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Antimicrobial Research and One Health in Africa

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Editors

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We dedicate this book to our beloved parents
Yussuf and Farida Bayat and Debora Abia.
They instilled in us the value of education.

Foreword

For tomorrow belongs to the people who prepare for it today. (African Proverb)

Africa currently faces enormous challenges as it strives to move forward in economic development, educational opportunities, and the modernization of its science infrastructure. The efforts to respond to these challenges fall under the global umbrella of the climate change emergency. Although Africa has 17% of the global population, it has historically accounted for a negligible 3% of the planet's carbon dioxide emissions. However, climate change, extreme weather events, and disease transmission disproportionately affect Africa resulting in severe economic, social, and environmental consequences for its people. Despite these challenges, African countries received only $18.3 billion in climate finance between 2016 and 2019, producing a projected climate finance gap of up to $1288.2 billion annually from 2020 to 2030.

One major challenge driven by climate change in Africa is the need to identify and develop new responses to address the resistance to antibiotics (AMR) and antibiotic resistance genes (ARGs). The antibiotics commonly used to treat microbial diseases in humans and animals used for food are developing new resistance patterns driven by climate change events. Responses must be developed using the One Health model to be effective because it includes the major interactions that affect microbial antibiotic resistance and efforts to deal with that challenge. *Antimicrobial Research and One Health in Africa* consist of 14 chapters that provide an update on different dimensions of the research underway to address the AMR challenges on the diverse continent of Africa. Two chapters describe the importance of context in understanding the social and behavioral aspects of antimicrobial use and resistance in Africa and the value of antibiotic stewardship (AMS) as an essential strategy for reducing and optimizing antibiotic use and preventing the emergence of AMR. Three other chapters discuss the topic of the occurrence and health risks of antibiotic resistance in African aquatic systems, the etiology of early-onset bacterial sepsis and antibiotic resistance in neonates in an Algerian intensive care unit, and the genetics of viral resistance as it relates to the clinical relevance and role in viral disease outbreaks. In addition, four chapters focus on food production and food safety with

information on the distribution and prevalence of antimicrobial resistance of NTS *Salmonella* isolated from farm animals and animal food products in Africa, a description of the current state of antimicrobial use in bovine mastitis in various African countries, a report of the current status of antibiotic-resistant bacteria and resistance genes in African aquaculture, and studies of microbiological safety and antimicrobial resistance in fresh produce production in Africa. Two chapters describe the biosecurity and disinfectant resistance in a post-antibiotic era and the critical linkage between antibiotic and disinfectant resistance noted in recent decades. Finally, the book is completed with three chapters describing the biocidal activity of plant extracts in Algeria, the combined use of African natural products and conventional antimicrobials as alternative tools against antimicrobial resistance, and an African overview of the use of nanomaterials for the elimination of antibiotic-resistant bacteria from water and wastewater.

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Preface

The threat posed by antimicrobial resistance (AMR) to human, animal and environmental health continues to rise, placing a tremendous burden on the global economy. If no solution is found to curb this ill, it is estimated that tens of millions of lives and hundreds of trillions of dollars will be lost in the next few decades. The situation is exacerbated by the massive demand for animal protein that has engendered an ever-rising use of antimicrobials in food-animal production. Furthermore, the indiscriminate use of these therapeutics continues to be reported worldwide. Unfortunately, the bulk of the antimicrobials consumed by humans and animals is excreted into the environment partially or unmetabolised and potent enough to exert selective pressure on environmental microorganisms, further escalating the environmental dimension of AMR. This, therefore, calls for concerted efforts between stakeholders within environmental, animal and human health – One Health.

Although AMR is of global concern, Africa remains the most affected continent. This is driven by a complex network of circumstances, including a high disease burden, favoured by poverty, malnutrition and lack of access to potable water and sanitation facilities. Also, the lack of adequate policies to guide antimicrobial use and the lack of implementation of these policies, when they exist, further places pressure on the already stressed continent.

We have compiled this volume on antimicrobial resistance and One Health in Africa, aiming to stimulate greater discourse on the spread of AMR on the continent. The ultimate goal is to create greater awareness while proposing possible alternatives for use by all sectors to allow better management and prevention of AMR in Africa. In addition, the presented chapters would spur policymakers to set mechanisms enabling more excellent stewardship guided by scientific evidence.

We firmly believe that this book, being the first of its kind on the continent, would open in-depth debates on AMR in Africa, calling on human, animal and environmental health practitioners to come together in a joint effort to create an AMR-free Africa.

If you want to go fast, go alone; if you want to go far, go together. (An African proverb)

Westville, Durban, KwaZulu-Natal, South Africa — Akebe Luther King Abia
Sabiha Yussuf Essack

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Chapter 6
The Current Status of Antibiotic-Resistant Bacteria and Resistance Genes in African Aquaculture

S. M. Limbu

6.1 Introduction

Aquaculture is currently the fastest-growing food production sector, supplying half of the fish consumed by humans globally (Limbu et al. 2021). The global human per capita fish consumption is estimated at 20.2 kg annually, of which aquaculture contributes 49% of the total production and 56% of human fish consumption (FAO 2022). The world aquaculture grew at an average rate of 6.7% per annum between 1990 to 2020, attaining a record high production of 122.6 million tonnes in response to the ever-increasing population (FAO 2022). Aquaculture has been forecasted to grow to 106 million tons at the end of 2030, supplying most of the consumed fish and seafood products (Reverter et al. 2020; FAO 2022). The increased demand for animal protein in developing countries has prompted fish rearing in intensive systems. Fish cultured in intensive systems have reduced immunity response leading to diseases eruption and promoting antibiotic use in aquaculture (Reverter et al. 2020; Limbu et al. 2021). Consequently, there has been an increase in antibiotic-resistant bacteria (ARB) and their corresponding antibiotic resistance genes (ARGs) in aquaculture. Currently, ARB and ARGs represent one of the challenges facing aquaculture production, requiring immediate actions.

Antibiotic resistance threatening global public health also originates from antibiotics used for treating bacterial diseases in livestock, agriculture, and humans (Watts et al. 2017). Therefore, aquaculture has been reported as a major contributor to ARB and ARGs (Nallaiah et al. 2021) because it is an environmental gateway (Cabello et al. 2016) and at the crossroads of the development of bacteria resistance (Reverter et al. 2020). Thus, ARB and ARGs have been reported as a crisis for

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concern (Preena et al. 2020a) due to their prominence in the aquaculture industry (Preena et al. 2020b). Although the development of ARB and ARGs is ancient (Watts et al. 2017), the current increase is mainly due to the rampant prophylactic use of antibiotics in global agriculture, including aquaculture (Nallaiah et al. 2021). Similar to the global situation, African aquaculture has also been considered "a genetic reactor" or "hotspot" for ARB and ARG development (Iwu et al. 2020). This is due to an increase in reliance on aquaculture to supply safe, reliable, and economical food, responding to the fast population growth in the continent (FAO 2018). As a result, the rest of African aquaculture has increased its production by 14.5% between 2019 to 2020, when the analysis excludes data from Egypt and Nigeria (FAO 2022). This entails using intensive systems inheritably characterised by antibiotics use for treating bacterial diseases (Bouelet Ntsama et al. 2018).

The African continent has distinctive characteristics concerning antibiotic use. For example, many African countries have a high prevalence of communicable diseases and weak healthcare systems (Mathew et al. 2020). Moreover, most African countries have either inefficient regulatory agencies or absent/weak regulations concerning antibiotics usage (Byarugaba 2004) and inappropriate prescription and self-medication of readily available antibiotics (Sanou et al. 2018). Furthermore, most African countries have inadequate systems for surveillance and monitoring of used antibiotics. Accordingly, antibiotics are primarily given as over-the-counter drugs at community pharmacies (Mukonzo et al. 2013); this has been strongly linked to ARB and ARGs in low-income and middle-income countries (Alsan et al. 2015). Therefore, it is not surprising that the African aquaculture industry is also characterised by abuse, overuse and misuse of antibiotics leading to the natural selection and spread of resistant bacteria and the development of ARB and ARGs. This is an alarming situation because the types of ARB and ARGs in aquaculture can be transferred from animals to humans through various routes, causing devastating socioeconomic consequences. However, the precise sources, factors responsible, types and effects of ARB and ARGs in African aquaculture are currently unknown.

This chapter fills such a knowledge gap by discussing the sources of ARB and ARGs in aquaculture, the possible factors contributing to their increase, the types of ARB and ARGs found in the industry and the socioeconomic consequences to human health. The information generated informs the need for a "One Health" approach to combat ARB and ARGs while formulating stringent measures, legislations and regulations for antibiotics use in aquaculture, agriculture and sick patients to safeguard human health.

6.2 The Sources of ARB and ARGs in Aquaculture

The ARB and ARGs in the aquaculture environment originate from various sources (Fig. 6.1). These sources are described in this section.

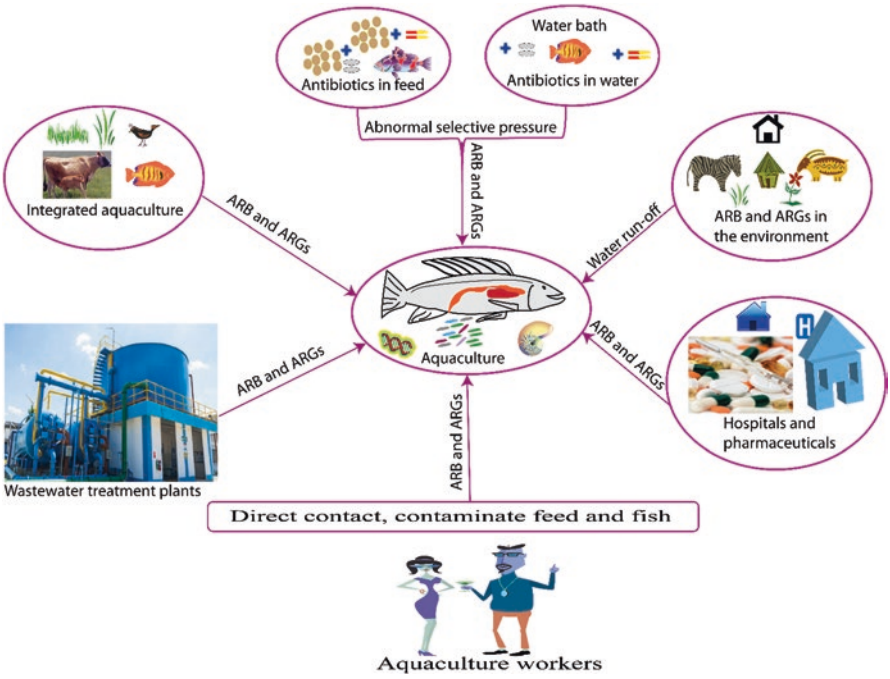


Fig. 6.1 The potential sources of antibiotic-resistant bacteria and resistance genes in aquaculture

6.2.1 Application of Antibiotics in Aquaculture

Using antibiotics for fish health management is an integral practice to intensive aquaculture systems (Limbu 2020; Limbu et al. 2021). Antibiotics are used in aquaculture feeds, either mixed during manufacturing or surface-coated onto pellets and as immersion medication (Musefiu and Olasunkanmi 2015; Preena et al. 2020a). Although the available information suggests minimal use of antibiotics in African aquaculture (Minich et al. 2018; Limbu 2020), the industry represents one of the sources of ARB and ARGSs (Cabello et al. 2016). Antibiotics applied in aquaculture are a source of ARB and ARGs due to three scenarios.

First, antibiotics lead to ARB and ARGs due to their application. Antibiotics are administered abusively for longer periods due to producers' inadequate knowledge about their purpose and proper application (Pham et al. 2015). Moreover, antibiotics are abusively used due to a lack of legislation, enforcement and inspection by regulatory agencies (Limbu et al. 2021). Commonly, antibiotics are used in cultured fish daily and in the absence of disease problems to health, carrier and diseased fish (Limbu et al. 2021). Second, antibiotics applied in aquaculture are not completely metabolised in the body of cultured organisms. Therefore, residues remain in the tissues and organs of cultivated species (Chuah et al. 2016) because they have high-water solubility and degradation resistance (Limbu et al. 2018). The third scenario for increased ARB and ARGs in aquaculture is through antibiotic-supplemented

feeds. The antibiotics-contaminated feeds retain antibiotic residues depending on biodegradability, initial concentration and physical and chemical characteristics of antibiotics (Preena et al. 2020a). Consequently, bacteria in the tissues and organs of cultured species, water or culture structure and facilities used in aquaculture are exposed to antibiotics cocktail for a prolonged time, which generates abnormal selective pressure (Samreen et al. 2021). Accordingly, antibiotics cause resistant strains development (Chuah et al. 2016; Kathleen et al. 2016) through mutation or acquisition of new resistance genes by genetic exchange mechanisms (Samreen et al. 2021) depending on antibiotics types. The resistance determinants could be retained within the microbial population even without the respective antibiotics (Martinez 2009). Thus, genes are transferred widely to susceptible microbes giving rise to resistant types (Nallaiah et al. 2021).

Evidently, ARB and ARGs have been isolated in cultured Nile tilapia in Egypt (El-Gohary et al. 2020), Tanzania (Aron 2017) and Ivory Coast (Koudou et al. 2020); tilapia and catfish in Malawi (Minich et al. 2018) and Uganda (Wamala et al. 2018); tilapia, trout and koi aquaculture systems in South Africa (Jacobs and Chenia 2007); and aquaculture abattoir environments in South Africa (Igbinosa et al. 2017a, b). Moreover, ARG and ARGs have been isolated in aquaculture systems (Mukwabi et al. 2019) and farmed fish (Wanja et al. 2020) in Kenya and a marine fish (*Argyrosomus japonicus*) and water samples at aquaculture farms in South Africa (Fri et al. 2018). In general, the application of antibiotics in aquaculture acts as a source of ARB and ARGs.

6.2.2 Animal Manure and Integrated Aquaculture as ARB and ARGs Sources

Animal wastes are used as fertilisers for fish cultured in African aquaculture ponds (Limbu et al. 2016; Shoko et al. 2019). Manures from livestock such as cattle (Rapatsa and Moyo 2013; Limbu et al. 2016; Minich et al. 2018), chicken (Rapatsa and Moyo 2013; Minich et al. 2018; Shoko et al. 2019), pigs (Rapatsa and Moyo 2013; Bouelet Ntsama et al. 2018; Minich et al. 2018), rabbit (Rukera Tabaro et al. 2012) and goat (Lundeba et al. 2022) production are administered to fish ponds mainly to release nutrients to support the photosynthetic organisms. Apart from manure fertilisation, livestock animals and plants are reared together or concurrently with fish in integrated farming systems. Such systems include fish-poultry (Bouelet Ntsama et al. 2018; Shoko et al. 2019), fish-piggery (Bouelet Ntsama et al. 2018), fish-rabbit (Tabaro et al. 2012) and fish-crop farming (Limbu et al. 2017; Bouelet Ntsama et al. 2018). In these systems, the livestock animals and plants are reared intensively, necessitating antibiotics use for prophylactic and therapeutic purposes (Aly and Albutti 2014). Antibiotics are poorly absorbed in the animals' guts after medication, remaining in manures, either unchanged or modified into metabolites (Chuah et al. 2016; Limbu et al. 2018; Limbu 2020), which consequently act as ARB and ARGs sources. Apparently, animal manures contaminated with antibiotics served as ARB and ARGs sources in fish with no history of

antibiotic use in Tanzania (Shah et al. 2012). Moreover, manure has been reported as ARB and ARGs source in fish in Uganda (Bagumire et al. 2009) and Malawi (Minich et al. 2018). Similarly, integrated fish farming has also been reported to spread ARB and ARGs in Nigeria (Adeyemi et al. 2022). Elsewhere, integrated aquaculture systems exhibited a higher prevalence of antibiotic resistance than traditional aquaculture systems in China (Zhang et al. 2013; Klase et al. 2019) and for a report on global catfish aquaculture (Chuah et al. 2016). These studies indicate that livestock manure and integrated aquaculture systems contribute for developing bacterial resistance and disseminating ARGs in African aquaculture.

6.2.3 Aquatic Environment as a Source of ARB and ARGs

The antibiotics used in aquaculture are also administered in agriculture and human medicine (Done et al. 2015). Recent data suggest that over 70% of all antibiotics sold globally are used in animals raised for food (Van Boeckel et al. 2019). Tanzania alone consumed 12,147,491 kg of antibiotics from 2010 to 2017 (Sangeda et al. 2021). Antibiotics applied in various compartments are poorly absorbed in the intestine and subsequently are released into the aquatic environment (water and sediment) at low concentrations (Chuah et al. 2016; Limbu et al. 2018; Zhou et al. 2018), through effluent discharges, sewage and river runoff where they selectively cause ARB and ARGs (Fu et al. 2017; Nallaiah et al. 2021). The extensive use of antibiotics for treating human infections, livestock and agriculture acts as a source of ARB and ARGs in the water used for aquaculture (Miranda and Zemelman 2001). The ARB from these systems enter aquaculture, spreading their genes into water-indigenous microbes, which also contain resistance genes (Baquero et al. 2008). Accordingly, river surface water was reported as a possible source of ARB in South Africa (Mariano et al. 2009) and Egypt (Azzam et al. 2017) and ARGs in Ghana (Chester et al. 2022). The water has also been reported to contribute to ARB and ARGs in South Africa (Adegoke et al. 2018) and Nigeria (Adesiyan et al. 2019). Moreover, river bed sediments in South Africa (Abia et al. 2015) and Ghana (Chester et al. 2022), river and estuarine water (Suzuki et al. 2015) and coastal water (Adeniji et al. 2021) were reported as ARB and ARGs sources in South Africa. In a nutshell, the widespread use of antibiotics in different environmental compartments, including fish, agriculture and human health, contributes to the development of ARB and ARGs existing in aquaculture.

6.2.4 Wastewater Treatment Plants as ARB and ARGs Sources

The antibiotics or their residues from manufacturing industries or any other activities contained in influent or effluent water are supposed to be treated using wastewater treatment plants (WWTPs). However, most WWTPs were originally not designed to treat antibiotic wastes or their residues (Iwu et al. 2020). Accordingly,

most WWTPs are inefficient in eliminating antibiotic wastes or their residues, thus discharging them into the aquatic milieu (Igwaran et al. 2018; Hamiwe et al. 2019; Molale-Tom and Bezuidenhout 2020). Antibiotics residues have been reported at various concentrations after the WWTPs in South Africa (Faleye et al. 2019), Kenya (Ngigi et al. 2019; Kairigo et al. 2020; Muriuki et al. 2020) and Nigeria (Ajibola et al. 2021). The antibiotics in WWTPs represent a source of ARB and ARGs (Faleye et al. 2019) due to the use of the recipient water for aquaculture activities. Several ARB strains have been isolated in WWTPs in South Africa (Okoh and Igbinosa 2010; Igbinosa et al. 2011; Igwaran et al. 2018; King et al. 2020; Molale-Tom and Bezuidenhout 2020; Mbanga et al. 2021). Moreover, ARGs were prevalent in WWTPs in South Africa (Suzuki et al. 2015) and Nigeria (Obayiuwana and Ibekwe 2020). Furthermore, WWTPs contributed as ARB and ARGs sources in South Africa (Hamiwe et al. 2019; Nzima et al. 2020) and Nigeria (Adesoji et al. 2020). ARGs were detected in a pond receiving municipal wastewater, an important fishing ground in Nigeria (Abu and Wondikom 2018). These studies indicate the potential of WWTPs acting as ARB and ARG sources when the water is used in aquaculture activities.

6.2.5 Hospitals and Pharmaceutical Industries as ARB and ARGs Sources

Hospitals are crucial hotspots for disseminating ARB and ARGs (King et al. 2020) due to the extensive antibiotics use for treating bacterial diseases in patients. However, the antibiotics consumed or injected into patients are not entirely absorbed. Ultimately, they are released in urine and faeces into the WWTPs, which inadequately treat the antibiotics and their residues. Moreover, antibiotic residues from pharmaceutical industries also circulate in water environments following poor treatment by WWTPs (Baquero et al. 2008). Therefore, it is unsurprising that ARB were isolated from hospital effluent (King et al. 2020) and high-risk effluent hospital water (Eze et al. 2021) in South Africa. Moreover, ARB and ARGs were detected from effluents in various hospitals in the Democratic Republic of the Congo (Laffite et al. 2016) and South Africa (Perovic et al. 2020; Mbhele et al. 2021; Ramsamy et al. 2022). Regardless of the source, antibiotics and their residues stimulate ARB and ARG development once the water is used for aquaculture. The current studies emphasise the source of ARB and ARGs from hospitals and pharmaceutical industries entering into African aquaculture industry.

6.2.6 Aquaculture Workers as ARB and ARGs Sources

Aquaculture workers contaminated with ARB and ARGs are a potential source of antibiotic resistance in an aquaculture setting (Chuah et al. 2016). The transfer of ARB and ARGs from aquaculture workers to aquaculture may occur via various

pathways. First, ARB and ARGs may be transferred to aquaculture when wounded farmworkers are in contact with fish, water or aquaculture facilities (Jacobs and Chenia 2007). Second, ARB and ARGs colonising aquaculture workers can enter the aquaculture during fish feed production and hand-dispersing (Madubuike and Kennedy 2016). Third, contaminated fish-farm workers may also act as a source of ARB and ARGs during fish handling for food preparation or consumption (Chenia and Jacobs 2017). Fourth, ARB and ARGs in contaminated workers may be transferred into aquaculture systems through faeces especially in rural areas with limited toilets or when vectors such as insects transfer them to aquaculture systems (Klase et al. 2019). Accordingly, Hamza et al. (2020) found that half of the workers in the integrated agriculture-aquaculture system in Egypt carried *Enterobacteriaceae* strains, which were also present in the fish-rearing water and the fish. Elsewhere, aquaculture workers, especially in intensive culture systems, acted as ARB and ARGs sources in the aquaculture systems (Pruden et al. 2013). These studies highlight that occupational exposure to antibiotics may also contribute to increased resistance rates.

In summary, ARB and ARGs occurring in aquaculture systems originate from several sources (Fig. 6.1). The ARB and ARGs caused by antibiotics application in aquaculture combine with those used in other activities such as livestock, humans and plants and find their way into the aquatic environment following inefficiency treatment in WWTPs. Moreover, ARB and ARGs also originate from hospitals and pharmaceutical industry effluents and contaminated workers at farms. Consequently, aquaculture retains ARB and ARGs, acting as a hotspot for their dissemination.

6.3 Factors Causing ARB and ARGs in Aquaculture

Antibiotic resistance is currently one of the major public health crises worldwide. It is usually known that antibiotic resistance evolves naturally via natural selection through random mutation or evolution in a stressed population (Iwu et al. 2020). Therefore, the evolution of resistance in bacteria is deemed a natural process (Watts et al. 2017; Samreen et al. 2021). However, the recent increase in the number of ARB and ARGs is contributed by several factors as discussed in this section.

6.3.1 Antibiotics Overuse and Misuse

The discovery of antibiotics by Fleming (1944) marked an important milestone in treating bacterial diseases. Since then, antibiotics have been commonly used to treat diseases caused by bacteria in humans and economically important livestock animals and plants. Antibiotics are also used to treat bacterial diseases in aquaculture for therapeutic and prophylaxis purposes. Unfortunately, antibiotics are used abusively in aquaculture and other organisms due to overprescription (Iwu et al. 2020),

inadequate knowledge about their purpose and proper application by producers (Pham et al. 2015) and inappropriate socio-ecological behaviours (Iskandar et al. 2020). Misuse of antibiotics in aquaculture in developing countries causes ARB and ARGs development in different cultured organisms (Limbu 2020). The overprescribed or abusively used antibiotics kill or inhibit drug-sensitive bacteria, leaving resistant strains to proliferate through natural selection (Limbu et al. 2021). As such, the tolerant bacterial strains develop resistance to further application of antibiotics. The resistant bacteria mutate, altering the target sites of the antibiotics through various factors (Iwu et al. 2020), thus developing ARGs. Consequently, ARB and ARGs develop in Africa's various components of aquaculture systems due to antibiotics overuse and misuse in the sector.

6.3.2 Regulatory Barriers

It is globally advised that all antibiotics legally used in aquaculture must be approved by the government agency responsible for veterinary medicine (Limbu et al. 2021). However, many regulatory agencies on antibiotic use in African aquaculture are absent or weak. In some countries, regulations may exist but are not effectively enforced due to loose rules (Iskandar et al. 2020), causing farmers to use any antibiotics available in the markets as in countries with no regulations (Musefiu and Olasunkanmi 2015). In addition, in some countries, regulations on antibiotics used in aquaculture are hampered by ineffective communication channels and fluctuations in licensing, administrative and regulatory rules (Iwu et al. 2020). Accordingly, antibiotics use for treating cultured species in African aquaculture is largely unregulated (Aly and Albutti 2014), which causes antibiotics overuse, leading to the development of ARB and ARGs.

Moreover, the ARB and ARGs in African aquaculture are caused by inadequate surveillance and monitoring systems (Iskandar et al. 2020). Lack of surveillance and monitoring systems has been reported to exacerbate the magnitude of ARB and ARGs in African aquaculture in South Africa (Ekwanzala et al. 2018), Ivory Coast (Koudou et al. 2020) and Tanzania (Mzula et al. 2021). In addition, most surveillance and monitoring systems for antibiotics in African aquaculture have inadequate funds (Mzula et al. 2021), poor coordination and lack adequately trained staff (Mathew et al. 2020). In general, ARB and ARGs in African aquaculture are caused by lack of regulations, ineffective enforcement, loose rules and lack of surveillance and monitoring systems.

6.3.3 Availability, Accessibility and Affordability of Antibiotics

The lack of/weak regulations for antibiotics use in African aquaculture have increased their availability to practitioners. Most antibiotics used in African aquaculture are those intended to treat bacterial diseases in humans and other animals,

which are readily available due to diverse distribution systems caused by inadequate designated healthcare systems (Byarugaba 2004). Accordingly, antibiotics intended for aquaculture can be purchased in community pharmacies (Mukonzo et al. 2013), general stores and even market stalls (Aly and Albutti 2014). Antibiotics in Africa are given as over-the-counter drugs at community pharmacies. This practice increases the accessibility of the antibiotics required for treating diseased animals in aquaculture. Moreover, the common antibiotics used in African aquacultures, such as tetracyclines (Bouelet Ntsama et al. 2018), are cheap and thus affordable to most farmers (Iwu et al. 2020). Selling antibiotics over-the-counter has been strongly correlated with ARB and ARGs in low-income and middle-income countries (Alsan et al. 2015). Therefore, the injudicious sale of antibiotics over-the-counter increases their availability and accessibility. The easy availability and accessibility, coupled with the affordability of antibiotics, increase the development and spread of ARB and ARGs in African aquaculture.

6.3.4 Incorrect Antibiotic Prescriptions

The African aquaculture is characterised by inadequate expertise in fish disease diagnosis and treatment (Mathew et al. 2020; Mzula et al. 2021). Consequently, aquaculture practitioners use antibiotics without correct prescriptions, similar to common self-medication for human disease treatment (Sanou et al. 2018). Inappropriate prescription of antibiotics in African aquaculture might also be caused by increasing intensification to improve fish production (Mathew et al. 2020). Incorrect prescriptions of antibiotics in African aquaculture might lead to ARB and ARGs in produced cultured animals (Minich et al. 2018). In addition, incorrectly prescribed antibiotics may also lead to ARB and ARGs by promoting gene modifications such as mutagenesis and deviations in gene expression (Iwu et al. 2020). Incorrect prescriptions of antibiotics in African aquaculture include improper choice of antibiotics and treatment period, which is one of the factors for the existence of ARB and ARGs in the industry.

6.3.5 Prolonged Use of the Same Antibiotics

Globally, the aquaculture industry mainly uses eight groups of common antibiotics (Limbu et al. 2021). Similarly, the African aquaculture also uses common antibiotics such as tetracycline, oxytetracycline, florfenicol, and chloramphenicol, usually for prolonged periods (Limbu 2020). The continued use of similar antibiotics creates selective pressure on sensitive bacteria strains leading to the proliferation of resistant ones (Iwu et al. 2020). In addition, specific antibiotics have been linked to selective pressure on distinct bacteria strains leading to antibiotic resistance elsewhere (Kolář et al. 2001). Therefore, the continued use of similar antibiotics in African aquaculture might be one of the factors causing ARB and ARGs in the sector.

In summary, overuse and misuse of antibiotics in the sector, lack of regulations, ineffective enforcement, loose rules and lack of surveillance and monitoring systems coupled with easy availability, accessibility and affordability of antibiotics increase the development and spread of ARB and ARGs in African aquaculture. Moreover, incorrect prescriptions of antibiotics and continued use of similar antibiotics in African aquaculture are responsible factors for the increased ARB and ARGs in the sector.

6.4 Types of ARB and ARG in Aquaculture

Aquaculture has been considered as one of the "hotspot environments" for ARB and ARGs transfer (Cabello et al. 2016; Watts et al. 2017; Reverter et al. 2020; Hossain et al. 2022). The ARB and ARGs in aquaculture are similar due to the use of related antibiotics, level of aquaculture production and inadequate laws, regulations and enforcement (Limbu et al. 2021). Unfortunately, aquaculture practices from low- and middle-income countries, which characterise most African nations, contribute high ARB and ARG levels (Reverter et al. 2020). This chapter recorded 27 bacterial species causing ARB in African aquaculture, as depicted in Table 6.1. The ARB were dominated by *Citrobacter* spp., *Aeromonas* spp., *Escherichia coli*, *Klebsiella* spp., *Enterobacter* spp., *Vibrio* spp., *Pseudomonas* spp., *Proteus* spp., and *Enterococcus* spp., with rare species such *Edwardsiella tarda*, *Salmonella typhi*, *Plesiomonas* spp., *Exiguobacterium* spp., *Providencia* spp. and *Staphylococcus* spp. (Table 6.1).

Antibiotic resistance in these bacteria is alarming because they cause various human diseases. For instance, *Citrobacter* spp. and *Salmonella typhi* cause intestinal diseases such as typhoid (Johnson et al. 2018); *Aeromonas* spp., *Vibrio* spp., *Plesiomonas* spp., *Enterococcus* spp. and *Edwardsiella tarda* cause foodborne illnesses (Bhunia 2018); and *Escherichia coli*., *Staphylococcus* spp., *Exiguobacterium* spp. and *Providencia* spp. are causative agents for diarrheal disease (Schuetz 2019). Moreover, *Pseudomonas* spp., *Proteus* spp. and *Klebsiella* spp. are responsible for the common urinary tract infection (UTI) (Marques et al. 2019a) in African people. Furthermore, *Enterobacter* spp. is a causative agent for nosocomial infections (Ramirez and Giron 2022), while *Kurthia* spp. is responsible for sexually transmitted diseases (Marques et al. 2019b), and *Vagococcus* spp. cause bloodstream and decubitus ulcer infection (Matsuo et al. 2021).

The bacteria studied were resistant to a total of 53 antibiotics, mainly dominated by tetracycline (TCN), gentamycin (GEN), sulfamethoxazole plus trimethoprim (clotrimazole, SXT), ampicillin (AMP), chloramphenicol (CAP), ciprofloxacin (CIP) and erythromycin (ERM). Other main antibiotics were nalidixic acid (NAL), streptomycin (STP), aztreonam (AZT), imipenem (IMP), cefuroxime (CEF), ceftazidime (CAZ), amoxicillin (AMX), ceftriaxone (CFX), trimethoprim (TMP), kanamycin (KAN), cefotaxime (CFT) and amoxicillin/clavulanic acid (AMC) (Table 6.1). Similar to ARB, several ARGs were also detected dominated by *tet*, *dfr*,

Table 6.1 The types of antibiotic-resistant bacteria and resistance genes isolated in African aquaculture

Source of sample	Type of ARB and ARGs	Resistant to antibiotics	MAR	Country	Reference
Fish	*Proteus mirabilis*, *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Enterobacter aerogenes* and *Staphylococcus aureus*	LIN, AMP, PCN, ERM, TCN, NEC, CLX, KAN and SMZ	0.2–0.7	Zimbabwe	Gufe et al. (2019)
Tilapia, trout and koi aquaculture systems	*Aeromonas* spp.	AMP, OXA, AMX, AUG, CEF, CFX, IMP, CAP, SXT, ERM, GEN, AMK, NAL, OFX, CIP, TCN and AZT	0.12–0.59	South Africa	Jacobs and Chenia (2007)
	*Tet*A and class 1 integron such as *ant(3″)Ia*, *aac(6′)Ia*, *dhfr1*, *oxa2a* and/or *pse1* genes	TCN, GEN, STP, CAP, TMP and β-lactam	NA		
Fish pond water	*Vibrio* spp.	AMP, ERM, NAL, SMZ, TMP, SXT, TCN, OTC and CAP	0.365	Nigeria	Igbinosa (2016)
Nile tilapia and African catfish	*Aeromonas* spp. and *Plesiomonas shigelloides*	SXT, TCN, GEN, STP, IMP, ERM, AMP, CXT, CFT, CAP, AZT NAL and ENF	NR	Uganda	Wamala et al. (2018)
Water, sediments and fish pond	*Aeromonas* spp., *Acinetobacter* spp., *Exiguobacterium* spp., *Kurthia gibsonii*, *Empedobacter brevis*, *Klebsiella oxytoca*, *Proteus* spp., *Planococcus* spp., *Providencia alcalifaciens* and *Vagococcus fluvialis*	TCN, TMP, SFM, AMX, OXA, STP, CAP, FFO and ERM	0.2–1	Tanzania	Shah et al. (2012)
	*tet*A, *tetG*, *dfrA1*, *dfrA5*, *dfrA7*, *dfrA12*, *dfrA15*, bla_{TEM}, *strA*, *strB*, *cat-1*, *mefA*, *int1* genes	TCN, TMP, AMX, STP, CAP and ERM			

(continued)

Table 6.1 (continued)

Source of sample	Type of ARB and ARGs	Resistant to antibiotics	MAR	Country	Reference
Nile tilapia and water samples	*Escherichia coli*, *Citrobacter freundii*, *Morganella morganii*, *Enterococcus faecalis*, *Enterobacter hormaechei* and *Pseudomonas aeruginosa*	AMC, TCC, TZP, PIL, TIC, CAZ, CEF, AZT, NAL, TCG, FSF and SXT	Multidrug resistance for three classes of antibiotics	Ivory Coast	Koudou et al. (2020)
Aquaculture and abattoir environments	*Pseudomonas aeruginosa*	GEN, KAN, AZT, MRP, TCN, CAZ and CEF	0.4–0.8	Nigeria	Igbinosa et al. (2017a)
Aquaculture and abattoir environments	*Aeromonas* spp.	PCN, CFP, CEF, GEN, KAN, AZT, ETP, MRP, CIP and TCN	0.3–0.7	Nigeria	Igbinosa et al. (2017b)
	pse, bla_{TEM} and class 1 integron	Carries two integrons and encodes multiple drug resistance and β-lactam	NA		
Mullet and tilapia from fish farms	*Aeromonas hydrophila*, *Klebsiella pneumoniae*, *Enterobacter cloacae*, *Escherichia coli*, *Citrobacter koseri* and *Vibrio alginolyticus*	AMC, AMP, AZT, CAZ, CAP, CIP, CPD, CFX, CTT, CFT, CEF, GEN, IMP, KAN, NAL, NOR, OXC, STP, SXT and TCN	Multiple resistance	Egypt	Ishida et al. (2010)
	*tet*A, *tet*E, *tet*C, *tet*D, *tet*B, *dfrA1*, *dfrA2*, *dfrA5*, *dfrA7*, *dfrA12*, *dfrA17*, *aadA1*, *aadA2*, *aadA5*, *aadA7*, *aac(3)-Id*, *catB3*, bla_{TEM}, $bla_{TEM-104}$, bla_{TEM-1}, bla_{OXA-30}, $bla_{CTX-M-15}$, bla_{SHV-89}, *qnrS*, *qnrA*, *qnrB*, *aac(6′)-Ib-cr* and *floR* genes	TCN, TMP, STP, SPT, GEN, SSM, CAP, *β*-lactam, QNL and FFO	NA		

(continued)

Table 6.1 (continued)

Source of sample	Type of ARB and ARGs	Resistant to antibiotics	MAR	Country	Reference
Tilapia aquaculture system	*Aeromonas* spp., *Salmonella* spp., *Shewanella* spp., *Citrobacter* spp., *Myroides* spp., *Chryseobacterium* spp., *Enterobacter* spp., *Serratia* spp., *Bordetella* spp., *Klebsiella* spp., *Pseudomonas* spp., *Vibrio* spp.	AMX, AUG, CFX, CEF, IMP, SMZ, SHR, TMP, SXT, NAL, CIP, AMK, GEN, STP, AZT, ERM, TCN, CAP, and COL	0.14–0.67	South Africa	Chenia and Jacobs (2017)
	aac(6')Ia, *pse1*, *oxa2a*, *catB3* and *sulI* genes	GEN, STP, *β*-lactam, CBP, CAP and SMZ	NA		
Commercial dusky kob aquaculture farms	*Vibrio* spp.	GEN, NOR, FFO, TCN, CAP, STP, IMP, SXT, and NAL	0.0–0.67	South Africa	Fri et al. (2018)
	ampC, *blaOXA*, *tetA*, *tetM*, *dfr1*, *sul1*, *sul2*, *ermB*, *nptII*, *strA*, *SXT*, *ermB*	*β*-lactam, TCN, SFM, SMZ, STP, ERM, SXT	NA		
Nile tilapia and African catfish	*Edwardsiella tarda*	AMX, AMP, CFT, ERM, STP, GEN, ENF, CIP, COL, TCN and SXT	Multidrug resistance to six antibiotics	Egypt	Algammal et al. (2022)
	bla_{TEM}, *sul1*, *tet*A, $bla_{CTX\text{-}M}$, *aad*A1, *qnr*S, and *qnr*A	*β*-lactam, SMZ, TCN, QNL and AMG	NA		
Freshwater aquaculture systems	*Aeromonas* spp.	NAL and OFX	NR	South Africa	Chenia (2016)
	qnrB and *qnrS* genes	QNL	NA		
African catfish	*Escherichia coli*	AMX, GEN, SXT, CIP, CEF, CFX, CAZ, AMC and TZP	> 0.2	Nigeria	Akande and Onyedibe (2019)
	AmpC	AMP	NA		

(continued)

Table 6.1 (continued)

Source of sample	Type of ARB and ARGs	Resistant to antibiotics	MAR	Country	Reference
Infected African catfish from a pond	*Pseudomonas putida*, *Escherichia coli*, *Staphylococcus aureus* and *Enterococcus* spp.	CAZ, CRO, CTX, CPX, TCN, GEN and CIP	NR	Nigeria	Ogbonna and Inana (2018)
Coastal waters	*Enterococcus* spp.	RFP, ERM, TCN, VCM, ERM, AMP and CIP	0.3–0.9	South Africa	Adeniji et al. (2021)
	*erm*B, *tet*M, *tet*L, *gyr*A, *amp*C and *Van* C2/3 genes	ERM, TCN, CIP, AMP and VCM	NA		
Aquaculture pond water	*Vibrio* spp.	AMP, AMX, AMC, CAZ, IMP, CIP, SXT, CAP and TCN	NR	Nigeria	Adekanmbi et al. (2021)
River and estuarine water	*sul*1, *sul*2, *sul*3 and *tet*M genes	SMZ and TCN	NA	South Africa	Suzuki et al. (2015)
African catfish, Nile tilapia and water samples	*Serratia marcescens*, *Citrobacter freundii*, *Klebsiella oxytoca*, *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumonia*, *Edwardsiella tarda, Salmonella typhi*, *Proteus mirabilis*, *Citrobacter amalonaticus*, *Shigella sonnei* and *Citrobacter diversus*	SXT, GEN, CEF, CAP, CFX, CFT, AMP and TCN	0.00–0.88	Ghana	Adinortey et al. (2020)

ARB antibiotic-resistant bacteria, *ARGs* antibiotic resistance genes, *MAR* multiple antibiotic resistance, *LIN* lincomycin, *AMP* ampicillin, *PCN* penicillin, *ERM* erythromycin, *TCN* tetracycline, *NEC* neomycin, *CLX* cloxacillin, *KAN* kanamycin, *SMZ* sulfamethoxazole, *OXA* oxacillin, *AMX* amoxicillin, *AUG* augmentin, *CFX* ceftriaxone, *IMP* imipenem, *CAP* chloramphenicol, *GEN* gentamicin, *AMK* amikacin, *NAL* nalidixic acid, *OFX* ofloxacin, *CIP* ciprofloxacin, *AZT* azithromycin, *TMP* trimethoprim, *SXT* sulfamethoxazole plus trimethoprim, *OTC* oxytetracycline, *OXA* oxolinic acid, *STP* streptomycin, *FFO* florfenicol, *SFM* sulfonamides, *CFT* cefotaxime, *AZT* aztreonam, *ENF* enrofloxacin, *AMG* aminoglycoside, *AMC* amoxicillin/acid clavulanic, *TCC* ticarcilline/clavulanic acid, *TZP* piperacillin/tazobactam, *PIL* piperacillin, *TIC* ticarcillin, *CAZ* ceftazidime, *CEF* cefoxitin, *TCG* tigecycline, *FSF* fosfomycin, *MRP* meropenem, *CEF* cefuroxime, *CFP* cefepime, *ETP* ertapenem, *CPD* cefpodoxime, *CTT* cefotetan, *NOR* norfloxacin, *OXC* oxacillin, *SPT* spectinomycin, *SSM* sisomicin, *QNL* quinolone, *SHR* sulphatriad, *COL* colistin sulphate, *CBP* carbapenem, *CAZ* ceftazidime, *CRO* ceftriaxone, *CTX* cefotaxime, *CPX* cephalexin, *RFP* rifampicin and *VCM* vancomycin

bla, *sul*, *qnr* and *aadA* coffering resistance to TCN, TMP, β-lactam, sulfamethoxazole (SMZ and other sulfonamides), a quinolone (QNL) and aminoglycoside (AMG), respectively (Table 6.1). It is possible that the ARGs detected in cultured fish might be transferred to humans due to the existence of class 1 integrons responsible for the horizontal transfer of ARGs (Jacobs and Chenia 2007; Shah et al. 2012; Igbinosa et al. 2017b). Notably, the bacteria and genes identified in African aquaculture were resistant to common antibiotics used for human bacterial diseases treatment. The socioeconomic consequences are further enhanced by the fact that most of the bacteria isolated from African aquaculture had multiple antibiotic resistance (MAR) (Jacobs and Chenia 2007; Ishida et al. 2010; Shah et al. 2012; Igbinosa 2016; Chenia and Jacobs 2017; Igbinosa et al. 2017a, b; Fri et al. 2018; Akande and Onyedibe 2019; Gufe et al. 2019; Adinortey et al. 2020; Koudou et al. 2020; Adeniji et al. 2021; Algammal et al. 2022). The identifications of ARB and ARGs in aquaculture and their potential transfer to people manifest damaging health and socioeconomic effects because the main antibiotics to which bacteria and genes were resistant are often used to treat common bacterial diseases in humans.

6.5 The Socioeconomic Consequences of ARB and ARGs in Aquaculture

The possible transfer of ARB and ARGs indicates devastating human socioeconomic effects and is discussed in this section. The socioeconomic effects in humans vary depending on distinct settings.

6.5.1 The Transfer of ARB and ARGs from Aquaculture to Humans

The ARB and ARGs in aquaculture and other environmental components can be transferred from animals to humans through various routes (Fig. 6.2). First, ARB and ARGs may be transmitted to humans via the food chain through contaminated aquaculture products while handling and consuming raw or undercooked food (Ramsamy et al. 2022). Aquaculture animals harbour deposits of ARB and ARGs in their edible tissues (Iwu et al. 2020). Furthermore, the ARB and ARGs in aquaculture products are transferred from host to host after contamination with biological substances such as blood, urine, faeces, milk, saliva and semen or direct human contact (Founou et al. 2016). Occupationally exposed workers such as veterinarians, farmers, abattoir workers, food handlers and those directly in contact with them are at a high risk of being colonised or infected with ARB and ARGs (Igbinosa et al. 2017a, b). Moreover, the human population may be exposed indirectly to ARB and ARGs via contact with or consumption of other contaminated food products such as

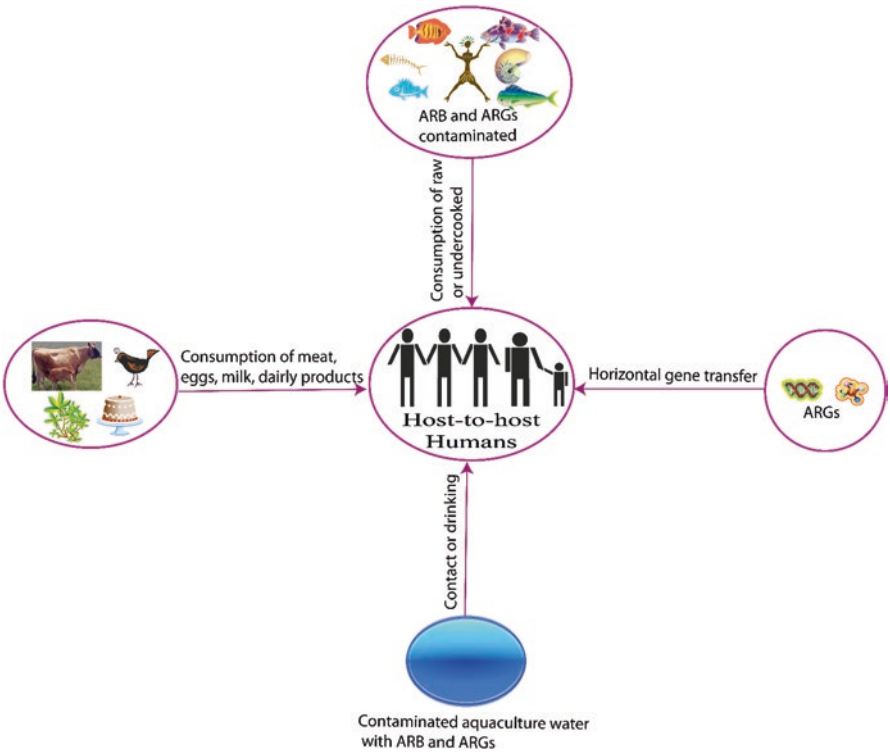


Fig. 6.2 The possible transmission routes of antibiotic-resistant bacteria and genes from aquaculture to humans

meat, eggs, milk and dairy products (Founou et al. 2016). In fact, food animals have been suggested to possess substantial ARB and pose a serious threat for food safety and security in Africa (Badi et al. 2018; Founou et al. 2018).

The second means of ARB and ARG transfer from aquaculture products to human health is through horizontal and vertical gene transfer (Iwu et al. 2020). Horizontal gene transfer can occur from bacteria to other bacteria through mutation, recombination, conjugation, transformation and transduction (Chuah et al. 2016). Horizontal gene transfer promotes genetic communication, changing bacterial pathogenicity, which increases ARB and ARGs (Iwu et al. 2020). The third route for the spread of ARB and ARGs from aquaculture to humans may be through direct contact with water or drinking contaminated water (Aly and Albutti 2014). Drinking waters from rivers in South Africa (Abia et al. 2015) and Nigeria (Adelowo et al. 2018) and well water in Guinea-Bissau (Machado and Bordalo 2014) contaminated with ARB and ARGs posed severe health risks for users. The ARB and ARGs transmitted through the above routes cause various socioeconomic effects, as detailed in the next section.

6.5.2 Human Health Risk

The results in Table 6.1 indicate a fearful situation on the number of ARB and ARGs and the common antibiotics used for treating human diseases to which bacteria are resistant. The ARB and ARGs from aquaculture have been detected across the African continent in South Africa (Jacobs and Chenia 2007; Chenia 2016; Chenia and Jacobs 2017; Fri et al. 2018; Adeniji et al. 2021), Nigeria (Igbinosa 2016; Igbinosa et al. 2017a, b; Ogbonna and Inana 2018; Akande and Onyedibe 2019; Adekanmbi et al. 2021), Egypt (Ishida et al. 2010; Algammal et al. 2022), Tanzania (Shah et al. 2012), Uganda (Wamala et al. 2018), Zimbabwe (Gufe et al. 2019), Ivory Coast (Koudou et al. 2020) and Ghana (Adinortey et al. 2020). The detection of ARB and ARGs from aquaculture poses public health hazards because they are transmittable to humans. A previous study reported that aquaculture workers are at an increased risk of developing occupational diseases such as leptospirosis and skin problems such as dermatitis, skin abrasions and skin infections (Ngajilo and Jeebhay 2019). Moreover, the ARB were reported as media for potentially transferring waterborne bacteria or ARGs to aquaculture workers in South Africa (Jacobs and Chenia 2007).

Indeed, half of the examined workers at an integrated agriculture-aquaculture farm in Egypt carried resistant *Enterobacteriaceae* strains, harbouring a wide range of multidrug resistance (Hamza et al. 2020). In China, workers and community members in contact with waste-fed aquaculture water were reported to have an increased risk of acquiring diarrhoea and skin diseases (Klase et al. 2019). The consequences of ARB and ARGs causing human infections include increased infections, frequency of treatment failures, severe infection, prolonged duration of illness and increased frequency of bloodstream infections and hospitalisation (Aly and Albutti 2014). Furthermore, the spread of ARB and ARGs and increasing resistance to the commonly prescribed antibiotics make primary healthcare redundant (Mathew et al. 2020), thereby significantly reducing the available medical treatment options for previously curable infections (Watts et al. 2017). Accordingly, Mathew et al. (2020) reported frightening ARB and ARGs situation in Tanzania, Uganda, Ethiopia, Kenya and Egypt. In a nutshell, the ARB and ARGs from aquaculture are worsening the already limited health facilities for treating bacterial diseases in Africans.

6.5.3 Economic Consequences

The economic consequences of ARB and ARGs are twofold. On the one hand, the widespread ARB and ARGs in cultured species in Africa causes repeated applications of antibiotics, weakening the immunity of fish (Limbu et al. 2018; Zhou et al. 2018; Limbu 2020; Limbu et al. 2021) and further prompting continued use of antibiotics. Consequently, aquaculture production costs are increased (Musefiu and Olasunkanmi 2015) because of money spent on purchasing higher antibiotics

(Mathew et al. 2020). On the other hand, the ARB and ARGs acquired by humans confer resistance to prescribed antibiotics. Consequently, healthcare costs are increased due to poor outcomes, the need for more patients to undergo more diagnostic tests and extended hospitalisation periods (Nyasulu et al. 2012). Human healthcare costs are also increased because patients need to travel great distances to access higher medical centres. Thus, they spend more money on advanced bacterial diagnostic tools to identify appropriate cures and purchase more potent antibiotics for treatment (Mathew et al. 2020). Therefore, the ARB and ARGs from aquaculture increase the cost to society for treating cultured species and humans.

6.5.4 Increased Human Deaths

The presence of ARB and ARGs in aquaculture contributes to the increased severity of infection (Aly and Albutti 2014) and reduces the available medical treatment options for previously curable infections (Watts et al. 2017). Consequently, ARB and ARGs have led to increased mortality of hospitalised patients (Aly and Albutti 2014) and deaths from infections, which were treatable formerly (Watts et al. 2017). Regrettably, the number of deaths due to ARB and associated ARGs is not consistent and only available in certain areas. Reverter et al. (2020) estimated that over 35,000 human deaths occurring annually in the USA, 33,000 in the European Economic Area and 58,000 in India are caused by ARB and ARGs. Mathew et al. (2020) estimated that around 50,000 deaths happen every year in Europe and USA due to ARB and ARGs. Samreen et al. (2021) reported that infections with multidrug-resistant microbial pathogens cause approximately 700,000 annual deaths globally.

Despite the inconsistency in data, the deaths reported are already alarming. The numbers may dramatically worsen if the unavailable data from other parts of the world, such as low-middle income countries, become available or improved data quality (Mathew et al. 2020). Future projections indicate that more than ten million human deaths will occur every year globally due to ARB and ARGs by 2050, assuming the current resistance increase by 40% and the mortality risk per infection remains unchanged (O'Neill 2014). Currently, the direct contribution of aquaculture to human deaths caused by ARB and ARGs remains challenging to unravel. Other global weather patterns also contribute to the difficulty in realising the data due to climate change (Reverter et al. 2020) and morbidity from other diseases.

In summary, African aquaculture might be contributing to ARB and the associated ARGs, increasing the severity of infections and reducing available medical treatment options for previously curable diseases, thus increasing human deaths. However, the precise number of deaths attributed to antimicrobial resistance from African aquaculture is difficult to estimate, an aspect that requires further research.

6.6 Conclusion

The African aquaculture represents a hotspot reservoir of ARB and ARGs. However, the ARB and ARGs existing in African aquaculture are complex and not solely derived from the industry. They originate from multiple sources, including antibiotics application in aquaculture, livestock manure and integrated aquaculture systems, agriculture and human health. The ARB and ARGs also originate from WWTPs, hospitals and pharmaceutical industries. The ARB and ARGs in aquaculture are caused by overuse and misuse of antibiotics in the sector, lack of regulations, ineffective enforcement, loose rules and inadequate surveillance and monitoring systems, which increase the availability and accessibility of antibiotics. Moreover, incorrect prescription, easy affordability and prolonged use of the same antibiotics also contribute to increased ARB and ARGs in the African aquaculture industry.

The African aquaculture sector is currently dominated by multiple ARB and their genes, resistant to antibiotics commonly used to treat human diseases. The ARB and ARGs in aquaculture are transferred to humans via aquaculture product contamination during handling and consumption of raw or undercooked food, horizontal and vertical gene transfers and direct contact with water or drinking contaminated water. The consequences of ARB and ARGs from aquaculture include increased infections, frequency of treatment failures, severe infections, prolonged duration of illness and increased frequency of bloodstream infections and hospitalisation. These make primary healthcare redundant for previously curable diseases, thereby increasing costs to the society on treating cultured species and humans, leading to animal and human deaths.

6.7 Recommendations

Combating ARB and ARGs requires collective effort in all sectors using a “One Health” approach. Therefore, stringent measures, legislations and regulations for antibiotics use in aquaculture, agriculture, livestock and humans should be developed and implemented. In addition, research should be conducted to design proper treatment for ARG and ARGs in hospital sewage wastes and pharmaceutical industrial effluents. Furthermore, the African continent should institute coordinated, continuous monitoring programmes following appropriate legislation and regulations. The African continent should also emphasise alternative treatment options for bacterial diseases, considering the existence of diverse medicinal plants.

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