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The Association Between Antibiotic Misuse and the Development of Antimicrobial Resistance: A Systematic Literature Review

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Abstract: The misuse of antibiotics has been widely recognized as a critical driver of antimicrobial resistance (AMR), yet a comprehensive synthesis of evidence across diverse sectors remains fragmented. This systematic literature review was conducted to critically examine the association between antibiotic misuse and the subsequent development of AMR, with particular attention to the underlying drivers, epidemiological patterns, and the effectiveness of interventions. We designed a structured review protocol to identify, appraise, and synthesize empirical studies spanning human medicine, veterinary practice, agriculture, and community settings. The methodology involved a rigorous selection process informed by predefined inclusion criteria, followed by thematic synthesis and quality assessment of included studies. Our results reveal that antibiotic misuse is consistently associated with increased AMR prevalence, with key drivers including inappropriate prescribing behaviors, patient demand, over-the-counter access, and insufficient diagnostic capacity across low-, middle-, and high-income settings. The evidence further indicates that AMR development is not solely a clinical phenomenon but is deeply intertwined with socioeconomic inequalities, regulatory gaps, and political inertia. Consequently, we found that standalone educational campaigns often yield limited impact, whereas integrated stewardship programs coupled with robust surveillance systems demonstrate greater efficacy in curbing misuse. The review also highlights emerging threats from global crises, including pandemics and climate change, which exacerbate existing misuse patterns. We conclude that addressing antibiotic misuse requires a multisectoral, systems-based approach that simultaneously targets behavioral, structural, and policy determinants.

Keywords: Antibiotic misuse, Antimicrobial Resistance, Antibiotic stewardship, Drug resistance, Systematic literature review.

Introduction

Discovery and use of antibiotics in clinical practice, making use of them became one of the most significant medical advancements in medicine from the viewpoint of infectious diseases (Davies & Davies, 2010). With the advent of these agents in the 20th century, more complicated surgical procedures have become possible, as have immune suppression and effective treatment of many common infections, once life-threating. However, the overuse and in some cases overuse, of these much needed resources, has created a problem of astronomical proportions – antimicrobial resistance (AMR). Not only does the effect of the drugs diminish, but what is going on in the ecological environment as well – can the microorganisms become so resistant to the activity of the drugs that they need to fight against in order to regrow and be passed on in a persistent infection, as seen in Standard treatments fail to eradicate (Prestinaci et al., 2015)?

The issue of antibiotic overuse and development/resistance of organisms is at the core of this problem. The antibiotic misuse is better defined as complex and it describes the use of antibiotics in a non bacterial infection, as doses below the recommended therapeutic doses, early stopping treatment, self-medication, access to antibiotics without a medical prescription and overuse of antibiotics as prophylactic and growth-promoting agents in animal production (Holmes et al., 2016). This non-specific use imposes a very heavy selection pressure on bacteria and stimulates resistant strains of bacteria to grow and survive at the expense of more susceptible ones. This is a vast amount and a high percentage of antibiotic use in the world is either unnecessary, or not optimally used, especially in primary care settings for respiratory tract diseases (Appaneal et al., 2023). Moreover, the nature of human–medicine, veterinary and agriculture continuum generates a multilayered environment for resistance to dissipate—even across species and regions—which is difficult to control, and can become endemic (Palma et al., 2020). Infections with multidrug resistant organisms (MDROs) cause a disproportionate disease burden, as they have been associated with higher mortality, longer hospital stays and more health care costs.

There is a general agreement that the use of antibiotics is a key challenge for the emergence of AMR, however there remains a significant ‘gap' in providing a consolidated, evidence-based understanding of this problem, which is widespread and scattered across individual sectors. There have been many systematics reviews within specific areas of antimicrobial stewardship, including the effectiveness of antimicrobial stewardship programs (ASPs) in hospitals (Huebner et al., 2019), and the drivers of antimicrobial resistance in food animal production (Silbergeld et al., 2008). Unfortunately, there was no detailed synthesis that at the same time takes in account all the sectors (such as communities, agriculture and human and veterinarian medicine) where the abstraction of antibiotics is occurring, and then systematically connects the various metrics to the clinical burden of AMR and the proven effectiveness of various measures. For example, the social, economic and behavioral drivers of barriers to patient access to antibiotic prescriptions and provider prescribing practices—and that underlie this need—fell short in the volume of attention and research devoted to them, and had to be addressed in designing context-sensitive interventions. Hence, there is an urgent need for a systems level analysis of how the pattern of instances of mistreatment to one part of a system leads to clinical resistance to another part and how this can be managed.

This knowledgeable gap is thus the key driver behind this systematic review to provide an integrated and critical review of literature. Of importance: this research work may offer a unified evidence-basis for policy makers, clinicians and veterinarians and health officials. This review aims to offer a conceptual framework going beyond a ‘one and done’ approach to managing misuse, and to understand abuse range of interventions and build up a resistance profile for the corresponding epidemic. It underscores the need to refresh the approach to antibiotic use and AMR to emphasize the adaptive, ecological, economic and social aspects instead of a straightforward problem of the misuse of antibiotics which inevitably leads to AMR. The relevance of this research is that it is an effort to map out a potential more coherent path for a future research and to offer guidance on how to craft more robust and all-encompassing policy alternatives in order to maximize the future effectiveness of Antibiotics.

The methodology used in this systematic review, search strategy, and selection criteria for and how data was extracted from the eligible articles is detailed in the remainder of this paper. The results section is presented in multiple sub-themes including research progress over time, the multifaceted nature of factors that can lead to misuse in various settings, the mechanism of AMR, its implications for public health, and the socioeconomic, ethical and political issues related to AMR. The results section is then followed up with a review of results on stewardship and education and behavioral interventions, the use of surveillance and digital technologies, and the promise of novel therapeutics. Then, synthesising these findings is analysed, gaps identified and drivers analysed and implications for integrated policy and practice in an international perspective examined.

Methodology

Review Protocol

This systematic literature review has been realized according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) with the goal of guaranteeing a high methodological and transparent approach. The review procedure is carefully laid out and a priori determined, decreasing the probability of a biased review and adding uniformity. This protocol aimed to identify, evaluate and integrate empirical material that has directly studied the relationship between antibiotic overuse and any resulting emergence of antimicrobial resistance in a variety of settings. The AMR search strategy has been as all-encompassing as possible, taking into account the nature of the AMR problem, its multidisciplinary character and complexity.

Four major online electronic databases (PubMed, Scopus, Web of Science, ScienceDirect) were used for systematic searches. This is because the databases selected are databases that possess a very broad spectrum of biomedical, public health and life science literature coverage. Taking into account the clinical importance of AMR in medical and clinical research, Pub Med was selected and chosen the prime database since it has unique indexing of medical and clinical research articles, which were a major part in understanding the clinical burden of AMR (McNamara & Jr, 2011) Studies not conducted in the agricultural field but with more of a interdisciplinary nature, for example, studies in social sciences were also included as these are highly relevant to understanding the motivation for drug use (V. Singh et al., 2021). The decision to use Web of Science was based on its superb coverage of high impact journals of the scientific field, and its very wide citation analysis capabilities (Birkle et al., 2020). Elsevier Journal publishing received a good deal of internal credit from ScienceDirect for its inclusion of many full-length articles in open access format, some of which had an environmental microbiology or pharmaceutical science as the basis of the focus. As a last resort, Google Scholar was used to search for an additional source as well as grey literature and conference proceeding research studies were found; however, "rener filtering care was used with Google Scholar searches due to lack of quality assurance and because of inconsistencies in the indexes.

The search terms used were constructed to focus on the main ideas of antibiotic misuse and antimicrobial resistance, and exclude the review literature. The PubMed search was performed as follows: ("'Anti-Bacterial Agents"[MeSH] OR antibiotic* OR antimicrobial*) AND (" Drug Resistance, Microbial"[MeSH] OR "antimicrobial resistance" OR AMR) AND ("misuse" OR "abuse" OR "inappropriate use" OR "overuse" OR "irrational prescribing") NOT ("Review"[Publication Type] OR "Systematic Review"[Publication Type] OR "Meta-Analysis"[Publication Type]). This was further limited to only articles that had the Article type Journal Article and Clinical Trial. For Scopus, our search was: (TITLE-ABS-KEY(("antibiotic misuse" OR "antibiotic abuse" OR "inappropriate antibiotic use" OR "antibiotic overuse")) AND (antimicrobial resistance OR AMR OR "drug resistance")) and we only looked at articles. The following search of Web of Science was performed: TS=(antibiotic misuse OR antibiotic abuse OR inappropriate antibiotic use OR antibiotic overuse) AND antimicrobial resistance OR AMR OR drug resistance NOT TS=systematic review OR review article OR meta-analysis. ScienceDirect: We used the terms antibiotic misuse, antibiotic misuse, inappropriate antibiotic use, and antibiotic misuse or antibiotic abuse, and then used Article type and the filters (systematic review, review, and meta-analysis) to exclude those terms. For Google Scholar, the search performed was: ("antibiotic misuse" OR "antibiotic abuse" OR "antimicrobial resistance" OR "AMR" OR "drug resistance" OR "antibiotic resistance" OR "multi-drug resistance") -"systematic review" -"meta-analysis" -"review". The year of the publication was not restricted in the years in the database, so all the searches were carried out in October 2025.

Research Questions

As part of the systematic synthesis of the evidence, we developed a series of interconnected research questions that together encapsulate the multifaceted link between antibiotic misuse and emergence of antimicrobial resistance. The "intention" of these questions is to go one step beyond just describing an association, and to dive deeper into how the association is formed, what drives an association, and the context of an association. The first question looks at the drivers and determinants of antibiotic misuse and asks three questions - in what ways does inappropriate antibiotic use exist at the human medicine, veterinary practice, agriculture and community levels and what are the behavioral, structural and systemic factors driving this inappropriate use. The second question focuses on resistance mechanisms, epidemiology and clinical relevance of antimicrobial resistance, describing the microbiological mechanism of increased risk for antimicrobial resistance due to the misuse of antimicrobials, and quantifying impacts on clinical and health services outcomes from antimicrobial resistance. The third question focuses on the social, economic, ethical and political aspects of AMR, recognising that AMR is far from being a biological problem and that it must remain firmly in the cultural, social, economics, equality, governance and health security framework. The fourth question assesses the success of using antimicrobial stewardship, antimicrobial education and behavioral strategies for the prevention of misuse and decrease of antimicrobial resistance. The fifth question is related to the future – that is, the possibility to monitor and react to the issue through the use of surveillance systems, data analysis and digital health solutions. The sixth question considers the possibility of innovation of therapeutics, alternatives and novel mechanisms of action to create solutions that will exceed the capabilities of the “old” antibiotics. Last, the seventh question looks at how global crises, especially Covid, conflict and climate change, have exacerbated antibiotic use patterns and facilitated the spread of AMR. These seven research questions provide an outline for our analysis and give an idea of the broad and deep spotting on it will provide in this review.

Inclusion and Exclusion Criteria

A set of rigid inclusion and exclusion criteria were established which aligned with our research questions to limit studies and ensure relevance, consistency and suitability. Studies had to be original, peer-review published, in an English language journal, and either clinical trial or research article, it was noted. There was no limit on the number of years of study - articles in Geographical Names and Article of the Week were selected from all years of study to be included wherever they were available in one of the databases during the search. The studies were done globally without any geographical restriction so there was a truly global view of the misuse of antibiotics and AMR. The participants' research topic and focus needed to relate directly to one of our set pre-defined research questions, which spanned the association of antibiotic misuse (whether this could be defined as inappropriate prescribing, overuse, self-medication, or misuse in agricultural production) with the onset, prevalence, or spread of antimicrobial resistance. Furthermore, studies needed to be empirical (contain quantitative data like prevalence, odds ratio, resistance, clinical or patient report data), or qualitative data such as interviews to respond to qualitative queries on prescribing attitudes from the clinician or patient perspective. The studies that we excluded were review articles, systematic reviews/meta-analyses, editorials, commentaries, and opinion pieces since we were looking to synthesize primary evidence. Studies were also excluded if there was not enough information around the link between misuse-resistance and specific misuse behaviors, such as detailing misuse patterns without associating them with any specific behavior. Epidemiological and/or clinical relevance to resistance was not required for the research to be included if it was at a molecular level. Finally, due to language and feasibility limits in translation and retrieval of relevant study information from studies written in other than English languages, these were not included.

Study Selection Process

Studies were selected in a systematic and multi-stage process, with an aim of avoiding and being transparent about bias. Following the database search, we first combined all the records into a reference management program called Zotero, and gathered a total of 682 database records. Then 82 of the records were eliminated down as being duplicates and 3 records were eliminated for other reasons (e.g., full text was irretrievable, incorrect document type), which left 597 records for the initial screening phase. These records of a total of 597 were retrieved and screened by the two independent reviewers (both authors) with pre-established inclusion/exclusion. This primary screening was done in a 'blind' fashion in order to minimize bias. At this stage 285 records were cross checked and those records were discarded that were obviously not relevant to the research questions (for instance, antiviral resistance was discussed, plant pathogen-only, or editorials-only, or not experiments). A total of 167 reports were then looked for to retrieve and be evaluated in full text. There were no reports available -- all 167 were retrieved. These were then read independently for eligibility by both reviewers and full text reports were evaluated individually. A detailed analysis of the eligibility criteria included a detailed examination of methods, findings and discussion sections to make sure that the paper provided specific evidence of the relationship between misuse resistance. Of these, 14 reports were dropped because the objective(s) they were addressing made them ineligible, for example, if they addressed only drug use and not resistance data or if the type of misuse studied was not measurable in relation to resistance. Typical reasons for excluding were that there was no measurable relationship between the type of misuse and the resistance data reported (e.g., when they reported only on drug consumption rather than resistance, when they did not clearly classify misuse and resistance, when they did not include any resistance information, etc.).

Interrater rating was high in the screening and eligibility phases and any differences were settled by discussion and/or consultation with a higher-ranking third party rater. All included studies were subject to a critical appraisal using an instrument appropriate to the design of the study. All of the observational studies were analyzed using the Newcastle-Ottawa Scale to determine the items related to selection, comparability and outcome/exposure assessment (Wells et al., 2000). We used the Cochrane Risk of Bias tool for non-randomized studies (Jüni et al., 2016), quasi-experimental and intervention studies. This quality assessment criterion was not employed to exclude studies, or to assign studies to exclusion groups; this criterion was used to highlight the quality of the evidence, which is the more so the lower the quality the more cautious the interpretation of this study. The flow of information during the various steps of the search for studies in the study selection process is displayed in the study-specific flowchart to follow the PRISMA study selection pathway (Figure 1: PRISMA flowchart).

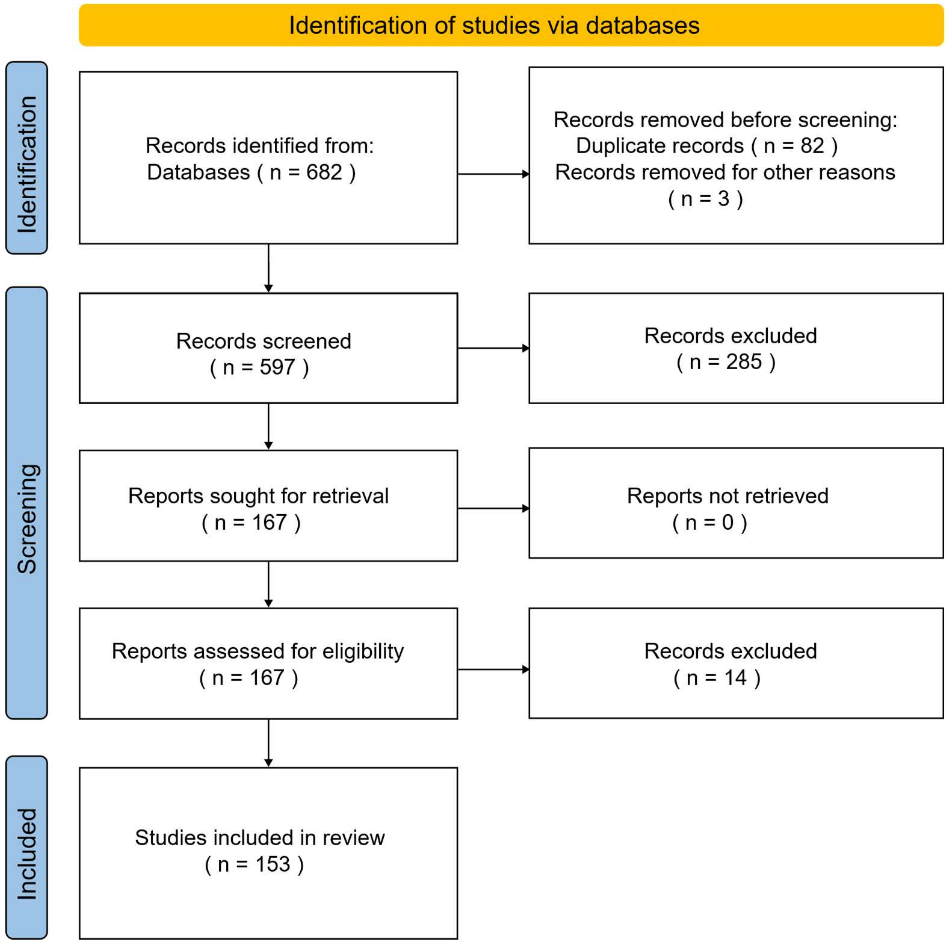

Figure 1. *PRISMA 2020 flow diagram for the systematic review of studies on the association between antibiotic misuse and the development of antimicrobial resistance.*

The selection of the studies was carried out with great attention to detail, but had certain limitations we are aware of that can trigger bias. Secondly, because this search is only for English-language publications, it subjects the search results to a language bias that may miss valuable sources of research for research organizations more easily accessed by researchers in their own language. Secondly, grey literature – such as policy documents and notice to status documents from institutions or governments – might be excluded meaning that valuable real world data around national level interventions will not be gathered. Thirdly, while the search string was highly adapted, some studies with alternative wording of the concept of using an antibiotic "discountersuely" might not have been included. Additionally, although we did our best to standardize the screening process, it was still performed independently, thus resulting in human errors and discrepancies in interpretation among the reviewers. Descriptions of these limitations should be taken into account in interpreting the overall synthesis of the findings.

Results

Drivers and Determinants of Antibiotic Misuse Across Sectors

The findings collated from the studies that were included suggest that antibiotic use in different settings among humans, veterinary medicine, agriculture and community medicine, is not simply one or the other but rather a multifaceted, and interlinked, issue depending on the context. There are three types: bexhavioural, structural, systemic and each of these can have a differential effect on the use of antibiotics, which could be interconnected. The understanding of these determinants will assist with effective and targeted intervention as it is highly unlikely that a single intervention would be effective due to the diversity of causes.

Prescriber attributes are very common in the human health care literature. Misprescribing is one of the most common factors found in research literature about the misuse, and is mostly attributed to the lack of diagnosis, time constraint, and pressure from patients to remain unaffected by time or diagnosis (Saini et al., 2014), (Broom & Doron, 2020), (Darj et al., 2019), (Nair et al., 2023), (Sannathimmappa et al., 2021), (Ahmed, 2019), (Ibrahim & Saber-Ayad, 2012), (Pearson & Chandler, 2019), (Osailan et al., 2021). As one example, antibiotics are routinely prescribed to patients suffering from viral upper respiratory infections by their primary care doctors that have no beneficial effect, and which contribute directly to the selection cycle of bacteria within a human population. This is compounded due to absence of Rapid Diagnostic capacity, and the reliance on empirical treatment strategies, which are increasingly employing broad-spectrum antibiotics (George et all., 2015), (Nair et all., 2023), (Ibrahim & Saber-Ayad, 2012). Additionally, from the socio-cultural perspective of the patient–clinician interaction, the patient might hope for a quick fix (antibiotic), and the clinician might complicate the situation by accepting this option because he/she does not want the patient angry at him/her or to feel that he/she has missed the treatment for his/her bacterial infection (Ahmed, 2019, Vazquez-Cancela et al., 2021). The unregulated sales and dispensing of antibiotics without prescriptions is an increasing trend, especially in areas with non-enforcement of regulations, where patients are easily able to order prepackaged medications from private vendors (Aden & Bashiru, 2022), (Darj et al., 2019), (Mitema, 2009), (Ahmed, 2019). Formal and informal health care providers come together in pharmacists and drug sellers, who are rarely formally prescribed, but can prescribe antibiotics based on symptomology, rather than a formal diagnosis, a common practice in the informal sector of health services in many developing countries (Darj et al., 2019), (Mitema, 2009).

Another major user class are patient and public behaviours, such as self-medication and pharmaceutical misuse by the public, which is the most common misuse worldwide. Self-medication with antibiotics is very high that have been reported in diverse geographical regions like Bangladesh (Islam et al., 2024), China (Wang et al., 2017), (Xu et al., 2020), Egypt (Mostafa et al., 2021), (El-Hawy et al., 2017), India (Aden & Bashiru, 2022), (Nasir et al., 2019), Libya (Dyab et al., 2026), Saudi Arabia (Shatla et al., 2022), (Awadh et al., 2017), and Spain (Vazquez-Cancela et al., 2021). The KAP studies conducted in several countries clearly show that there is a lack of overall knowledge, many having attitudes towards the use of antibiotics for all diseases including common cold and flu, and their willingness to terminate the use of the drug early if symptoms improve (Nasir et al., 2019); (Darwish et al., 2014); (Enechukwu & Saka, 2024); (Banerjee & Raghunathan, 2018); (Vazquez-Canc, 2026); (Dyab et al., 2026); (Osailan et al., 2021); (Mostafa et al., 2021); (Sakeena et al., 2019); (Shatla et al., 20 The misunderstandings present not only in the general population, but also among the university students even those belonging to non-medical departments and is a generalisation throughout the country Mostafa et al., 2021; Wang et al., 2017). Also, socio-economic issues such as poverty and eagerness to use informal care despite not being able to afford consultation fees or the format to receive formal care are other determinants of self medication (Aden & Bashiru, 2022), (Obua et al., 2023), (Islam et al., 2024). Specifically, antibiotic use seems to be more educated in some settings than others, perhaps due to purchasing capabilities (and less in others due to lack of access) so there is a need for context specific analyses, noting the link between poverty and antibiotic use/stewardship is complex (Obua et al., 2023).

Two (main) drivers for difference in Agriculture and Vetmed: use of antibiotics in non-therapeutic context. Highly effective growth promoters (HEGP) also widely used in livestock and poultry, which is banned in many areas, but continues in others, is one of the most important drivers of AMR on a global scale (B. Singh et al., 2024), (Poole & Sheffield, 2013). The term “Sub-therapeutic” refers to giving even antibiotics to healthy animals for long periods, thus promoting the growth and spread of resistant bacteria. Poor veterinary management of the use of antimicrobials, especially for critically important antimicrobials that are used alone or in combination with vaccines, and the routine use of antimicrobials to ward off illness under inapp opriate animal husbandry practices contributes to their overuse in animal production (Smith et al., 2019), (Nukala & Tripathi, 2022). The biggest challenges that people have here are not knowing about antimicrobial resistance's problems, the withdrawal period and the potential for antimicrobial resistance to spread from animals to humans and back. Smith et al. (2019) and Nukala & Tripathi (2022) both went on to discuss this issue. A very troubling aspect is the tendency of AMR to expand the difference between sectors and to facilitate the transfer of AMR along the One Health continuum which is often described as "crossover-use" (Ozeta & Nair, 2017) of antibiotics within humans and animals or vice versa. Chloramphenicol that is used in human medicine though banned for such use in Uganda due to its toxicity, is sold and utilised in animal husbandry a practice which is interferring with human health through the food chain, as in the case of Uganda (McCubbin et al, 2021).

A selection of drivers of use, identified across the sectors and critical to the sector-specific drivers, are displayed, alongside a number of drivers of use that are identified as systemic or global and understood to be fundamental drivers of antibiotic use. While social and economic development play intricate part in (AMP), and AMR is itself a complex system, Malak & Bhattacharyya (2019) believe that there are connections between economic growth of a country and AMR, and that more economic growth equals more (AMP), which equals more AMR. The highly mobile nature of pathogens for travelling and trading makes it easy to spread between countries, in addition to the global connectedness of travelling and trading (Shao et al., 2025); (Chokshi et al., 2019). However, the marine environment has its own unique problems: long journeys, restricted access to medical services, using antibiotics to treat human and animal diseases means a poorly managed situation on board ships (Shao et al., 2025). Also, the issues of politics and regulations play an important role. Weak prescribing regulations, lack of effective antimicrobial stewardship policies, and the impact of the pharmaceutical industry on prescribing practices in many countries gives an opportunity to potentially misuse (Broom & Doron, 2020), (Garg, 2021), (Nair et al., 2023) this medicine. As global crises, both famines and epidemics worsened these systems failures, the Covid-19 pandemic has been a stark reminder of the magnitude of increased antibiotic prescription, even for Covid19 patients who did not have a bacterial co-infection, greatly contributing to the spread of AMR (Garg, 2021). These drivers are multifaceted and a taxonomy (presented in Table 1) has been developed distinguishing them by domain, by category of drivers, by specific drivers and by studies' sources.

Table 1. *Taxonomy of Drivers and Determinants of Antibiotic Misuse Across Sectors*

Domain	Driver Category	Specific Determinant	Sources
Human Healthcare	Prescriber-Related Factors	Inappropriate prescribing practices	(Saini et al., 2014), (Broom & Doron, 2020), (Darj et al., 2019), (Nair et al., 2023), (Sannathimmappa et al., 2021), (Ahmed, 2019), (Ibrahim & Saber-Ayad, 2012), (Pearson & Chandler, 2019), (Osailan et al., 2021)

Domain	Driver Category	Specific Determinant	Sources
		Lack of diagnostic capacity / empirical treatment	(George et al., 2015), (Nair et al., 2023), (Ibrahim & Saber-Ayad, 2012)
	Patient & Public Behaviors	Self-medication & non-prescription use	(Aden & Bashiru, 2022), (Nasir et al., 2019), (Mostafa et al., 2021), (Islam et al., 2024), (Wang et al., 2017), (Xu et al., 2020), (Shatla et al., 2022), (El-Hawy et al., 2017), (Azim et al., 2023), (Dyab et al., 2026), (Awadh et al., 2017), (Sachdev et al., 2022), (Vazquez-Cancela et al., 2021)
		Poor knowledge & awareness (KAP gaps)	(Enechukwu & Saka, 2024), (Nasir et al., 2019), (Darwish et al., 2014), (Akande-Sholabi & Ajamu, 2021), (Mostafa et al., 2021), (Banerjee & Raghunathan, 2018), (Shatla et al., 2022), (El-Hawy et al., 2017), (Sakeena et al., 2019), (Sannathimmappa et al., 2021), (Azim et al., 2023), (Dyab et al., 2026), (Awadh et al., 2017), (Osailan et al., 2021), (Vazquez-Cancela et al., 2021)
		Socio-cultural & socio-economic drivers	(Byrne et al., 2019), (Aden & Bashiru, 2022), (Obua et al., 2023), (Islam et al., 2024), (Ahmed, 2019), (Vazquez-Cancela et al., 2021)
	Health System & Regulatory Failures	Unregulated sale & dispensing	(Aden & Bashiru, 2022), (Darj et al., 2019), (Mitema, 2009), (Ahmed, 2019)

Domain	Driver Category	Specific Determinant	Sources
		Lack of effective stewardship & policy	(Broom & Doron, 2020), (Garg, 2021), (Nair et al., 2023)
	Specific Contexts	COVID-19 pandemic impact	(Garg, 2021)
		Healthcare students & professionals (training)	(Akande-Sholabi & Ajamu, 2021), (Sakeena et al., 2019), (Smith et al., 2019), (Sannathimmappa et al., 2021), (Pearson & Chandler, 2019), (Osailan et al., 2021)
Agriculture & Veterinary	Animal Production Practices	Routine & sub-therapeutic use in livestock/poultry	(B. Singh et al., 2024), (Poole & Sheffield, 2013), (Smith et al., 2019), (Nukala & Tripathi, 2022)
		Misuse as growth promoters	(B. Singh et al., 2024), (Poole & Sheffield, 2013)
	Farmer/Producer Behavior	Poor knowledge of AMR & withdrawal periods	(Smith et al., 2019), (Nukala & Tripathi, 2022)
	Non-Human Environments	Cross-sectoral contamination & “crossover-use”	(B. Singh et al., 2024), (McCubbin et al., 2021)
Environmental / One Health	Global & Systemic Drivers	Socio-economic growth & complex systems	(Malik & Bhattacharyya, 2019), (Obua et al., 2023)
		Poverty and access to healthcare	(Obua et al., 2023), (Islam et al., 2024)
		Global interconnectedness (travel, trade)	(Shao et al., 2025), (Chokshi et al., 2019)
Cross-Sectoral / Integrative	Multi-Sectoral Drivers	Overarching misuse contributing to AMR	(B. Singh et al., 2024), (Nammi et al., 2025), (Al-Zidan et al., 2019), (Otia, 2024), (Garg, 2021), (Mathew et al., 2019), (Sannathimmappa et al., 2021), (Sachdev et al., 2022)
		Global research & policy perspectives	(Sweileh, 2021), (Chokshi et al., 2019),

Domain	Driver Category	Specific Determinant	Sources
			(Broom & Doron, 2020), (Mathew et al., 2019), (Nair et al., 2023)
	Specific Geographic & Population Studies	Community-based studies in specific regions	(Aden & Bashiru, 2022), (Enechukwu & Saka, 2024), (Nasir et al., 2019), (Darwish et al., 2014), (Akande-Sholabi & Oyesiji, 2023), (Mostafa et al., 2021), (Islam et al., 2024), (Wang et al., 2017), (Banerjee & Raghunathan, 2018), (Xu et al., 2020), (Shatla et al., 2022), (El-Hawy et al., 2017), (Azim et al., 2023), (Dyab et al., 2026), (Awadh et al., 2017), (Vazquez-Cancela et al., 2021)
		Maritime & unique settings	(Shao et al., 2025)

In terms of levels of problems, the taxonomy given in tabular Table 1 highlights this: Clearly, there are one or more measures that will not be able to cover all these drivers. It may be less effective to have an education campaign designed to promote awareness, if the problem is that people are able to access antibiotics more easily and are purchasing antibiotics from informal providers more frequently. In similarly, no one would imagine that it is feasible to ban growth promoters used in ag when the questions people have about the diagnosis are similarly high in humans. However, (Al-Zidan et al., 2019), (Nammi et al., 2025) and (Otia, 2024)'s literature reviews provided general, overarching recognitions of AMR as a global public health crisis that requires concrete research and an agenda toward policy action to reduce AMR. This is particularly enlightening because (Byrne et al., 2019), presented a pragmatic measure of the community based on a theory process that has moved beyond simple KAP-surveys, and one step towards measuring the themes and norms within the community that drive a person's behavior. This study, combined with the research on the topic carried out by (Akande-Sholabi & Oyesiji, 2023) regarding the factors that encourage the use of non-recommended side effects as identified in Nigeria healthcare system and (Mathew et al., 2019) which examined communicative strategies to address the non-recommended side effect of medicines among Nigeria's consumers in the community pharmacies, agrees that such drivers are not limited to informational gaps but extend to the social and cultural practices, beliefs and the structure of the healthcare system that the public within a specific country use. Further, by adding the example of the Iraqi community in Jordan (Darwish et al. 2014), and also the slum communities in Karachi (Nasir et al. 2019), it is evident that even the overall classifications of drivers are universal, but occur and are more or less important in different periods and situations. These are all very different from Assad in terms of approach to intervention, whether in the clinical context or the regulatory framework or in terms of the needs of the person and the global economy.

Mechanisms, Epidemiology, and Clinical Burden of Antimicrobial Resistance

Understanding the biological mechanisms that underlie the clinical expression of antimicrobial resistance is a complex process that involves molecular genetic mechanisms, population ecology and clinical epidemiology. In basic terms, when an antibiotic is deployed, it can create a high selection pressure with the super seeds with mutation conferring resistance on the bacteria multiplying as the mutation is spread through the population (Prestinaci et al., 2015), (Jindal et al., 2015) and (Holmes et al., 2016). It is located in the human body, as well as in strains of animals and environmental conditions, where it can be able to horizontally transfer resistance genes from one host to another one, either through mobile genetic element like plasmid and transposon (Rosenblatt-Farrell, 2009) (Brinkac et al., 2017), or directly to another host (Aruković et al., 2019). This intensive antibiotic usage gives rise to the resistance among the pathogen under selection, but creates an environmental resistome (pool of antibiotic resistance genes in soil, water, and commensal microbiome) which can provide resistance to clinically significant pathogens (Abushaheen et al., 2020; Brinkac et al., 2017). Understanding these mechanistic pathways is important to improve awareness of the relevance of the association between misuse and resistance and how this might mean that the sole aim of human use reduction may not be effectively.

Sometimes more extreme than the geographical differentiation, the burden of antimicrobial resistance as recorded in the studies included in this document is evident in the epidemiological picture, and is closely connected to the consumption of antibiotics. There is indirect data available at the national level relating to the use of antibiotics and level of resistance in the country such as Global surveillance system GLASS system (Ajulo & Awosile, 2024), but this may be complicated by different levels of control over infections, sanitation/hygiene and health care or service delivery infrastructure within countries. Significant resistance level has been reported by different resistance studies carried out by the researchers in other high-density countries such as China (Yezli & Li, 2012), India (Sharma et al., 2023) and Pakistan (Shaikh, 2017) and (Abdalla, 2011) which was reported for common pathogens with resistance rate over 50% in some cases. Some of the contributing factors that cause high Prevalence of methicillin-resistant Staphylococcus aureus (MRSA) and extended-spectrum beta-lactamase (ESBL)-producing enterobacteriaceae in South Asian and Middle Eastern countries include: high antibiotic use rates, lack of proper antibiotic usage practices, poor infection control measures, and OTC availability of antibiotics (Aly & Balkhy, 2012); (Shaikh, 2017); (Sharma et al., 2023). Some multidrug-resistant azole-resistant pan-drug resistant strains like Zinzanations of Acinetobacter baumannii and Pseudomonas aeruginosa created a dilemma for clinicians; leaving them with few treatment options against infections (Abushaheen et al., 2020) (Rosenblatt-Farrell, 2009). Such epidemiology has brought to light the urgency of this situation and emphasized the need to develop countermeasures to address development of resistance.

The implications for antimicrobial resistance in terms of morbidity, mortality and cost of health services are immense: Stretched health systems are increasingly under strain. It was seen that perceived hospital stay duration, treatment failure percentage and mortality rate was significantly higher in the patients with MDRO infections (Gautam, 2022), (Zhu et al., 2022), (Dadgostar, 2019) than the patients with infection from conventional organisms. It is particularly placed on the weaker individuals – neonates in a low resource setting, suffer from sepsis secondary to pathogenic organisms that are resistant to treatment, and patients in intensive care units, who are susceptible to opportunist infection due to their low immune status and recently due to invasive devices; (Chaurasia et al., 2019) and patients in intensive care units, who are susceptible to opportunist infection due to their low immune status and recently due to invasive devices (Harbarth et al., 2000). Economically, the impact of AMR is also massive, as sick leave leading to loss of productivity, premature deaths, and increased costs for more expensive secondary treatment and use of third line antibiotics that tend to be more toxic are all indirect economic losses suffered by AMR antibiotic resistance (Dadgostar, 2019), (Al-Zidan et al., 2019). This isn't just in hospitals, where bacteria - such as ESBL producing Escherichia coli (E. coli) and drug resistant Streptococcus pneumoniae (S. pneumoniae) - require antibiotic drugs known as 'reserve' antibiotics to deal with them, even in Primary care settings (Paul, 2018), (Harish & Menezes, 2011). We present a wide taxonomy in Table 2 to systematically organise the evidence presented on these mechanisms and patterns as well as clinical outcomes included in the studies.

Table 2. *Taxonomy of Mechanisms, Epidemiology, and Clinical Burden of Antimicrobial Resistance*

Dimension	Sub-Dimension	Specific Focus	Sources
Mechanisms of Resistance	Genetic & Molecular Mechanisms	Genetic alterations, intrinsic vs. acquired resistance, and resistance gene dissemination	(Holmes et al., 2016), (Aruković et al., 2019), (Rosenblatt-Farrell, 2009), (Abushaheen et al., 2020), (Brinkac et al., 2017)
	Drivers of Resistance	Selection pressure from antibiotic misuse in humans, animals, and agriculture	(Poole & Sheffield, 2013), (Prestinaci et al., 2015), (Jindal et al., 2015), (Economou & Gousia, 2015), (Robinson, Wertheim, et al., 2016), (Rosenblatt-Farrell, 2009), (Abushaheen et al., 2020)
Epidemiology of Resistance	Global & Regional Burden	Global surveillance, regional prevalence, and country-specific challenges	(Sharma et al., 2023), (Abdalla, 2011), (Osman et al., 2019), (Yezli & Li, 2012), (Ajulo & Awosile, 2024), (Zowawi, 2016), (Shaikh, 2017), (Aly & Balkhy, 2012), (Abdelmoneim et al., 2024)
	Pathogen-Specific Resistance	Resistance profiles in key bacterial pathogens (e.g., *E. coli*, *Salmonella*, *S. aureus*, *Streptococcus*)	(Reinert, 2009), (Vital et al., 2017), (Kanaan, 2023), (Harish & Menezes, 2011), (Paul, 2018), (Pesavento et al., 2007), (Biadglegne & Abera, 2009), (Dutta et al., 2021), (Koluman & Dikici, 2013), (Nguyen et al., 2016), (Ndip et al., 2008), (Ochoa et al., 2009)
	Sector-Specific Epidemiology	Resistance in healthcare, community, food animals, and food products	(Jindal et al., 2015), (Larson et al., 2007), (Robinson, Wertheim, et al., 2016), (Vital et al.,

Dimension	Sub-Dimension	Specific Focus	Sources
			2017), (Nelson et al., 2019), (Ajulo & Awosile, 2024), (Harbarth et al., 2000), (Aly & Balkhy, 2012), (Dessinioti & Katsambas, 2022), (Ranasinghe et al., 2022), (Patel et al., 2019), (Izydorcyzk & Church, 2026), (Chaurasia et al., 2019), (Gawad et al., 2023)
Clinical Burden & Implications	Economic & Health Impact	Costs of resistance, implications for treatment failure, and public health threat	(Dadgostar, 2019), (Mah & Memish, 2000), (Zhu et al., 2022), (Al-Zidan et al., 2019), (Gautam, 2022), (Sutton & Ashley, 2024)
	Impact of COVID-19	Acceleration of AMR during the pandemic	(Abdelmoneim et al., 2024), (Hsu, 2020), (Gawad et al., 2023)
	Clinical Practice & Stewardship	Antibiotic stewardship, prudent use, and infection control to mitigate burden	(Jindal et al., 2015), (Nicolini et al., 2014), (Larson et al., 2007), (Harbarth & Samore, 2005), (Abushaheen et al., 2020), (Harbarth et al., 2000), (Patel et al., 2019), (D. Graham et al., 2021)

A kind of addenda are important research studies called to attention here which otherwise would just not be so listed in the categories as mentioned in Table 2. Poole & Sheffield, 2013 looks at the resistance mechanism level of antimicrobial use and misuse in agriculture and gives a concept of how and why antimicrobial use in animal husbandry protects humans as well as farm animals. Likewise, the report on agriculture and food animals as a source of antimicrobial-resistant bacteria by (Economou & Gousia, 2015) makes clear that there is a dissemination issue as well as a selection issue; with resistant bacteria and their resistant genes lingering in agriculture after antibiotic usage has stopped. Beyond selection, the review of Aruković et al., 2019, is focused on the molecular mechanisms that underlie how sub-inhibitory concentrations of antibiotics can lead to the selection of bacterial genetic changes that can result in greater evolvability of antibiotic resistance. The studies by (Dadgostar, 2019) and (Al-Zidan et al., 2019) were particularly informative with regard to the effects and costs of AMR awareness, allowing them to highlight the human and cost implications and the undeniable importance of AMR as a looming crisis that needs the coordinated effort and intervention of all parties concerned. The clinical study by (Robinson, Wertheim, et al., 2016) on Animal Production and Antimicrobial resistance makes it clear that clinical AMR is not exclusively and inevitably linked to hospital stewardship efforts, but transitioning away from the use of medically important antibiotics in animals is a threat to it. Since antimicrobial resistance mechanisms are different, their mechanisms can differ in the laboratory and consequently on the patient's bedside where the effect in treatment failure can be different. The study (Abushaheen et al., 2020) bridges the gap between the laboratory and the bed, and elucidates the mechanisms of antimicrobial resistance and its contribution towards failure of therapy and resistance of some drugs to certain infection. The empirical evidence from across the globe on antibiotic information collected through surveillance programs (Ajulo & Awosile, 2024) also suggests that a relationship exists between the prevalence of drug resistance and extent of antibiotic use, but one that is non-causal, and influenced by other factors such as sanitation and infection control. Various reasons such as increased use of antibiotics during COVID-19 pandemic and the disruption of healthcare services and routines of infection control were identified as contributing to the high level of AMR to different extents in the pandemic (Hsu, 2020) and (Gawad et al., 2023). Finally, some studies have specifically studied AMR to a pathogen, such as Salmonella (Harish & Menezes, 2011); Campylobacter (Nguyen et al., 2016) and Vibrio (Dutta et al., 2021), highlighting the vast number of different AMR mechanisms and the epidemiological pattern, and that AMR is not a single problem but rather many pathogen-specific problems, and a greater need than ever for targeted surveillance and intervention approaches.

Socio-Economic, Ethical, and Political Dimensions of Antimicrobial Resistance

Hence we can conclude that the issue of antimicrobial resistance goes beyond the biological/ clinical aspects, and becomes a huge socio-economic, ethical and political challenge. The overall results of the studies included show that inequalities in status, power, access to resources, as well as different principles of morality and poor governance are important drivers of AMR and its geographical distribution, and a key determinant of response. It is the size of the dimensions that is crucial in overcoming all Biomedical interventions and even in shifting to a more holistic, more just and more sustainable approach.

There are numerous and complex socio-economic concerns on AMR. Malik and Bhattacharyya (2019) describe a non-linear and complex relationship between positive economic development and decreased antibiotic misuse, concluding an increase in socioeconomic development can lead to an increase in antibiotic usage, with only this increase able to lead to a better regulator and stewardship for increased AMR. Poverty in some low- and middle-income countries (LMICs) makes people more vulnerable to infections and exposes them more to purchasing substandard, counterfeit, or stocked-out antibiotics in informal markets; the vicious cycle that emerges is that they purchase these substandard products to treat infections, which in turn leads to further poverty (Ehsan, 2025), (Nweneka et al., 2009), (Sorn, 2026), (Sosa et al., 2010), (T. Ali et al., 2024), (Dadgostar, 2019). This is compounded by that very LMICs also suffer from a higher burden of AMR related mortality and morbidity even though these efforts expend less per capita antibiotics usage than high-income countries, which is explained by poor infection control, lack of diagnostic capacity, and weak healthcare infrastructures (Sorn, 2026), (Ehsan, 2025), (T. Ali et al., 2024). Besides, AMR is likely to be passed between different countries and populations very rapidly since there is no single protection against AMR given the international dimension of trade and travel (Adebisi, 2023); (Aijaz et al., 2023); (Thornber & Pitchforth, 2021); (Robinson, Bu, et al., 2016). Interlinkages between human, animal and environmental health are important in regard to AMR for instance, exposure to antibiotics and resistance genes in the human and animal health systems can be transmitted to the environment through food chains, water bodies and people to people interaction (Alhassan & Ahmad, 2025; Fletcher, 2015). Females in this context are also exposed to greater risk and have less access to health services than men and their quest to seek health services and use of antibiotics is different (Batheja et al., 2025). Similarly, the inclusion and exclusion of marginal groups like refugees, indigenous peoples and people who live in conflict zones are differential and unequal, leaving these groups invisible in AMR policy, while also making them vulnerable (Adebisi & Ogunkola, 2023). Armed conflict has a catastrophic effect on AMR, as noted by

(Jumba, 2026), which outlines the dramatic changes in antibiotic circumstances that occur during war, such as health system malfunctions, unregulated use of antibiotics on the battlefield and loss of infection control in field hospitals.

One of the challenging tasks of AMR is to the moral challenges and provoke an emotional question why is there no cure for the crisis? The outputs are generally presented as the “tragedy of the commons”, in which the individual user benefits immediately; and the increase and dispersal of resistant organisms have longer delayed effects with large acreage of customers whose costs are being sold. (Conly, 2010) This creates an important ethical dilemma on the one hand about benefiting each individual patient and the non-maleficence on the other hand concerning any future patient that may discover that a world of diminished, reduced and reduced effective treatment exists (Littmann & Viens, 2015), (Adebisi, 2023). Such a large number of unnecessary prescriptions of antibiotics in this setting are an example of intergenerational injustice—a shared resource is being used up by current generations that deprives future generations. The multiborder nature of the issue, which means that there are likely to be distributive justice and liability issues related to the effectiveness of antibiotics in one country as a result of consumption and prescribing within another country adds to this competition (Roope et al., 2019), (Lomazzi et al., 2019). Moreover, a general guideline to not prescribe an antibiotic when one is not warranted—from a population point of view an ethical course of action—can be difficult for those clinicians facing the pressure of a sick individual in need of Rx with the abstract risk of resistance playing a secondary part (Hooton & Levy, 2001). This is because the emphasis on AMR is on the situation of the person using antimicrobials and not on the structural/systems level drivers that lead to misuse of antimicrobials rendering those with the least capacity to do so. Instead of the 'patients and prescriptions' approach, it was now a different ethic: respect for man in the context of respecting people's health, and an equity approach; solidarity/cooperation approach with the rest of the world; and institutional/ governmental approach.

To understand why, despite decades of warnings and AMR action plans, AMR continues to escalate, political and governance elements are extremely important in the analysis of AMR. The study reveals that some countries have not developed comprehensive policies governing antibiotic usage, had weak prescription-only drug policy enforcement and had not strong drives for exploring new antibiotics (Mendelson & Matsoso, 2015), (Shelke et al., 2023), (C. Graham, 2017), (Williams, 2016), (Haldar, 2023), (Krishnaprasad & Kumar, 2024). While the Global Action Plan on Antimicrobial Resistance (GAP-AMR) is a broad strategy which can be used to inform national strategies, the step for implementation was found to be lacking with weak capacity building, technical know-how and political will to enact an effective AMR policy in many LMICs (Mendelson & Matsoso, 2015), (Shelke et al., 2023). According to (Wallinga et al., 2015) the following “biological governance” aspects are responsible for the lack of coordination of government action at all levels: The complexity and obscurity of the problem; the absence of a clear political group in the field. This further limits the problem she faces to the choice of the individual with current accounts of AMR being presented as individual problem rather than a structural problem as noted by (Chandler, 2019). On the national scale, this is exemplified by cases of significant change coming from policy advocacy and professional mobilisation, such as the ones in Broom & Doron (2020) in India, or the Chennai Declaration (Ghafur et al., 2013); efforts for change in these cases are less organised and do not receive political support over time. In Asia interdependency of various healthcare systems and cultural background is described by Song (2015) who indicates that coordination of collective action is hard because they are interdependent. Legally and from a public health perspective, there is a need for some strong responsive policies and accountability measures including: (1) restrictions on unrestricted sale of Antibiotics over the counter; (2) mandating reporting of drug use and resistances; (3) drug development incentives and diagnostics (Nwakoby et al., 2025). Furthermore, external factors, such as global events – including pandemics –

may affect AMR governance and participation in AMR programmes, decrease resources spent on AMR and increase lack of regulation of antibiotic use which may facilitate the emergence of AMR (MacIntyre & Bui, 2017). Furthermore, the political economy of AMR also includes the role of the pharmaceutical industry, which in spite of its potential for developing new antibiotics has not traditionally found the market highly attractive especially in comparison to chronic disease drugs, and requires some push incentives and public-private partnerships (PPPs) through government support (Krishnaprasad & Kumar, 2024), (Williams, 2016). The studies presented in this report have been detailed and placed in a systematic class based on their socio-economic, ethical and political themes in a specific manner as can be seen in Table 3. Two relevant papers, which expand on this discussion, are highlighted: Prestinaci et al (2015) looking at going beyond the human health sector in addressing AMR, and Thornber & Pitchforth (2021) on communicative strategies. This description of the governance picture given here comes best from yet another report by Desai et al, (2025) on the problems, effects, and response regarding AMR on a global scale.

Table 3. *Taxonomy of Socio-Economic, Ethical, and Political Dimensions of Antimicrobial Resistance*

Dimension	Thematic Area	Specific Focus / Sub-Theme	Sources
Socio-Economic Dimensions	Economic Drivers & Impacts	Economic growth and development as a complex driver of misuse	(Malik & Bhattacharyya, 2019), (Dadgostar, 2019), (Roope et al., 2019), (Sosa et al., 2010), (Nweneka et al., 2009), (Sorn, 2026), (Ehsan, 2025), (T. Ali et al., 2024)
		Globalization, trade, and the One Health paradigm	(Adebisi, 2023), (Aijaz et al., 2023), (Thornber & Pitchforth, 2021), (Robinson, Bu, et al., 2016), (Alhassan & Ahmad, 2025), (Fletcher, 2015)
		Poverty, inequality, and access barriers in LMICs	(Dadgostar, 2019), (Sosa et al., 2010), (Nweneka et al., 2009), (Sorn, 2026), (Ehsan, 2025), (T. Ali et al., 2024)
		Gender inequities and their influence on AMR	(Batheja et al., 2025)
		Marginalized populations and exclusion from policy	(Adebisi & Ogunkola, 2023)
		Conflict and war as amplifiers of AMR	(Jumba, 2026)
		Environmental factors in the spread of AMR	(Alhassan & Ahmad, 2025), (Fletcher, 2015)

Dimension	Thematic Area	Specific Focus / Sub-Theme	Sources
Ethical Dimensions	Collective Action & Common Goods	The tragedy of the commons and collective action failure	(Conly, 2010)
		Balancing individual benefit vs. societal risk	(Adebisi, 2023), (Littmann & Viens, 2015), (Hooton & Levy, 2001)
		Intergenerational equity and responsibility	(Littmann & Viens, 2015)
		Distributive justice and global health equity	(Roope et al., 2019), (Lomazzi et al., 2019)
Political & Governance Dimensions	Global Action & Policy Frameworks	WHO Global Action Plan and international coordination	(Walsh et al., 2023), (Mendelson & Matsoso, 2015), (C. Graham, 2017), (Shelke et al., 2023), (Haldar, 2023), (Krishnaprasad & Kumar, 2024), (Williams, 2016)
		National and regional policy responses	(Broom & Doron, 2020), (Ghafur et al., 2013), (Song, 2015)
		Legal frameworks and regulatory enforcement	(Nwakoby et al., 2025)
		Policy failure, governance challenges, and individualization of the problem	(Wallinga et al., 2015), (Chandler, 2019)
		Impact of global crises (e.g., pandemics) on governance	(MacIntyre & Bui, 2017)
		Healthcare system strengthening in LMICs	(Sorn, 2026), (T. Ali et al., 2024), (Hooton & Levy, 2001)
		Communication, awareness, and stewardship strategies	(Prestinaci et al., 2015), (Thornber & Pitchforth, 2021), (Haldar, 2023), (Hooton & Levy, 2001), (Krishnaprasad & Kumar, 2024)

Dimension	Thematic Area	Specific Focus / Sub-Theme	Sources
		The post-antibiotic era and future threats	(Lomazzi et al., 2019), (Desai et al., 2025), (Williams, 2016)

For instance, the AMR crisis's socio-economic, ethical and political shades are illustrated in the Taxonomy in Table 3 and are mutually entangled and given to different spectra of intensity. The studies in this report all show that, not only do biomedical innovations need to address the problem of AMR, but there is a need for a re-thinking of how healthcare is organised, resourced and governed globally. There is significant evidence of the massive expansion of awareness leading to less robust action on AMR: however, the following work – for example (Ghafur et al., 2013) – provides a real-world example of how, even with significant increase in national awareness, multistakeholder engagement and professional advocacy can lead to political and economic policy shifts on AMR. To save the future generations from a post-antibiotic era is an “ultimate challenge” for scientists, healthcare professionals and policymakers, writes (Desai et al., 2025). Focus on strengthening healthcare systems in LMICs, as expressed by (Sorn, 2026) and (T. Ali et al., 2024), highlights that they need to attack issues of health system structuring to systemic weaknesses if antibiotic misuse reduction efforts are to be superficial. Gender is an essential lens as highlighted in (Batheja et al., 2025), but rarely used in studies of exposure to infection, antibiotic uptake, and antibiotic behaviour, by genders. Secondly, the intervention of the focal population or some of the stakeholders mentioned in (Adebisi & Ogunkola, 2023), (Jumba, 2026) etc., should not be limited as the most affected population in the story of the refugees. Breakthroughs outlined in (Nwakoby et al., 2025) do exist for them to break through and implement legally steps like introducing and using Over The Counter (OTC) antibiotics and reporting the resistance cases. The two studies conducted jointly by (Wallinga et al., 2015) and (Chandler, 2019) offer a way to reflect on the present policy response, which has tended to be predominantly focused on the stabilisation of existing (if imperfect) power relations; and on going beyond individual agency to scale up change.

Antimicrobial Stewardship, Education, and Behavioral Interventions

An effective antimicrobial stewardship (AMS) program, along with robust efforts and educative and behavioral interventions, is the most direct operational solution to the issue of antibiotic misuse and the subsequent emergence of resistance to antibiotics. Each of the studies examined employed a variety of strategies, from communicating with the general population about a particular message to highly politically-healthcare oriented stewardship programs with several component messages. But the evidence also shows there is significant difference in effectiveness at meeting the stated aims of these interventions, and the impact of context, structure and behaviours on the effectiveness as outlined in the previous sections.

Studies have shown that educational interventions that address healthcare providers and the general public have been a key part of the strategy to tackle antibiotic misuse; however, the success of such interventions is often seen as being lacking when used as stand-alone strategies. The latter contain several studies on analysing and improving knowledge, attitudes and practices (KAP) of a certain group of people in our corpus. For instance, baseline knowledge and awareness regarding AMR among healthcare students in Nigeria demonstrated gaps in knowledge and awareness of the AMR resulting in targeted educational programmes to fill the gaps. Similarly, Orok et al. (2025) conducted a pre- and post-test study, which demonstrated that teaching antimicrobial resistance awareness among HCPs is possible to enhance students' knowledge of the phenomenon and adaptive strategies to antibiotic use, although this may not ensure lasting changes to antibiotic use in the healthcare industry. The efficacy of an education stewardship program aimed at assisting pharmacists was assessed in a primary care study conducted by Bizri et al. (2026) which found pharmacists' knowledge of AMR and stewarding actually increased following an educational stewardship program, but noted that increases in knowledge did not necessarily equate to the changes in dispensing practices noted, where economic and political pressures against prescription-only rules remained. This highlights an important limitation of education alone as a strategy to combat misuses: Although important and necessary for education, it is not sufficient for the systemic factors that contributes to and perpetuates such misuse, such as prescribing rates if financial incentive available, diagnostic uncertainty and patient demands.

A more integrated and effective way to AMS requires more than education to structural/behavioural changes in health care systems that can involve elements of policy enforcement activities, diagnostics and seeking feedback. A number of such comprehensive plans are presented in the literature. Public and clinician education are community level interventions that can see modest impacts in reducing inappropriate use of antimicrobials, especially in conjunction with awareness raising campaigns, according to a Uchil et al. (2014) review, but these impacts will vary by context. But in paediatric care, antimicrobial stewardship will need a sensitive treatment, accounting for the fact that some infections, such as those of viruses, are more frequent, and that doses of specific medicines are required in children differently from adults (Principi & Esposito 2016); moreover, the involvement of parents in antimicrobial decisions must be carefully implemented. Reduction of antimicrobial resistance through AMS Khadse et al. (2023) is fundamental tenet of the AMS paradigm but the evidence base for a correlation between 'AMS interventions' and ‘decreases in antimicrobial resistance rates' is not consistent nor is it easy to interpret, due to the long-term, population-level nature of the problem of antimicrobial resistance. More interesting is the qualitative study by India Nair et al. (2023) which calls for interventions to be based on structural alignment in primary healthcare settings as part of the existing disease control programme – and not just to get patients and clinicians to do all the work of behaviour change. This view is attainable on the basis of another study carried in the community pharmacy of Nigeria by Akande-Sholabi & Oyesiji (2023) which found that education programmes addressing the prescribers or antimicrobial consumers must be coupled with stringent regulation of practice of Pharmacy to achieve the desired drug safety.

Most literature provides policies and national action plans (NAPs), representing the greatest amount of structure intervention with AMS. In India's strategic context, however, not just misuse and overuse, but underuse because of lack of access is a prevalent problem, while new antibiotics can quickly become ineffective if not used appropriately – a review of India's NAP for antimicrobial resistance (AMR) Ranjalkar & Chandy states this. To prevent AMR within the public health sector, AMR should be recognised as a public health issue, and clinician communication efforts regarding the issue of appropriate prescription should begin. AMR Hooton & Levy (2001). In this study Tang et al. (2016) provide the government with options for policies and medical practitioners with advice on preventing anti-bacterial resistances, clearly stating that antibiotic resistance requires coordinated action to reduce the "no time to waste" urgency to act. Within the Eastern Mediterranean region, Nashwan et al., (2024) have recently highlighted the importance of taking the One Health approach at the national level, using the stewardship programmes. Last but not least, the qualitative systematic literature review by Balea et al. (2025) aimed to analyse the barriers and facilitators of patient education by healthcare professionals (HCPs) on antibiotic use and antibiotic resistance (AMR) in primary care settings also saw the need for HCPs to be trained not only on the technical side of AMR but also in communication skills in order to manage patient expectations and social dynamics in the course of the consultation. In another included study, Mathew et al 2019 discuss the communication strategies needed to increase public awareness of appropriate antibiotic use – this paper proposes that to bridge the gap between public knowledge and behaviour, more sophisticated knowledge of audience segmentation and message framing is needed.

The interventions illustrated in the table are classified into four intervention focus areas, which are the fourth level of analysis in the intervention matrix, listed in the domain of intervention: energy (table 4 domain 1), education (table 4 domain 2), behavioral (table 4 domain 3) and The/ms: energy, education, and behavioral (table 4 domain 4).

Surveillance Systems, Data Analytics, and Digital Health Solutions

Implementing robust surveillance systems, understanding the trends in the use and resistance of antibiotics and using the latest tools in data analysis and digital health to do so is a vital part of any strategy to address AMR. If interventions are to be both proactive and preventive, effective, timely, and detailed information about the rates and extent of misuse—including the extent of misuse, where and how, and why—of antibiotics is essential, along with relevant and timely data about when and where resistant pathogens start to emerge and spread. The studies included emphasize a variety of possible solutions from international and standardized monitoring and reporting systems to different methods of data collection, integration and making data into actionable policy on a subnational level.

The World Health Organization's Global Antimicrobial Resistance and Use Surveillance System (GLASS) is the largest international initiative to facilitate standardisation of data collection, analysis and sharing of AMR data among the member states at the global level. The GLASS initiative (Ajulo & Awosile, 2024) used a recent analysis of the relationship between the national level of AMR and AAMS, revealed that the national level of antibiotic use has been correlated with higher prevalence of AMR of the major bacterial pathogens, except where there was no confounding effect of national income, healthcare facility and infection control indicators. The study highlights the importance of this aggregated surveillance data for global trends and prioritising interventions, but also calls on a lack of representation in the analysis for LMICs, differences in laboratory methods and the time delay between data collection and reporting. These blind spots hinder in detecting threats in progress and in responding proactively. Together, these two studies bring our understanding of the global burden of antimicrobial resistance (AMR) more comprehensive and varied: a global perspective and a methodological framework to quantify the impact of AMR in purely epidemiological terms of attributable deaths and disability adjusted life years (DALYs), as well as the economic costs to society (Hay et al., 2018). But the burden mapping approach is essential to advocacy and resource allocation – that is, turning survey statistics into a good story and helping to move the conversation to the level of politics.

Unlike the current computerization of laboratory-based surveillance, the use of digital innovations and multi-source analytics for digital health holds the potential to be another paradigm shift in how the sub-optimal, granularity and timeliness limitations of traditional surveillance systems can be overcome. One comprehensive and forward-looking study (Asamoah 2022) proposes a conceptual framework that could be adopted to track new AMR in real-time globally, with the support of multi-source data analytics. The method does not depend on the clinical microbiology report alone, but combines data from a comprehensive and wide range of non-traditional sources, such as information in social media sites (Twitter, Facebook), online news and information retrieval services (Google, scholarly searches), and digital information about the pharmaceutical supply chain. Suscious trend in infections, outbreaks or reports of inappropriate antibiotic use is often communicated in these digital channels days or weeks ahead of the event officially being documented in a health system for example through reports of counterfeit medications, of certain antibiotics being out of stock or anecdotes showing why an infection was not treated with the standard antibiotic. From the data streams, these attributes can be used to make statements in near real-time about potential resistance mechanisms or possible AMR hotspots using natural language processing, machine learning algorithms and anomaly detection methods. An algorithm that can identify such an escalation – could be an antibiotic resistant persistent UTI report for example, or a news report on a factory that throws antibiotic effluent into a watercourse – could trigger an automatic notification to public health officials to initiate an investigation. The authors acknowledge the large number of potential barriers to an early event, such as concerns about data privacy, concerns about a bias problem with algorithms, excessive false alarms in systems, and the need to test and validate systems with traditional surveillance for safety before deployable in a decision making process.

The creation of a national and/or sub-national platform for surveillance or policy aimed at addressing local trends of antibiotic misuse at a level that is relevant within the context of the country/region. A few studies focus on a specific national scenario to show and present the challenges of antibiotic use. Furthermore, a recent study (Lawal et al., 2025) recommends that digital surveillance measures be used to help curb resistance as a Nigerian "double trouble" of high rates of ICDs and high levels of OTC antibiotic availability and regulatory leniency demands innovative surveillance solutions. This proposed model can collect data from all community pharmacies, patent medicine shops and community primary health centers and hospitals laboratories in one database on a common electronic dashboard and allows for real-time monitoring of antibiotic consumption, real-time trends in the number of antibiotic sales, prescriptions, and reported resistance. This granular data which is the data from the lowest point is crucial to pinpointing the local factors which contribute to misuse in each community in Nigeria and testing the results of targeted interventions. A second complementary policy analysis (Egberi et al., 2025) envisions an interconnected landscape of AMR (ASM) policies and programmes in Nigerian cities and considers a shift in focus from responding to a crisis to proactively managing AMR through appropriate policy administration, informed by the live signal microscopy provided by AHRF's surveillance algorithms and Nigeria's AMR data. Such a prophylactic approach calls for political commitment, proper financing as well as local health workers' training in data collection and interpretation. The framework identifies the importance of integrating surveillance with existing disease control programmes such as malaria, TB and HIV programmes to allow a more complete picture of infectious disease burden and of the uses of antibiotics among urban populations to be developed.

However, good surveillance needs to be underpinned by public awareness and involvement, as the issue will not be solved with digital surveillance alone, without an enabling social and professional environment. Please read Clean atmosphere with respect to AMR week 2023: a narrative from AMR in Preventing antimicrobial resistance together (MRPAT; Al-Tawfiq et al., 2024) acknowledging the importance of a 'One Health' perspective on tracking and surveillance—collecting data on antimicrobial resistance from humans, animals and the environment. The aim of a digital platform is to inform experts about AMR; in the conclusion this piece suggests they should be a data repository, preferably divert attention to the public, healthcare professionals and policy-makers in a common understanding of the AMR crisis. For instance, local dashboards made public to show local antibiotic resistance rates, and antibiotic prescribing patterns, could help raise questions among patients and drive accountability among antibiotics prescribers. Also, social media campaigns using real-time surveillance data could be useful to raise awareness about incorrect use of antibiotics and instill good practices. Its success is bound up within the wider communication and behaviour change strategy, as well as its technical sophistication. Within the commissioned work in this theme, a taxonomy has been developed, which organises the variety of approaches and tools used into a tabular form, shown in Table 4. This table specifies the studies and categorises them by key attribute of the surveillance (perspective) the type of data (source and method) and application/scope, and further identifies each of the listed studies.

Table 4. *Taxonomy of Surveillance Systems, Data Analytics, and Digital Health Solutions for AMR*

Dimension	Data Source & Method	Application & Scope	Sources
Global Surveillance Systems	Aggregate Health Data & Reports	National & international burden mapping and trend analysis; quantifying attributable deaths and economic costs of AMR	(Ajulo & Awosile, 2024), (Hay et al., 2018)
	Standardized Laboratory Data (GLASS)	Investigating the relationship between national antibiotic consumption and resistance rates; identifying global trends and priorities	(Ajulo & Awosile, 2024)
Multi-Source & Real-Time Analytics	Social Media, News Reports, Online Forums, Supply Chain Data	Near real-time detection of outbreaks, unusual infection patterns, and signals of antibiotic misuse; application of natural language processing and machine learning	(Asamoah, 2022)
Regional & Contextual Surveillance	National Digital Health Platforms	Addressing antibiotic misuse in specific country settings (e.g., Nigeria) through integrated dashboards and local data tracking	(Lawal et al., 2025), (Egberi et al., 2025)
	Policy & Governance Frameworks	Transitioning from crisis response to preventive administration of AMR management in urban centres; integrating surveillance into existing disease control programs	(Egberi et al., 2025)
Public Engagement & Collaboration	Public Awareness Campaigns (e.g., AMR Week)	Reflecting on collaborative prevention efforts; advocating for a One Health approach to surveillance and public engagement in digital platforms	(Al-Tawfiq et al., 2024)

Table 4 draws attention to a key approach change in the landscape; from a practice-driven-oriented surveillance approach to a predictive and participatory approach. The research papers all stress the value of traditional surveillance techniques, like GLASS, as an effective means of tracking longer time horizons and establishing an international benchmark, as well as the increased adoption of new data and analysis instruments that would enable more timely, high-resolution and action-oriented local surveillance. The article by (Asamoah, 2022) is highly inspiring with the suggestion of the "digital exhaust" of the current generation of social media postings, news reports, web searches, etc. as a helpful sentinel tool to monitor AMR – which is now beginning to join the "new future" category. However, the Nigerian study conducted by Lawal et al., 2025 and Egberi et al., 2025 suggests that significant issues to successful surveillance among LMICs include inadequate infrastructure, limited funding, insufficient skilled workforce, and lack of political commitment. The reflective piece authored during AMR week (Al-Tawfiq et al. 2024), reminds us that surveillance is not for the sake of mere surveillance. Surveillance is supposed to be for the purpose of information and action. An information system that results in many data, but does not generate any information transfer to policymakers or alter the prescribing activity is a lost opportunity. Hence, digital health solutions that are technically strong, but still rooted in and responsive to the social, political and economic landscape they seek to impact, will be most successful, creating a culture of shared responsibility and learning from evidence, from the clinic to the cabinet room.

Innovative Therapeutics, Alternatives, and Novel Mechanisms of Action

The enormous challenge created by more and more antibiotics becoming resistant is inspiring a new generation of research into alternative modalities of hands-on immediate antibiotic therapy that are different to the "small molecule" drug therapy now used to treat bacterial infections, and which Timberlake and his colleagues aim to develop and test. The projects in this thematic cluster are highly diverse projects that range from finding new antibiotics that have not been identified before, uncovering new mechanisms of action to finding solutions through biological alternatives or using the latest technology such as Artificial Intelligence. Overall, these investigations reveal a paradigm shift in the management of infectious diseases, as treatments may shift from 'magic bullets' of a single vaccine to 'portfoli sijo' of clever strategies that will evolve to seek out the evolutionary creativity of the bacteria and viruses that cause them is yet to be seen.

One of the major research themes is the discovery of novel mechanisms of antibiotic action and re-emerging the usage of old antibiotic agents, which have been discontinued. New mechanisms of action for antibiotics is explored – a direct attack on the problem – which is what one study did (Opitz & Sass, 2020). That bacteria have evolved very sophisticated resistance mechanisms against existing antibiotic classes, and this paper argues that as an alternative, innovative targets must be sought, ranging from new methods (e.g. disrupted microbial quorum-sensing), through disrupting non-essential but important metabolic pathways, all the way to interference with bacterial virulence systems. One review study (J. Ali et al., 2018) will provide a detailed description of the mechanism of antibiotic resistance and search for synthetic antibiotics. The first part of this work catalogues the mechanisms by which bacteria have evolved to evade antibiotics: enzymatic degradation, target modification and efflux pumps; while the second part is a list of solid-state alternatives, which attempt to defeat the resistance mechanisms: from antimicrobial polymers to nanoparticles to synthetic peptides, among others. As it pertains to chemistry, some groundbreaking research is reported (Wu et al., 2024) about a novel innovation: an antibiotic preorganized to bind to the ribosome which could evade antimicrobial resistance. The scientists demonstrate that, no matter the class of the designed antibiotic, it can be delivered with a chemically preorganized structure that makes it more stable to bind to the targeted structure (ribosomes), and the drugs can then have resistance-override functions, e.g., methylation of the ribosome. Along with the new molecules, another research paper (Cassir et al., 2014) proposes another method of discovering new antibiotics – the study and revival of old drugs! The counter-arguments concerns the fact that most antibiotics that are useless today are not because of its inefficacy, but because of its toxicity, its poor pharmacokinetically or because newer generations of antibiotics have appeared, which are more convenient. Three of these “forgotten” agents may be reformulated more effectively, delivered more accurately to the target and finally, be used in combination with existing ones in a synergistic fashion to develop the desired activity, and may be returned to clinical use against resistant organisms, bypassing years and billions of dollars of de novo drug development.

An area of quality alternative solutions to antibiotics is also in expansion, with probiotics, microbiota modulation and antimicrobial peptides making the move to the spotlight. A comprehensive review

(Aghamohammad & Rohani, 2023) has been provided to address antimicrobial resistance and offers insight into the root of the issue while offering a compelling argument that fostering and sustaining a microbial ecosystem could be an effective way to prevent and treat infections. Those are ideas that can lead to a healthy or balanced microbiota, enhancing the immune system, and even disrupting the emergence of antibiotic resistance genes in bacteria, causing a reduction in the selection pressure for their spread. The availability of new antimicrobial(s) is required, and resistant isolates will subsequently emerge, which means that probiotics and other non-killing strategies could give a complimentary sustainable solution, the study concludes. Another study (Li et al., 2018) is about livestock production (amr), and suggests AMR as a novel put forth by antimicrobial peptides against the challenge of antimicrobial resistance in livestock. The paper proposes that the increasing prevalence of AMR in agriculture is due to inappropriate and excessive use of antibiotics, and that AMRs, such as the naturally occurring molecules, the antimicrobial peptides, which are part of the innate immune system of many organisms, offer a number of benefits: a wide activity spectrum, a mechanism of action which makes them less prone to giving rise to bacterial resistance, and the possibility to produce them recombinantly at a large scale. The step from lab to product testing would be a major hurdle, however, for the use of these peptides in animal feeds where safety and effectiveness needs substantial testing. This is followed by the third study (Gupta & Sharma, 2022) looking forward towards the alternatives to antibiotics that could help to address the larger issue of antimicrobial resistance. The authors accept that often antibiotics are not indicated, particularly for a diagnosis of viral infection, where that diagnosis can be unclear, and that prescribing a secondary bacterial infection is common. It then reviews various alternatives to antibiotics such as vaccines, monoclonal antibodies, bacteriophages, and microbiome-modulation drugs and finds none that is going to replace antibiotics but concludes that a combination of alternatives can be used in the right context to cut down on the use of antibiotics and the resulting spread of antibiotic resistance.

Thirdly, the study of the research field is focusing on innovation and technology, such as artificial intelligence and synthesized materials. The latest report (Lau et al. 2021) explores artificial intelligence for combating antimicrobial-resistant bacteria, and is more of a glimpse into the future where machine learning could revolutionize many aspects of the challenge. There are also opportunities to use AI to predict antibiotic resistance of the most likely strains, and to guide the rational design of new antibiotics, and assist with the determination of 'empirical' treatment. In addition, it can be employed in a much more rapid and efficient manner than conventional high throughput drug screening in order to screen the large library of commercially available chemical compounds for new antibiotic properties, complementing the well documented antibiotic discovery market failure. Furthermore, AI-based diagnostic platforms can analyse patient information, pathogen genome information and demography to track epidemics and provide virtual real-time advice to healthcare practitioners, reducing unnecessary antibiotic prescribing. The research (J. Ali et al., 2018) also fits into the theme of potential synthetic treatments including engineered nanomaterials (ENMs) including metal nanoparticles (e.g. silver, zinc oxide) as well as carbon based nanomaterials that are killing bacteria due to physical disruption and production of reactive oxygen species (ROS), to which bacteria have yet to develop an extensive resistance. Last, but definitely not least, a paper (Laxminarayan et al., 2024) has emphasized the importance of a systems approach to tackle antimicrobial resistance, outlining a need for antibiotic, vaccine and diagnostics development and accessibility. The paper suggests vaccines have the potential to eliminate infection altogether which could greatly alleviate the burden of AMR, and that better diagnostics could help ensure that antibiotic use is only on patients that require them, to avoid collateral damage on the microbiome and create less selection pressure. Among the most important points that can be taken from the study is that innovative therapeutics must go hand-in-hand with innovative prevention and diagnostics, and that solutions must be innovative in each of the three fields. Rendering meat to combat the rise of antimicrobial resistance is a new concept and solution, and its solutions are systemwide. Incorporating farming of antimicrobial resistant meat could serve as a solution to antimicrobial resistance (McNamara & Bomkamp, 2022). The study acknowledges common animal farming conventional methods have a strong dependence on antibiotics to maintain animals' health and growth rate, and this has put strain on the system, resulting in the increased risk of misuse of antibiotics towards cross resistance, which threaten human medicine. At the other extreme is the meat industry without live animals, which can take the place of meat that is produced by live animals (cellular agriculture) and reduce the use of antibiotics, thereby relieving the one of the biggest causes of resistance in the food production chain. Table 6 indicates that there is considerable on-going uncertainty, and indeed consensus, that there is no one solutions roadmap for AMR, but rather one resting, building on a diversity of action and innovation. The research of Opitz & Sass (2020), (J. Ali et al., 2018) and (Wu et al., 2024) are cutting edge basic science studies that help further our understanding of the biophysical mechanisms of bacteria's functions. The reuse of old antibiotics (Cassir et al. 2014) is a realistic and cost effective measure in order to build into it the ongoing and complex process of the development of a totally new antibiotic. To prevent infection and to reduce selection pressure for a resistance, a different paradigm of "Biological alternatives" which is based on working with, not against the microbial paradigms of ecology and evolution needs to be followed as explained by Aghamohammad & Rohani (2023), (Li et al., 2018), and (Gupta & Sharma, 2022). A series of new innovations in technology and synthetic chemistry have emerged (J Ali et al., 2018), (Lau et al., 2021), (Laxminarayan et al., 2024) which have tools that could greatly assist with the race to find effective therapies, more accurately diagnose existing infections, and entirely new families of antimicrobials. Lastly, the concept of systemic and agricultural interventions (McNamara & Bomkamp, 2022), (Li et al., 2018) is not only about interacting with medicines or labs, but also food systems food is part of, and interventions in good alternative foundations can be. What makes the study on cultivated meat (McNamara and Bomkamp, 2022) unique is that it aims at an intervention on a societal level which is preventive and structural and not therapeutic and downstream. Taken together, these studies reflect a level of innovation and vibrancy in an area keen on evolving from a world of static "old" antibiotics into one more dynamic and sustainable in the battle against infectious diseases.

Impact of Global Crises: Pandemics, Conflict, and Climate Change on Antimicrobial Resistance

One that should not be ignored when discussing AMR is one of the global crises – a seemingly intractable entity. The studies included in this thematic cluster offer strong evidence that the advent of large-scale disruptions, be it biological, social or environmental, can lead to significant shifts in antibiotic use and the emergence and spread of antibiotic resistance. Crisis situations tend to highlight pre-existing weaknesses in health systems, health publications and health laws and introduce themselves as situations in which the problematic relationship between antibiotic overuse and AMR is amplified. This information will be vital in helping health systems become resilient enough to uphold the principles of antimicrobial stewardship in today's unparalleled challenges.

The COVID-19 pandemic is the latest COVID-related crisis (and best documented) of the ways big antibiotic use can change during an emergency, potentially accelerating the development of AMR. Given the mix of uncertainty, fear and disruption it has caused throughout this pandemic, so far it's a perfect storm from bacteria use. One study (MacIntyre & Bui, 2017) takes an epidemiology and risk assessment point of view and highlights that when the topic of a pandemic or public health emergencies (PHEs) comes up, the accepted guidelines and frameworks of epidemiological and risk assessment do not always apply or come into play when dealing with AMR. The initial stage of the current pandemic saw many COVID-19 patients admitted to hospital treated with a broad spectrum of antibiotic drugs as differentiating viral from bacterial pneumonia became difficult due to inadequate rapid diagnostic tools, and a co-infection with both pathogens was common. One commentary (Hsu, 2020) in particular makes a point of explaining the impact of the COVID-19 pandemic on the threat of AMR, as some AMR surveillance and stewardship programs at health care facilities have been reduced or eliminated due to resources being dedicated to responding to the pandemic. The pattern of predispositions flourished in this way, without being challenged. This problem is empirically determined through the comparative cross-sectional study of burden of antimicrobial resistance (AMR) pre- and post-COVID-19 and the mapping of multidrug resistance by studying carried out in Egypt by Abdelmoneim et al. (2024). These findings indicate that common gram-negative pathogens exhibited higher antibiotic resistance levels during the pandemic period when compared to pre-pandemic period and confirmed that there is direct link between increased antibiotic consumption and increased antibiotic resistant situation. Another hospital-based epidemiologic study performed in Egypt (Gawad et al., 2023) considered only uropathogens in the COVID-19 era and found high rates of resistance to widely used antibiotics such as ciprofloxacin and cephalosporins, assuming that these agents have been frequently used in hospitalized COVID-19 cases. Another research (Garg, 2021) intensely refers to this as “a recipe for disaster” and offers a narrative review that draws evidence on how COVID-19 has affect AMR and calls for the optimization of antibiotic stewardship during a pandemic as the unnecessary use of antibiotics is a key driver of resistance. All of these studies clearly indicate that the COVID-19 pandemic did not result in a new issue but simply exacerbated patterns of misuse of drugs and alcohol and escalated what was already an acute crisis.

The other unfortunate scenario that exacerbates the global spread of AMRs is armed conflict, a peculiar situation where public health measures are not taken. Even when healthcare is disrupted, no regulations are in place and there's no rule of law in the zones of war, uncontrolled use of antibiotics goes on smoothly. The focus is war and the transmission of antibiotic resistance and war in the study (Jumba, 2026): the idea is that when there is war, there is near-absolute transmission of antibiotic resistance as unwanted use of and mismanagement of antimicrobial agents occur. The shortage of lab space, under-developed infection control systems, and limited resources and supplies in field hospitals in times of conflict can result in improper management of war wounds - in particular, reliance upon broad-spectrum antibiotics (exposing patients to more than one bacterial infection at a time). They are often poorly provided, poorly managed, and poorly monitored, leading to problems of stockpiling, inadequate quality/age of the stock, and lack of completion of courses of treatment. Moreover, refugee camps are already oversubscribed, and sanitation and hygiene standards are poor, and resistant pathogens easily transmitted. The study highlights that these are all prime conditions for the emergence and spread of antibiotics resistant organisms to multiple drugs internationally; high antibiotic selection pressure, poor infection control and population movement. Similar to the socio-economic analysis of AMR, the theme of the unique vulnerability of marginalised populations is common in a conflict context and those who are least responsible for the crisis tend to suffer the most.

Though the climate change is a gradual change compared to Pandemic and War, it has tremendous and multi-factorial impacts on the AMR. A study (Alhassan & Ahmad, 2025) looking at antimicrobial resistance in the context of a changing climate suggests considering both Human Health, Animal health and Environmental Health in both adaptation and mitigation solutions as part of considering a One Health approach. The authors of the paper propose a number of possible ways that climate change may lead to the development of AMR. The reason could be that as the temperature rises everywhere the bacteria are able to share DNA more rapidly, thus sharing resistance genes. Under extreme weather events like flooding or drought periods (EWEPs) new routes to human exposure of water sources can be established through agricultural run-off and inadequate sanitary practices, resulting in the release of antibiotic residues and resistant bacteria. Temperature and precipitation changes are also shifting the spread of infectious diseases to new locations in areas where they were once not a concern, creating a a need for more antibiotics, and the risk of overuse. In addition, because agriculture production systems are impacted by climate change, there is a greater likelihood that livestock will be stressed, which means antibiotics may be used more often; and, as production systems become more of an economic threat under climate change, more antibiotics may be bought by farmers to protect their livelihoods, the study states. The research concludes with the need to think systemically about addressing AMR, emphasize how thinking about the interconnections of human, animal and planetary health are critical, and the need to integrate resilience into health systems and food systems to be resilient to climate shocks.

These strands form a reflection on AMR week 2023 (Al-Tawfiq et al., 2024) under an umbrella of "preventing antimicrobial resistance together. The conviction in the liturgy is that the threats of pandemic disease, conflict and climate change are not mutually exclusive, nor would a purely sector-specific response, tackling the concerns at each of these points, be sufficient. It demands a collective world response of regionally coordinated and integrated AMR prevention campaigns coupled with the all-encompassing nature of a pandemic preparedness for conflict response and climate adaptation. The commentary implies there has to be more resilience to shocks, or multiple shocks, within health systems and that health systems must also demonstrate resilience following a particularly high shock with high capacity for surveillance and stewardship.

Discussion

The reviewed synthesis shows the complex and highly interwoven nature of the connection between antibiotic misuse and emergence of antimicrobial resistance. The underlying theme that was elaborated and restated throughout this paper and which forms the central theme of this paper is substantiated with quotes from a series of studies performed across a number of disciplines in human medicine, veterinary science, agro-industry and in community. When the findings are combined, however, the story gets more complicated than simply connecting a cause with a chain of events – a web of reinforcing mechanisms, contextual dependencies, and critical points for intervention emerge. Together the results indicate that, rather than being a single, isolated act of overuse, UAM is a range of behaviours and civil structures and each aspect of the misuse is affected by a complementary process of contributing behavioural, socio-economic, political and environmental factors. A common thread throughout the literature in each of the studies is the absence of a multi-sectored intervention that integrates different components to achieve a greater impact. Tobacco control campaigns that focus on raising awareness about health risks associated with smoking usually will not be successful unless they discuss the context in which tobacco is manufactured (selling practices of consultants, profits of tobacco) and the circumstances surrounding the current intensive marketing and promotion of these products. Similarly, in a situation of global crisis, interventions to address antimicrobial resistance in the hospital are no cure for antimicrobial use and resistance in agriculture and in community pharmacies. This synthesis point of light clearly showed that there is a need for a systems based approach that requires addressing multiple drivers at the human-animal-environment interface, which are the fundamental concepts of the One Health approach.

Their emergent syntheses have notable implications concerning both aspects of theoretical approaches and intervention design. In theory, our results throw into doubt the prevailing biomedical account, focusing AMR as mainly a clinical issue of resistance by bacteria and effectiveness of drugs. Indeed, there is evidence in support of a socio-ecological perspective in which AMR is considered to be a consequence of emergent properties of the complex adaptive system, with feedback loops between the components of individual behaviors, healthcare organization, economic incentives, agricultural policy and global governance. The socio-economic dimension also demonstrates how poverty, weak regulations, and lack of access to quality diagnostics and health services lead to a disproportionate burden in LMICs and are not just the results of higher numbers of infections. The change of theoretical orientation has important practical consequences. It needs interventions to extend beyond the prescriber/patient relationship and focus instead on common issues, that doing anything is possible – issues which are part of the same systemic factors implicated in the possibility of misuse. For practitioners, this means stewardship efforts need to be integral to ongoing efforts in quality improvement that involve the clinical practice's culture and economics and address diagnostic capacity, infection control, and managing patient expectations. For policy makers, the synthesis clearly needs to call for action, specifically in the need for coordinated multi-sectoral policies to reduce the promotion of OTC sales of antibiotics, implementation of policy in the agricultural sector, investments in surveillance and diagnostic infrastructure and bolstering primary care systems, particularly in under-served areas and rural regions. What these studies reveal globally makes it even more important that these systems are resilient in that they can continue to be stewarded during a pandemic or armed conflict – something certainly needed in the post-COVID-19 era.

However, some of the limitations in this systematic review should be acknowledged as these may impact the interpretation and generalizability of our results. This presents one of the key methodological challenges with this because only English language publications could be accessed. A significant portion of studies on antibiotic use has been done in a country that is not the origin of the English language (in some cases, studies disproportionately favor a country with sets of studies summarized in English) and in some cases may not have caught up on important empirical findings in other contexts; this would mean that some studies could have bolstered a result by another country with more studies written in English. This may result in the lack of capture of some drivers of misuse which are only clearly reported in languages other than English. Furthermore, there was a possibility of forgetting to include some information as grey literature, such as data coming from government policy reports, program evaluations or institutional monitoring, which might have lessened the real world feedback on the take-up of valuable practice from the success of large scale interventions and the national level implementation of policy. A restriction in the review procedure was the confined number of search terms and databases which were searched. There were other studies included such as ‘non prescribing antibiotic use', ‘self medication with antimicrobial' or ‘antibiotic monitoring' that were not selected because they are considered to be less relevant or cannot be cut into the same category as these studies. In general the quality of the included studies was evaluated using scales like the Newcastle–Ottawa Scale and ROBINS-I, which were used to aid interpretation of the results, but such scales were used in a liberal interpretation and may have introduced differential weighting of some studies. Again, the synthesis will be systematic and thematic, but it will rely on some interpretation by the researchers, which might have resulted in the identification of other patterns or the more emphasis on some results by another set of reviewers. Our conclusions need to be viewed with caution because of these limitations, especially with respect to the generalizability of the intervention methods we used.

There are a number of important directions revealed in gaps and inconsistencies in this review for future research. A need, beyond KAP studies, is to develop, rigorously test in different settings, and, importantly, theory-driven innovation implementation success measures, explaining what mechanisms and mediators are associated with the successful implementation of certain interventions that go beyond just implementation success measures to innovations regardless of their settings. For example although the relationship between diagnostic uncertainty and inappropriate prescribing is known, studies need to determine how to implement point of care diagnostics can be incorporated into the routine clinical workflow in the low-resource setting and what contextual factors (e.g., training, cost, supply chain) might moderate the effect of these on prescribing. There is a special need for studies that look at the various components of the broad term “low and middle income countries” as the causes of misuse in a rapidly expanding urban centre in India may differ significantly from those in an urbanising area in sub-Saharan Africa, or an area of conflict, within the Middle East. Further research should incorporate gender-specific gender dimensions of social and biological vulnerabilities toward the use and exposure to AMR, since several studies pointed out that there might be gender gaps with the gender dimension of social roles and social vulnerability and in the access to antibiotics; this is a significantly under-researched topic. Another critical missing component is the lack of RoL longitudinal studies at a community and/or ecosystem level that directly link measurable RoL shifts to defined patterns of misuse, over the long-term (multi-decade). At present, research papers are mainly snap shot or follow-up for a short period of time after the intervention leaving it difficult to create causal pathways and timeline lags between the antibiotic use and observed antibiotic resistance. Also, an investigation into the effect of global situation, such as climate change, armed conflict on the AMR is an emerging yet much needed field of research. Future research should explore how rising temperatures, other extreme events, and environmental resistome and horizontal gene transfer impact in conflict environments, and how the impact of health system breakdown in conflict environments can be prevented with SS intervention planning by developing and implementing planning. Finally, it is necessary to have more complex network and systems level analyses, which integrate all the information on the people, animals and environment to predict the consequences that will arise from policy decisions, such as the restrictions placed on growth promoters by Europe or the introduction of an entirely new class of antibiotics globally. This research could go a long way towards helping policy makers foresee unintended consequences and make decisions on more resilient and adaptive approaches for maintaining the efficacy of antibiotics. We recommend the use of participatory action research (PAR) techniques that have high levels of flexibility and accommodate the involvement of community members, clinicians and policy makers in intervention design or assessment based on the complex and context-specific nature of the use-misuse relationship.

Conclusion

This systematic literature review clearly shows that there is no simple linear relationship between inappropriate use of antibiotics and the development of antimicrobial resistance and that antibiotic resistance is not only a problem in any one sector. The uniform selective pressures we observe all over the place (with responsive use in human medicine, veterinary medicine, agriculture and peoples' homes) create a very random process of resistance formation. Furthermore, we emphasize the importance of the mediating role of social settings in which our relationships take place such as economic differences, or restricted diagnostic access and enhanced effects of global crises like epidemics and armed conflict. Evidence presented in the evidence bog gives clues to a need for integration, namely that systems and behaviors need to be changed in intervention in order to have enough, and suggests this is what is needed.

Our theoretical implications in relation to AMR is the need to approach the problem as a socio-ecological issue, as a challenge that needs to be addressed from an inter-disciplinary perspective. In practice, our results illustrate that a key element of good stewardship is keeping resilient health care systems in place able to maintain surveillance and prescribe wisely even during crisis. The papers discussed highlighted current need for further research into long-term and theory driven implementation research that is relevant to decreased resistance. Specific consideration needs to be given to context-specific areas (including in conflict; climate-sensitive; marginalized populations), since they tend to be more vulnerable as a result of multiple drivers, which converge in these contexts.

We feel the window of opportunity to effectively use antibiotics is closing, and that there is an urgent need for coordinated global action both in terms of implementing antibiotic policy and innovation in diagnostics and behaviour change. There is a need for a transition, from fragmentary, ad hoc approaches to a more holistic model for preventing human, animal and environmental diseases—one based on a systems approach. Such a revolution can be built on an evidence-based foundation, which we identified in our synthesis: concrete steps are suggested to take to avoid the post-antibiotic era.

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