight) and 8.4 – 77.5 ng/g (dry weight), while Ciprofloxacin levels were significantly higher, reaching up to 272.4 ng/g (dry weight). These results highlight the growing contamination of marine ecosystems, as antibiotic residues can persist in aquatic environments and enter the human food chain through seafood consumption. Given that antibiotic residues in seafood contribute to the spread of AMR, urgent action is needed to prevent antibiotic contamination in marine ecosystems through stricter regulations, improved wastewater treatment, and responsible antibiotic use in aquaculture.

Table 3: Antibiotic Concentration Levels in Environmental Samples [17]

Antibiotic	**Concentration Range (ng/g)**
Ampicillin (AMP)	2.6 – 14.6 (ww), 8.4 – 77.5 (dw)
Ciprofloxacin (CIP)	4.6 – 27.6 (ww), 77.8 – 272.4 (dw)
Erythromycin (ERY)	0 – 0.2 (ww), 0 – 0.7 (dw)
Sulfamethoxazole (SMX)	0 – 46.7 (ww), 0 – 80.7 (dw)

Antimicrobial Resistance (AMR) is a silent pandemic that demands immediate intervention at the global, national, and individual levels. If left unchecked, AMR will lead to a post-antibiotic era where common infections become untreatable, rendering routine medical procedures, including surgeries and cancer therapies, increasingly dangerous. The projected million deaths per year, along with severe economic consequences, underscores the urgency of taking decisive action. To mitigate AMR, several critical steps must be taken. First, strict regulation of antibiotic prescriptions and sales is necessary to prevent misuse and overuse. Second, investment in AMR research and the development of new antibiotics must be prioritized to counteract resistant strains. Third, public education on responsible antibiotic use is crucial in fostering behavioral change and reducing self-medication. Fourth, enhanced surveillance in healthcare, agriculture, and the environment is essential to monitor resistance trends and implement timely interventions. Finally, reducing pharmaceutical waste pollution is vital in minimizing antibiotic contamination in natural ecosystems, which contributes to AMR proliferation. Without immediate and sustained efforts, AMR will continue to threaten global health, economies, and food security, reversing decades of medical advancements. The time to act is now, and a coordinated, multi-sectoral approach is imperative to preserve the effectiveness of life-saving antibiotics for future generations.

4. 0 Antimicrobial Resistance (AMR): A Global and Environmental Challenge

Antimicrobial Resistance (AMR) is an escalating global health crisis that threatens modern medicine, public health, and environmental sustainability. It occurs when microorganisms evolve to resist the effects of antimicrobial agents, rendering infections increasingly difficult to treat. The primary drivers of AMR include the overuse and misuse of antibiotics, poor infection control measures, and the excessive use of antibiotics in agriculture and aquaculture. As a result, AMR leads to treatment failures, rising mortality rates, and a significant economic burden on healthcare systems worldwide. Beyond its clinical implications, AMR also poses a serious environmental challenge, as antibiotic residues and resistant bacteria enter water systems through hospital waste, pharmaceutical pollution, and agricultural runoff, accelerating resistance in natural ecosystems. This chapter examines the science behind AMR, its clinical and environmental impact, and the urgent strategies required to mitigate this growing global threat.

4.1 Understanding AMR, ARBs, and ARGs

The terms Antimicrobial Resistance (AMR), Antibiotic-Resistant Bacteria (ARBs), and Antibiotic Resistance Genes (ARGs) are interrelated yet distinct, each playing a critical role in the development and spread of resistance. AMR genes confer resistance to a broad spectrum of antimicrobial agents, including antibiotics, antivirals, antifungals, and antiparasitics, making standard treatments less effective. ARBs (Antibiotic-Resistant Bacteria) are bacterial strains that have acquired resistance genes, allowing them to survive antibiotic treatments, leading to prolonged infections and increased transmission risks. Meanwhile, ARGs (Antibiotic Resistance Genes) are the genetic material responsible for resistance, which can be transferred between bacteria through mechanisms such as horizontal gene transfer, further amplifying resistance in microbial populations. Specific examples illustrate the significance of these resistance mechanisms. In fungi, the ERG11 gene confers azole resistance, limiting the effectiveness of antifungal treatments. Similarly, in viruses, M2 gene mutations in influenza strains lead to amantadine resistance, reducing treatment options for influenza infections. Understanding the intricate relationship between AMR, ARBs, and ARGs is essential in tackling AMR from both clinical and environmental perspectives, ensuring that effective intervention strategies are developed to mitigate its spread [18].

4.2 Clinical Impact and Public Health Threat

Antimicrobial Resistance (AMR) poses a significant healthcare burden, driven by the rise of superbugs—highly resistant bacterial strains that make infections increasingly difficult to treat. Some of the most concerning drug-resistant pathogens include Methicillin-Resistant Staphylococcus aureus (MRSA), Carbapenem-Resistant Enterobacteriaceae (CRE), Vancomycin-Resistant Enterococci (VRE), and Multidrug-Resistant Tuberculosis (MDR-TB). These resistant bacteria complicate treatment options, prolong hospital stays, and increase mortality rates, leading to widespread public health concerns. The healthcare and economic impact of AMR is substantial. The presence of untreatable infections has led to longer hospital stays, higher treatment costs, and increased mortality rates. The financial strain on healthcare systems is immense, with AMR-related expenditures amounting to billions of dollars annually. Additionally, AMR compromises the effectiveness of medical procedures, including surgeries, cancer treatments, and organ transplants, as post-operative infections become harder to manage. Without urgent intervention, AMR is projected to cause large number of deaths, making it one of the leading global health threats [3]. Addressing AMR requires coordinated efforts to regulate antibiotic use, invest in new treatments, and enhance infection prevention measures to prevent a future health crisis.

4.3 Causes of Antibiotic Resistance

The rapid emergence and spread of Antimicrobial Resistance (AMR) are driven by multiple interconnected factors that span healthcare, agriculture, and public health policies. One of the primary contributors is the over-prescribing of antibiotics in healthcare settings, where antibiotics are often unnecessarily prescribed for viral infections or as a precautionary measure, leading to increased resistance. Additionally, patients failing to complete their prescribed antibiotic courses allows bacteria to survive and adapt, making future treatments less effective. Beyond human medicine, excessive antibiotic use in livestock and agriculture is another major driver of AMR. Antibiotics are widely used not only to treat infections in animals but also as growth promoters, which accelerates the development of resistance. Poor infection control in hospitals and clinics, combined with inadequate hygiene and sanitation in both medical and public environments, further facilitates the spread of resistant bacteria. Moreover, insufficient laboratory testing before prescribing antibiotics leads to inappropriate antibiotic use, allowing resistant strains to proliferate unchecked. Addressing these challenges requires a multi-sectoral approach that integrates healthcare regulation, responsible agricultural practices, improved hygiene standards, and stronger public policies. By tackling AMR through collaborative global efforts, the continued effectiveness of antibiotics can be preserved for future generations.

4.4 The Evolution of Antibiotic-Resistant Bacteria (ARBs)

Antibiotic resistance develops through the process of natural selection, enabling bacteria to adapt and survive in the presence of antibiotics. Within a bacterial population, some bacteria naturally possess resistance genes, allowing them to withstand antibiotic treatments. When antibiotics are introduced, they eliminate susceptible bacteria, leaving behind only the resistant strains. These resistant bacteria then multiply and dominate the population, making infections increasingly difficult to treat. A critical factor in the spread of resistance is the horizontal transfer of antibiotic resistance genes (ARGs) between bacteria. This occurs through three primary mechanisms: transformation, transduction, and conjugation. Among these, conjugation is the most common mechanism for horizontal gene transfer, allowing resistance genes to move from a donor bacterial species to a different recipient species. While transformation and transduction also enable gene transfer, they typically occur within the same species or closely related bacteria, making them less frequent in the spread of resistance [19]. This cycle of bacterial adaptation and gene transfer results in the widespread dominance of antibiotic-resistant bacteria (ARBs), ultimately compromising the effectiveness of existing treatments and increasing the difficulty of managing infectious diseases. Understanding these mechanisms is essential in developing targeted interventions to slow the spread of resistance and protect global health.

4.5 Environmental Spread of Antibiotic Resistance

The spread of antibiotic resistance genes (ARGs) extends far beyond healthcare settings, infiltrating natural ecosystems through multiple pathways. The selection for antibiotic resistance occurs across medicine, agriculture, and nature, significantly contributing to the persistence and spread of antimicrobial resistance [4]. In medicine, antibiotics are extensively produced and consumed, and waste from pharmaceutical industries often introduces antibiotic residues into the environment. Similarly, in agriculture, the use of antibiotics in livestock farming and contaminated manure runoff into water bodies serve as major sources of environmental antibiotic pollution. Beyond human-driven activities, nature itself plays a role in the evolution of resistance. Exposure to heavy metals and diverse microbial conditions promote the natural development of resistance mechanisms in bacteria. Once present in the environment, ARGs spread through both physical and biological forces. Physical forces such as wind and water runoff transport resistant bacteria across vast distances, contaminating soil and water sources. Meanwhile, biological forces, including human activities, animal movement, and the migration of insects and birds, further facilitate the transmission of resistant bacteria. These pathways accelerate the spread of antimicrobial resistance (AMR) globally, making it a pressing public health and environmental challenge. Without effective environmental regulations, proper waste management, and responsible antibiotic use, AMR will continue to proliferate, threatening both human health and ecological stability.

4.6 AMR in Malaysian Rivers

Recent studies have identified antimicrobial resistance (AMR) hotspots in major river systems across Malaysia, highlighting the increasing contamination of aquatic ecosystems with antibiotic-resistant bacteria. Research conducted by Ho et al. (2021) has detected high levels of AMR in the Johor River Basin, the presence of multidrug-resistant (MDR) bacteria in Sungai Melayu, and significant AMR gene pollution in Sungai Skudai. These findings raise serious concerns about the spread of resistant bacteria through water sources, emphasizing the urgent need for wastewater management strategies to curb AMR contamination. Further supporting this concern, research published in Environmental Science & Technology and Frontiers in Public Health has confirmed the presence of antibiotic-resistant bacteria in Malaysian rivers, including Skudai River (Johor) and Larut River (Perak). These studies demonstrate the public health risks posed by contaminated water sources, as resistant bacteria in rivers can enter drinking water supplies, fisheries, and agricultural irrigation systems, increasing the likelihood of human exposure. Addressing AMR in Malaysian rivers requires stringent wastewater treatment policies, improved environmental monitoring, and stricter regulations on antibiotic disposal to mitigate further contamination and protect both public health and ecosystems [20].

4.7 Mitigating AMR: Strategies for Control

Effectively combating Antimicrobial Resistance (AMR) requires a comprehensive, multi-sectoral approach that integrates public awareness, surveillance, policy enforcement, and the development of new treatment strategies. Strengthening public awareness is crucial in reducing unnecessary antibiotic use by educating healthcare professionals and the public about responsible antibiotic consumption and promoting hygiene and sanitation to prevent infections. Enhanced AMR surveillance and research play a vital role in monitoring resistance patterns and identifying emerging threats. Implementing nationwide AMR surveillance programs and encouraging research into alternative antimicrobial therapies, such as bacteriophage therapy and synthetic antimicrobial peptides, are essential steps toward developing next-generation treatments. Optimizing antibiotic use through strict regulation of prescriptions and banning the non-therapeutic use of antibiotics in agriculture can help limit the development of resistant bacterial strains. Strengthening environmental policies is also critical, particularly in reducing antibiotic pollution from hospitals, farms, and pharmaceutical industries. Improving wastewater treatment systems to remove antibiotic residues before they enter water bodies will help curb the environmental spread of AMR. Additionally, investing in the development of novel antibiotics, bacteriophages, and antimicrobial peptides offers promising treatment alternatives for drug-resistant infections. Exploring probiotics and microbiome-based therapies provides further potential in addressing AMR without over-reliance on traditional antibiotics. By implementing these integrated strategies, global efforts to contain AMR can be significantly strengthened, ensuring that antibiotics remain effective for future generations while reducing the overall public health and economic burden of resistance.

Antimicrobial resistance (AMR) is a silent global epidemic with profound consequences for public health, food security, and the environment. Without immediate and sustained intervention, AMR will continue to escalate, rendering common infections untreatable and jeopardizing modern medical advancements. To prevent this crisis, decisive action is needed to regulate antibiotic use across human and veterinary medicine, ensuring responsible prescribing and reducing unnecessary antibiotic exposure. Additionally, monitoring environmental AMR hotspots through enhanced surveillance programs will help track the spread of resistant bacteria and guide effective mitigation strategies. Investing in alternative therapies and novel antimicrobials is crucial to overcoming resistance, as current antibiotic pipelines struggle to keep up with the rapid evolution of resistant pathogens. Strengthening public education on AMR prevention is equally important, as increasing awareness and encouraging responsible antibiotic use can significantly slow the spread of resistance. Failure to act now could lead to a post-antibiotic era, where routine infections become life-threatening once again, and critical medical procedures such as surgeries and cancer treatments become far riskier. The time to take action is now, and a coordinated global effort is essential to safeguard the future of antimicrobial treatments.

5.0 From Toilets to Tributaries: Unmasking the Impact of Poor Sanitation on River Health

Water is a finite yet essential resource, and preserving its quality is crucial for public health, ecosystems, and sustainable development. However, poor sanitation practices have contributed to an escalating crisis in river health, particularly in developing regions where inadequate wastewater management, rapid urban expansion, and insufficient sewage systems have led to severe contamination. Polluted rivers not only threaten aquatic biodiversity but also serve as breeding grounds for waterborne diseases and contribute to the spread of antimicrobial resistance (AMR) by allowing resistant bacteria to proliferate in natural water bodies. Addressing this crisis requires a comprehensive and multi-disciplinary approach. This chapter explores the intricate relationship between sanitation and river health, emphasizing the urgent need for engineering solutions, policy interventions, and community-driven efforts. Additionally, it introduces the EREC (Eliminate, Reduce, Enhance, Create) framework, a structured strategy for achieving sustainable sanitation management that prioritizes eliminating outdated systems, reducing pollution sources, enhancing sewage infrastructure, and creating sustainable resource recovery initiatives. Implementing these strategies can help restore river health and ensure safe, clean water for future generations.

5.1 The Sanitation-Water Connection

Water and wastewater exist within a closed-loop system, meaning that once water is used, it becomes wastewater and must be treated before returning to the environment. When left untreated, wastewater flows back into natural water bodies, contaminating essential sources relied upon for drinking, agriculture, and industry. The failure to manage sanitation effectively leads to severe environmental and public health consequences, exacerbating issues such as waterborne diseases, antimicrobial resistance (AMR), and ecosystem degradation. Poor sanitation contributes to river pollution in multiple ways. Direct contamination of water sources occurs through open defecation and inadequate sewage disposal, particularly in regions lacking proper sanitation infrastructure. Additionally, urban wastewater discharge from informal settlements—often untreated—flows directly into rivers, increasing bacterial loads and nutrient pollution. Over time, harmful pollutants, including pharmaceutical residues, heavy metals, and microplastics, accumulate in water bodies, further degrading water quality and posing risks to both humans and aquatic life. Addressing these challenges requires the implementation of robust wastewater treatment systems, infrastructure improvements, and stringent policy enforcement to prevent untreated waste from entering natural water systems. A multi-sectoral approach, combining engineering solutions, regulatory frameworks, and public awareness initiatives, is essential to restoring and maintaining clean and sustainable water resources for future generations [21].

5.2 Ideal versus Reality: The Sanitation System Divide

An ideal sanitation system should ensure universal access to toilets, well-maintained sewer systems, and efficient wastewater treatment before any discharge into the environment. Additionally, strict enforcement of sanitation laws is necessary to regulate wastewater disposal and prevent pollution. However, in many regions, the reality falls far short of this vision, creating severe health and environmental challenges. In many informal settlements and rural areas, limited sanitation access forces communities to rely on open defecation or inadequate waste disposal systems, leading to direct contamination of water sources. Even in urban areas, aging or non-existent sewage infrastructure results in the discharge of raw sewage into rivers, worsening pollution levels. Furthermore, the lack of regulatory enforcement allows industries and households to dispose of wastewater untreated, increasing the presence of hazardous pollutants, bacteria, and antimicrobial-resistant pathogens in water bodies. These disparities exacerbate river pollution, contributing to the spread of waterborne diseases, antimicrobial resistance (AMR), and ecological degradation. Bridging this sanitation gap requires government intervention, infrastructure investment, and community-driven initiatives to ensure safe, sustainable, and universally accessible sanitation systems that protect both public health and the environment.

5.3 Key Causes of River Contamination

Poor sanitation plays a major role in river contamination, with multiple factors contributing to the degradation of water quality. One of the most pressing issues is open defecation, which persists in certain areas due to a lack of proper toilet facilities. This practice directly contaminates water bodies and groundwater supplies, introducing harmful pathogens into drinking water sources. Inadequate sewage systems further exacerbate pollution, as poorly maintained septic tanks and open drains often leak into rivers. In rapidly growing urban areas, the absence of proper sanitation planning leads to the unregulated disposal of human waste. Similarly, untreated wastewater from industrial and domestic sources frequently bypasses treatment due to poor infrastructure or cost-cutting measures, resulting in the accumulation of toxic chemicals, bacteria, and nutrients in river systems. In informal settlements, where formal sewer connections are lacking, raw sewage is often discharged directly into rivers, further intensifying pollution. Additionally, uncontrolled urban growth places immense pressure on sanitation systems, leading to pollution hotspots where wastewater treatment capacity cannot keep pace with the increasing population. Addressing these challenges requires comprehensive wastewater management strategies, including sanitation infrastructure development, stricter regulations on wastewater discharge, and community-driven efforts to promote proper waste disposal. Without intervention, the continued degradation of river ecosystems will pose severe risks to public health, biodiversity, and water security.

5.4 Sanitation Challenges in Malaysia

Malaysia has made significant progress in expanding its sanitation infrastructure, as highlighted in the Water and Sewerage Fact Book 2023 [9]. The country currently operates 7,642 sewage treatment plants, including multi-point and regional facilities, alongside 4,822 private sewage treatment plants. Additionally, there are 1,375,340 septic tanks and 1,140,552 pour flush toilets, demonstrating a widespread sanitation network across urban and rural areas. However, sanitation gaps remain, particularly in rural and informal urban settlements, where untreated wastewater continues to contribute to river pollution. Many septic tanks and pour flush systems are not connected to proper wastewater treatment facilities, leading to direct discharge of pollutants into rivers and groundwater. The lack of centralized sewerage systems in certain areas further exacerbates environmental contamination, increasing the risk of waterborne diseases and antimicrobial resistance (AMR). Addressing these challenges requires targeted investments in wastewater treatment infrastructure, improved regulatory enforcement, and enhanced community awareness programs. Strengthening sanitation planning in underserved regions is crucial to ensuring sustainable wastewater management and reducing river pollution in Malaysia.

5.5 Pathogen and Chemical Contamination from Poor Sanitation

Poor sanitation introduces a complex mix of pollutants into river ecosystems, significantly impacting water quality, biodiversity, and public health. According to Mahbudul Syeed et al. (2023), untreated wastewater carries a wide range of pathogens, physical pollutants, chemical contaminants, and emerging pollutants [7]. Pathogens, including bacteria, viruses, and parasites, are responsible for waterborne diseases such as cholera, diarrhea, and hepatitis A, posing serious risks to human populations reliant on contaminated water sources. Physical pollutants, such as solids, nutrients, and organic matter, lead to oxygen depletion in water bodies, further threatening aquatic life. Additionally, chemical contaminants, including pharmaceutical residues, heavy metals, and pesticides, accumulate in river ecosystems, disrupting natural microbial balances and contributing to antimicrobial resistance (AMR). Emerging pollutants such as antibiotics, microplastics, and hormones from personal care products introduce further environmental and health concerns. Alarmingly, research by Alexander et al. (2025) found higher levels of microplastics in brain tissue compared to liver and kidney tissue, with significantly higher concentrations in the brains of deceased patients diagnosed with dementia than in those without the condition [22]. These findings highlight the far-reaching consequences of poor sanitation, as contaminants persist in the environment, disrupt biodiversity, and increase public health risks. Addressing these challenges requires comprehensive wastewater management, strict regulations on pollutant discharge, and improved sanitation infrastructure to prevent further environmental degradation.

5.6 Consequences of River Health Degradation

The degradation of river ecosystems due to poor sanitation and wastewater mismanagement has severe consequences for public health, the environment, and the economy. Contaminated rivers become breeding grounds for waterborne diseases such as cholera, diarrhea, and hepatitis A, which spread rapidly among communities that rely on polluted water sources. Additionally, the presence of pharmaceutical pollutants and antibiotic residues in untreated wastewater exacerbates antimicrobial resistance (AMR), making bacterial infections harder to treat and posing a significant global health threat. Beyond health risks, river degradation has profound ecological impacts, including the loss of aquatic biodiversity due to the accumulation of toxic pollutants, heavy metals, and excess nutrients. These contaminants contribute to oxygen depletion in water bodies, triggering algal blooms and hypoxic conditions, which lead to mass fish die-offs and the collapse of aquatic ecosystems. The economic and social burden of river pollution is equally significant, as water treatment costs rise due to the increased need for purification processes, while healthcare expenses escalate from the growing prevalence of waterborne illnesses and AMR-related infections. Moreover, communities that depend on fisheries and clean water resources for their livelihoods face economic losses, as declining fish populations and contaminated water sources reduce their income opportunities. Addressing these challenges requires a comprehensive approach, including investment in wastewater treatment infrastructure, stricter enforcement of sanitation regulations, and community-driven efforts to promote sustainable waste management. Without immediate action, continued river degradation will pose even greater risks to human health, biodiversity, and economic stability, threatening the well-being of future generations.

5.7 The Eliminate, Reduce, Enhance, and Create (EREC) Approach to Sustainable Sanitation

To systematically address sanitation challenges and improve river health, the EREC framework provides a structured approach that focuses on modernizing wastewater management, reducing contamination, and promoting resource recovery. This strategy consists of four key components: Eliminate, Reduce, Enhance, and Create (EREC). The Eliminate (E) phase focuses on removing outdated sanitation systems, such as pour flush toilets and primitive sewage disposal methods, which contribute to untreated wastewater discharge and environmental pollution. Next, the Reduce (R) phase aims to lower dependency on septic tanks (IST/CST) by promoting centralized wastewater management systems that ensure proper treatment before discharge. The Enhance (E) phase emphasizes expanding sewage treatment plant (STP) connections through rationalization and regionalization programs, ensuring that more communities have access to efficient and sustainable wastewater treatment. Finally, the Create (C) phase promotes the development of new resources via resource recovery, such as biogas generation, nutrient recycling, and wastewater reuse, turning waste into valuable resources while reducing environmental contamination. By implementing the EREC approach, sanitation systems can be modernized, minimizing pollution risks while improving public health and ecological sustainability. This structured framework ensures that wastewater is effectively managed, contributing to the long-term restoration of river ecosystems and the promotion of clean and sustainable water resources.

5.8 Innovative Solutions for Sanitation and River Health

Addressing the sanitation crisis and its impact on river health requires a multi-dimensional approach that integrates engineering solutions, policy enforcement, and community-led initiatives. Investing in improved sewage treatment systems is essential to ensure that wastewater is properly treated before being discharged into rivers, removing harmful pollutants and improving water quality. Additionally, nature-based solutions, such as constructed wetlands, serve as eco-friendly filtration systems, helping to remove excess nutrients, heavy metals, and pathogens from runoff before they reach aquatic ecosystems. Strengthening wastewater regulations and enforcement is critical to prevent industries and households from polluting rivers, ensuring compliance with environmental standards. Moreover, integrating sanitation planning into urban development is necessary to create sustainable water management systems, particularly in rapidly growing urban areas where infrastructure expansion must keep pace with increasing wastewater production. Community participation is equally important in promoting responsible sanitation practices. Implementing public awareness programs can educate individuals on hygiene, proper waste disposal, and water conservation, while introducing incentives for proper septic tank management will encourage households to maintain and upgrade their wastewater systems, reducing groundwater contamination and improving overall sanitation. By implementing these integrated solutions, the sanitation crisis can be effectively managed, leading to cleaner rivers, healthier communities, and a more sustainable environment. A collaborative effort between governments, industries, and communities is essential to ensure the long-term protection of water resources and to mitigate the public health risks associated with poor sanitation.

5.9 The Role of Constructed Wetlands in River Restoration

One of the most promising nature-based solutions for improving river health and wastewater management is the constructed wetland, a biofiltration system designed to mimic natural water purification processes. Constructed wetlands utilize vegetation, biofilms, and microbial activity to absorb contaminants, filter pollutants, and improve water quality. These systems effectively remove sediment, excess nutrients, and pathogens from wastewater before it enters rivers and other water bodies. Beyond water purification, constructed wetlands also play a crucial role in enhancing biodiversity by creating ecological habitats for various plant and animal species. Their ability to replicate natural wetland functions makes them a cost-effective and sustainable solution to river pollution, particularly in urban areas where traditional wastewater treatment facilities may be insufficient or costly to implement. By integrating constructed wetlands into sanitation and water management strategies, communities can significantly reduce river contamination, improve ecosystem health, and promote long-term water sustainability. The connection between sanitation and river health is undeniable, and without improved wastewater management, river ecosystems will continue to deteriorate, posing severe health and environmental risks. Contaminated water bodies contribute to the spread of waterborne diseases, antimicrobial resistance (AMR), and ecological degradation, threatening both human populations and aquatic biodiversity. Addressing this crisis requires collaborative efforts from governments, industries, and communities to implement sustainable sanitation solutions.

To combat this growing issue, it is crucial to implement the EREC framework to modernize sanitation infrastructure, ensuring that outdated systems are eliminated and new, sustainable solutions are introduced. Investing in wastewater treatment technology is necessary to eliminate untreated discharges, reducing the burden of pollutants entering river ecosystems. Additionally, enforcing stricter sanitation laws will help control pollution at its source, holding industries and households accountable for their wastewater disposal practices. Finally, promoting sustainable water management practices is essential to protect ecosystems, maintain clean water sources, and support long-term environmental resilience. Only through innovative engineering, proactive policies, and strong community engagement can we secure clean and sustainable rivers for future generations. Immediate action is necessary to prevent further degradation and to create a future where rivers remain a vital, life-sustaining resource for both people and the planet.

Conclusion

Antimicrobial resistance (AMR) and environmental contamination pose significant global threats to public health, food security, and ecosystem stability. The overuse of antibiotics in healthcare, agriculture, and aquaculture has accelerated the emergence of antibiotic-resistant bacteria (ARBs), while inadequate wastewater treatment and poor sanitation have facilitated their spread in natural ecosystems, particularly rivers. Addressing AMR requires a multi-sectoral approach, integrating strict antibiotic regulations, enhanced surveillance, and improved wastewater management to minimize the environmental dissemination of resistance genes. Sustainable solutions such as the EREC (Eliminate, Reduce, Enhance, Create) framework and constructed wetlands offer promising strategies to mitigate pollution while restoring river health. Strengthening policies, investing in advanced water treatment technologies, and promoting global collaboration among governments, researchers, and communities are essential to safeguarding antimicrobial effectiveness and ensuring long-term environmental sustainability. Without immediate intervention, AMR will continue to undermine medical advancements and threaten global water security, making urgent and coordinated action imperative.

Acknowledgments

This research is supported by Agri Season Sdn. Bhd. The author acknowledged Agri Season Sdn. Bhd. approved fund which makes this important research viable and effective.

References

[1] World Health Organization (WHO) (2014). Antimicrobial Resistance: Global Report on Surveillance. Geneva: WHO Press.
[2] Ramanan Laxminarayan, Adriano Duse, Chand Wattal, Anita K M Zaidi, Heiman F L Wertheim, Nithima Sumpradit, Erika Vlieghe, Gabriel Levy Hara, Ian M Gould, Herman Goossens, Christina Greko, Anthony D So, Maryam Bigdeli, Göran Tomson, Will Woodhouse, Eva Ombaka, Arturo Quizhpe Peralta, Farah Naz Qamar, Fatima Mir, Sam Kariuki, Zulfiqar A Bhutta, Anthony Coates, Richard Bergstrom, Gerard D Wright, Eric D Brown, Otto Cars (2013) Antibiotic resistance—the need for global solutions. The Lancet Infectious Diseases, 13(12), 1057–1098.
[3] United Nations Interagency Coordination Group (UN IACG) (2019). No Time to Wait: Securing The Future from Drug-Resistant Infections. United Nations Report.
[4] Heather K. Allen, Justin Donato, Helena Huimi Wang, Karen A. Cloud-Hansen, Julian Davies, Jo Handelsman (2010) Call of the wild: antibiotic resistance genes in natural environments. Nature Reviews Microbiology, 8, 251–259.
[5] Thomas U. Berendonk, Célia M. Manaia, Christophe Merlin, Despo Fatta-Kassinos, Eddie Cytryn, Fiona Walsh, Helmut Bürgmann, Henning Sørum, Madelaine Norström, Marie-Noëlle Pons, Norbert Kreuzinger, Pentti Huovinen, Stefania Stefani, Thomas Schwartz, Veljo Kisand, Fernando Baquero, José Luis Martinez (2015) Tackling antibiotic resistance: The environmental framework. Nature Reviews Microbiology, 13, 310–317.
[6] Larsson, D. G. J., de Pedro, C., Paxeus, N. (2007) Effluent from drug manufactures contains extremely high levels of pharmaceuticals. Journal of Hazardous Materials, 148(3), 751–755.
[7] M M Mahbubul Syeed,, Md Shakhawat Hossain, Md Rajaul Karim, Mohammad Faisal Uddin, Mahady Hasan, Razib Hayat Khan (2023) Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review. Environmental and Sustainability Indicators, 18, 100247.
[8] Alexander J. Nihart, Marcus A. Garcia, Eliane El Hayek, Rui Liu, Marian Olewine, Josiah D. Kingston, Eliseo F. Castillo, Rama R. Gullapalli, Tamara Howard, Barry Bleske, Justin Scott, Jorge Gonzalez-Estrella, Jessica M. Gross, Michael Spilde, Natalie L. Adolphi, Daniel F. Gallego, Heather S. Jarrell, Gabrielle Dvorscak, Maria E. Zuluaga-Ruiz, Andrew B. West, Matthew J. Campen (2025) Bioaccumulation of microplastics in decedent human brains. Nature Medicine.
[9] SPAN (Suruhanjaya Perkhidmatan Air Negara) (2023). Water and Sewerage Fact Book 2023. Malaysia.
[10] Matgaret Chan (2015) Geneva (Switzerland) WHO Director General.
[11] Medscape (2009) Expert Rev Clin Pharmacol, Expert Reviews Ltd.
[12] McGann P, et al. (2016) Antimicrob Agents Chemother. pii: AAC.01103.
[13] MyAP-AMP 2022 - 2026 (2022) Malaysian Action Plan on Antimicrobial Resistance. Minitry of Health Malaysia & Ministry of Agriculture and Food Security.
[14] Yong Ee Ling (2025) Tentative Suspected Screening in Green Lipped Mussels Leading to The Quantification of Antibiotics and The Appearance of Antibiotic Resistance Bacteria. Joint Seminar on Antimicrobial Resistance 2025.
[15] Bernama (2024) Malaysia To Face 87,00 Deaths Due to Antimicrobial Resistance By 2030 Without Intervention.
[16] Zhi Yuan Yong, Yen San Chong, Muhammad Arif Haikal Mohamad Hanafi, Mohd Firdaus Abdul Wahab, Hooi Ling Lee, Mohd Bakri Bakar, Zaiton Abdul Majid, Norazah Basar, Sheela Chandren,

Hasrinah Hasbullah, Mohd Hafiz Dzarfan Othman, Wei Yee Chan, Siti Nur Tahirah Jaafar, Ee Ling Yong (2024) Suspect Screening in Mussels Cultured in Straits of Tebrau Leading to Public Perception and Awareness Survey on Pharmaceuticals and Personal Care Products (PPCPs) ACS ES&T Water 4 (9) 4099 -4109.

[17] Saffaatul Husna Ismail (2025) Effects of Antibiotic Pollutants on the Green-Lipped Mussels at the Estuary Aquaculture.

[18] Roshan Masxarenhas (2025) Genetcs of Antimicrobial Resistance. Joint Seminar on Antimicrobial Resistance 2025.

[19] Gary Kaiser (2024) Microbiology. Community College of Baltimore County (Cantonsville) LibreTexts.

[20] Jia Yee Ho, Mui-Choo Jong, Kishor Acharya, Sylvia Sue Xian Liew, Daniel R. Smith, Zainura Zainon Noor, Michaela L. Goodson, David Werner, David W. Graham, Jeyanthy Eswaran (2021) Multidrug-resistant bacteria and microbial communities in a river estuary with fragmented suburban waste management. Journal of Hazardous Materials 405, 124687

[21] Nur Syamimi Zaidi (2025) From Toilet to Tributaries: Unmasking The Impact of Poor Sanitation on River Health. Joint Seminar on Antimicrobial Resistance 2025.

[22] Alexander J. Nihart, Marcus A. Garcia, Eliane El Hayek, Rui Liu, Marian Olewine, Josiah D. Kingston, Eliseo F. Castillo, Rama R. Gullapalli, Tamara Howard, Barry Bleske, Justin Scott, Jorge Gonzalez-Estrella, Jessica M. Gross, Michael Spilde, Natalie L. Adolphi, Daniel F. Gallego, Heather S. Jarrell, Gabrielle Dvorscak, Maria E. Zuluaga-Ruiz, Andrew B. West, Matthew J. Campen (2025) Bioaccumulation of microplastics in decedent human brains. Nature Medicine.

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index