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A One Health Approach: Addressing the Overuse of Antibiotics in Agriculture

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Abstract

Antimicrobial resistance (AMR) has emerged as one of the leading public health threats of the 21^{st} century (Naghavi, 2022). Over the past decade, antimicrobial resistance has steadily increased despite the first recording of resistant bacteria in 1942 (Lowy, 2003). Since then, there have been several efforts to control and limit antibiotic exposure including the World Health Organization (WHO) and Centers of Disease Control (CDC) recommendations on reducing antibiotic use to slow the spread of resistant bacteria. This project reviewed existing literature and other documents to identify major gaps in policies and provide recommendations on possible pathways to decrease the development and distribution of antibiotic-resistance pathogens contributing factors in current policies using a socioecological model. Based on the finding of this study, more policies is needed to support implementation of organic practices in commercial farms, expansion of wastewater plants, and testing of meat and dairy products for AMR bacteria; also, an immediate amendment of the FDA's Guidance for Industry #213 must be made to increase surveillance data and track AMR rates to assist in the development of future antibiotics.

Keywords: Antibiotic resistance, transmission, agriculture, industrial farming, animal husbandry, antimicrobial resistance, environmental health, commercial farming, and policy reform

Contents

Introduction

Antimicrobial resistance (AMR) has emerged as one of the leading public health threats of the 21st century (Naghavi, 2022). AMR occurs due to an evolution of bacteria, making treatments of bacterial infections less effective (Naghavi, 2022). In recent years, several publications began identifying a linkage between antibiotic use in agriculture to humans. Roughly 70% of all antibiotics in the United States are being used in animal feed (Cable, 2018). More than 2.8 million antibiotic-resistance infections occur in the United States every year- which results in roughly 35,000 deaths (CDC, 2019). A comprehensive analysis estimated nearly 1.27 million deaths globally were attributed to AMR- surpassing HIV and Malaria mortality rate totals (Naghavi, 2022). Over the past decade, antimicrobial resistance has steadily increased despite the first recording of resistant bacteria in 1942 (Lowy, 2003). Reducing antibiotic use to slow the spread of resistant bacteria was recommended by the World Health Organization (WHO) and Centers of Disease Control (CDC). Extensive literature exists on the healthcare costs of AMR (Dadgostar, 2019), and varying strains of resistant bacteria (Lowy, 2003) but there is not enough information on policies to regulate and control the AMR. This paper conducts a multidisciplinary approach to identify possible policies in addressing the pathways that AMR transmit to humans, through agricultural practices. This project explores the existing levels of policies and considered current policies as a tool to redefine the agricultural system over time, while also labeling factors that recognize current policies are part of the institutional problem.

Background

In the United States, antibiotics have been used generously in animals for treatment, prevention, and disease control (Ma et al., 2021). In 1951, the Food and Drug Administration authorized the use of antimicrobial growth promoters (AGPs) (Ma et al., 2021). Agricultural animal farmers reported the use of AGPs in animal feed aid in animal production. Since then, this behavior became a routine practice. In fact, antibiotic use in animal husbandry is predicted to increase by 67% between 2010 and 2030, globally (Van Boeckel, et al., 2015). According to the CDC, the annual cost of antibiotic resistance in the United States is $55 billion, with $20 billion going toward health care and around $35 billion going toward lost productivity (Dadgostar, 2019). However, this practice is not just limited to the United States. In the European Union (EU), antibiotics in animal feed is being used in roughly 9,000 tons of animals (ECDC, et al., 2017). Furthermore, China, the biggest consumer of antimicrobial drugs reported using nearly 30,000 tons of antibiotics for their animal husbandry practices in 2018 (Hu, et al., 2014). 53% of that consumption assisted in animal growth (Hu, et al., 2014).

Antibiotic resistance occurs due to mutations in the pre-existing genome of a bacteria and from the absorption of DNA from foreign bacteria (Prestinaci et al., 2015). Foreign bacteria can be classified as another bacterial microorganism, living or dead. Although mutations are a natural phenomenon, resistance to antibiotics is exacerbated by the exposure to antibiotic drugs (Prestinaci et al., 2015). Misuse such as inadequate doses, poor adherence to instructions, and inappropriate prescriptions offer ideal circumstances for AMR bacterium to replicate (Larsson & Flach, 2021). Typically, when an antibiotic is introduced, the target bacteria is killed whilst the bacterium with the resistant mutation is left behind to multiply. As a result, the transfer of DNA can be transported between humans, animals, and the environment (Larsson & Flach, 2021).

According to recent estimates, infections with antibiotic-resistant bacteria impact all age groups, however, the burden is disproportionately greater in infants (aged <1 year) (Asbell, et al., 2020), and for adults over 55-65 years of age (Cassini, et al., 2018). Roughly 64% of infections with bacteria AMRs were linked to medical care, resulting in 72% of attributable deaths and 75% (127 of 180) DALYs per 100,000 people (Cassini, et al., 2018). Global mortality rates of AMR identified Sub-Saharan Africa and South Asia populations as the highest rate of mortality directly attributable to AMR, with 24 and 22 deaths per 100,000 people, respectively (ARC, 2022). In South Asia and Sub-Saharan Africa, AMR was linked to 77 and 99 fatalities per 100,000, respectively (ARC, 2022) and those who are at the greatest risk for antibiotic-resistant infections are infants and elders with pre-existing conditions.

In many animal production industries, poor sanitation and crowding stress are well known in suppressing animal immune systems (Ma et al., 2021). As a result, animals raised in industrial farms have high disease susceptibility (Ma et al., 2021). For example, a recent study identified 16% of all lactating dairy cows received antibiotics to treat mastitis within a one-year period (Landers, et al., 2012). Nearly all the dairy cows received antibiotics after each lactation to prevent future mastitis (Landers, et al., 2012). Similarly, 15% of cows used for meat products received antibiotics to treat respiratory diseases (Landers, et al., 2012). However, these antibiotics were also administered to 10% of healthy calves in anticipation to prevent a respiratory disease outbreak amongst other cattle (Landers, et al., 2012). To minimize economic loss, antibiotics are used in large amounts to combat unsanitary and high stress living conditions for animals (Ma et al., 2021).

It is essential to reduce the misuse of antibiotics in agriculture to decrease antibiotic resistance cases. Without immediate intervention, bacterium will continue to mutate against antibiotics, leaving our healthcare system without methods to fight infection. Herein is a compilation of current efforts made by organizations that have an impact on controlling antimicrobial resistance.

A main contributor to antimicrobial resistance is the patients demand for antibiotics-which is driven by the individual's perception of antibiotics and antibiotic resistance (Chan, et al., 2021). Chan, et al. designed an individual based study with 100 participants to examine the effectiveness of a brief, online education-based intervention. Participants were given a few scenarios to examine at which point the individuals felt they needed antibiotics. For example, a hypothetical situation describing cold and flu symptoms were presented. The participants were then evaluated based on their individual beliefs and antibiotic necessity, perception, and concerns. The main findings of the study concluded that there was a direct correlation with patient beliefs and an inappropriate demand for antibiotics (Chan, et al., 2021). The study recommended an increase in individual education is an effective tool to reduce antibiotic use.

Currently, there are policies assisting in the reduction of antimicrobial resistance at every level beginning with education which as a result aids in the public perception of antibiotic use (Chan, et al., 2021). An impact that directly affects the relationship of consumption of antibiotics and current policies. While the previously stated interventions are effective in reducing AMRs, they are insufficient in reforming current policies. This project explores existing levels of policies and proposes new steps to alleviate current health risks on diverse communities. This paper utilizes the Socio-Ecological model to discuss five policy recommendations that function within different systemic levels to address the gaps in current literature.

The Socio-Ecological model is defined as a system with five multitiered levels (Figure 1). The tiers are as follows: individual, interpersonal, organizational, community, and policy. This model identifies each tier to be interconnected affecting public health.

Figure 1. Socioecological Model

The Socio-Ecological model considers the complex interplay between each level. Policy is considered the broadest level which includes federal government agencies, nonprofit organizations, local, state, and national legislators. Community comprises of coalitions, health disparity collaboratives, medium, research institutions, community, state, and regional advocacy organizations. Organizational Systems include local health departments, employer worksites, health insurance plans, healthcare systems, professional organizations, and community-based organizations. The second to last tear comprises of the Interpersonal level. This level includes providers, family, peers, and social networks. Lastly, the Individual level includes knowledge, attitude, behaviors, and beliefs. The socio-ecological model was chosen for this project to highlight the effect that existing policies have on the health of diverse communities, while proposing new methods to address gaps in current laws.

Methods

This paper used the scholarly databases to review the relevant literature to propose a policy framework. To assist with the policy framework of this project, the research included legislation databases such as Congress.gov and the World Health Organization's 2022 publication for *Antimicrobial Resistance Surveillance in Europe*. The research compiled a variety of factors, including the environmental risk factors for underserved communities, and the routes of transmission between antibiotic resistance gene transfer to humans. From the finalized assessment, the social ecological model was used to identify the gaps within policies ranging from the societal to individual level. A final recommendation from the compiled list was conducted to build a strong intervention for any community to replicate. For the purpose of assembling relevant sources for this project, searches were limited to 2011 to 2022- with the exception of one article in 2003 for the background section. While this interval does not encompass the entirety of AMR prevalence, a search within this time frame tells a relevant story on environmental health and the main stakeholders.

Multiple searches were included in this review. They are as follows: [antibiotic resistance] AND [transmission] AND [agriculture], [industrial farming] AND [antimicrobial resistance] AND [environmental health], [cattle farming] OR [aquatic farming] OR [swine farming] OR [poultry farming] AND [policy reform], [United States] AND [Commercial Farming] "Impact*" of organic practices, limiting antibiotic usage, veterinary oversight on AMR prevalence. The following resources were accessed: CINAHL, Academic Search Complete, Google Scholar, PubMed, and ScienceDirect. Databases that offered articles including case studies were selected to compile relevant statistics for mortality rates, examples of antibiotic usage in industrial farming, and risk factors. Databases from the literature review and social sciences classification were selected to collect information on current policies to address which communities are most affected. Collectively, this project gathered 29 peer reviewed studies for review.

Recommendations

Policies are the most direct way to address the increase in cases of antibiotic resistant bacteria. Policy plays a major role in permitting access to safe water and food sources while ensuring a healthy environment for surrounding communities. When existing policies are actively enforced and new policies are designed to address the gaps, it builds a system where consumers have the confidence that their environment will not cause irreparable damage and poor health outcomes. Over the years several policies have been placed to control the development and expansion of AMR.

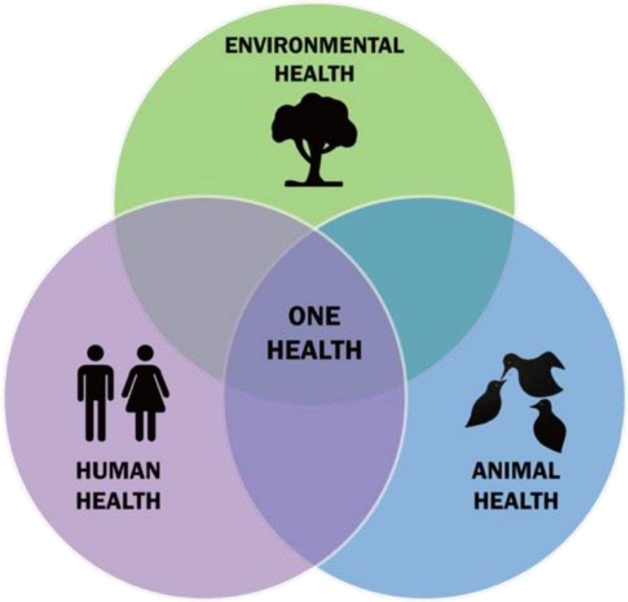
In the US, several efforts were established by the Centers of Disease Control. In 2013, the CDC was the first organization to publish an Antibiotic Resistance Threat report (CDC, 2021). This intervention was a catalyst in establishing a National Action Plan for Combating Antibiotic Resistant Bacteria (CDC et al., 2019). The National Action Plan organizes strategic goals to accelerate the US Government's response to antimicrobial resistance (ASPE, 2020). In 2019, the CDC updated the report to include serious, urgent, and emerging antibiotic resistant threats. The report details preventive measures to all individuals to reduce their risk of an antimicrobial resistant infection (Appendix H). Some points included: Refraining from direct or indirect contact with people with resistant strains, using contaminated water, consuming contaminated meat products, and risky sexual behavior (CDC et al., 2019). Lastly, the US Food and Drug Administration enacted the Guidance for Industry #213 in 2017. This guidance intended to restrict the use of antibiotics in animal husbandry practices. Before this policy was implemented, agricultural animal farmers could use low-dose antibiotics routinely in animal water and feed without a veterinary prescription (FDA, 2013). The guidelines required veterinary oversight for the use of these drugs for prevention purposes and a veterinary feed directive (VFD) to oversee antibiotic use in animal feed and water (FDA, 2013). In addition, the policy demanded that advertisement of growth promotion must be removed from all antibiotic labels (FDA, 2013). However, the effectiveness of this intervention is lacking due to the limiting use of surveillance and monitoring systems of industrial farms.

Keep Antibiotics Working (KAW) is a non-profit organization established in 2001. Through collaborative models, the KAW coalition has made impactful changes reducing the spread of antibiotics in the United States. Some recent victories include: 18 fast food chains have adopted stricter antibiotic policies from their suppliers, 92% of U.S. poultry farms limit the use of medically important antibiotics and assisted in the passing of the FDA’s Guidance for Industry #213. Another significant non-profit organization that guides change in AMR is Heath Care Without Harm (HCWH). Health Care Without Harm is an organization that leads communities in Asia, Europe, Canada, and the United States to establish safer healthcare for all. Although their non-profit has many focuses, they advocate for safer chemicals in food production, with a specific target on lowering rates of antibiotics in animal feed.

Another exceptional non-profit is The Alliance of Nurses for Healthy Environments (ANHE). To our knowledge ANHE is the only international organization that focuses on the convergence of the environment and human health. ANHE provides successful methods for an interpersonal approach. The Alliance for Nurses for Healthy Environments leads nurses by educating the public on issues such as food sustainability, safer chemicals, and climate change. Promoting healthy people and a healthy environment is the main goal for this organization. Specifically, in their food sustainability section, ANHE acknowledges the risks of AMRs and promotes a plant forward diet. Recent findings support reducing unsustainable animal-based diets reduce the risk of pandemic-based AMR outbreaks (Sandhu, et al., 2021). Participating nurses in ANHE's program educate their patients on the benefits of nutritious plant-based diets and implement safe antibiotic use practices.

The latest effort from the World Health Organization was their Call to Action on Antimicrobial Resistance 2021. This establishment called for national and global efforts to reduce rates of AMR through a "One Health approach" (Figure 2). The One Health Approach has parallel theories on the shared health of the environment and people. A One Health approach is a collaborative method to improve environmental, animal, and human health systems (Mackenzie, et al., 2019). This method identifies the environment, animals and human health systems as an interconnected network that contributes to the overall health of the environment. Acknowledgement of the One Health Approach is a necessary in proposing efficient and effective policies.

Figure 2. One Health Framework



As of March 2022, nearly 113-member state signatories were collected, including the United States and many EU countries (World Health Organization, 2021). Shortly after the WHO's call to action, France published a 2022-2025 National Strategy for Preventing Infections and Antibiotic Resistance. Some main points the report aimed to address are: Adoption of principles for the prevention of infection and antimicrobial resistance by the general public, prevention of infection and improvement of antimicrobial resistance of medical professionals across patient care channels, establishing a regional network for infection prevention and control for antibiotic management, sharing health and surveillance data to take action and developing products that help prevent infection and control antibiotic resistance.

Herein are the proposals gathered from the identified gaps in current systems:

Policies in support of Wastewater Treatment Plants

Due to incomplete metabolism of antibiotics in humans or because of inadequate disposal of unused antibiotics, significant levels of antibiotics are recorded in municipal wastewater reservoirs, which eventually find a way into different environmental avenues (Bouki, et al., 2013). For example, antibiotic-resistant bacteria and antibiotic-resistant genes are abundant in human and animal fecal matter (Pruden, et al., 2013). In current agricultural practices, animal manure from poultry and swine farming are often used to fertilize fishponds for growth promotion (Ma et al., 2021). However, the antibiotics used amongst poultry in swine farming can eventually contaminate other aquatic farming and even wild fish (Ma et al., 2021). Spreading manure to agricultural land is a potential route for antibiotic resistant bacteria to spread from livestock to crops to even our drinking water systems (Tyrrell, et al., 2019). Available data suggests the conditions of wastewater treatment reservoirs are complementary to the proliferation of antibiotic resistant bacteria (Bouki, et al., 2013). Therefore, to avoid cross contamination between waste reservoirs and human exposure, wastewater treatment programs should be implemented at every commercial farm to eliminate and control the spread to AMR genes.

Wastewater treatment plants use chemical processes to eliminate all organic and toxic matter. Current policies fail to control the distribution of the waste produced from commercial farming. By implementing a new policy that tests animal fecal matter for AMR genes before spreading manure to crops, we can reduce the number of pathways between AMR exposure. This organizational policy will also ensure any remaining waste from commercial farming will be distributed to a wastewater treatment plant. In 2019, roughly 70% of commercial farms received Government payments to assist with the high demand of animal products (Subedi, et al., 2021). Several USDA programs disperse payments to aid with the yearly cost of farm operations. Additional USDA funding could support this policy to regulate waste and enforce testing. Please see Appendix G for a detailed look at USDA payments to industrial farms.

Although USDA funding is essential for the success of this intervention, program management strategies should also be implemented to assist with the mobilization of funds and testing. Developing three SMART goals are recommended to ensure the achievement of desired milestones. Breaking down goals into three main milestones allows for personnel to visualize tasks at hand, making them more achievable. The main goal is to transition wastewater treatment plants in implementing new testing practices without overwhelming them. Please see Appendix J and K. The SMART goals are as follows: 1) Within the next week, staff will categorize 100% of commercial farm waste into designated sections to avoid cross-contamination between different regions. 2) In three months, 50% of waste will be tested before being spread to agricultural land. 3) Annual USDA grant applications will be applied for to ensure continual funding for this project. These SMART goals provide a guideline for wastewater personal to follow and distinguish tasks for the project.

Policies on Controlling Contaminated Meat Products

Retail beef, pork, and poultry products can function as a host for zoonotic foodborne transmission of antimicrobial resistant bacteria **(**Ballash, et al., 2021). A recent study randomly selected over 700 packets of fresh and fully cooked retail meat products in Ohio. The study identified 85 packages contaminated with MRSA resistant bacteria, 19 contained Salmonella resistant bacteria, and roughly 200 others with *Enterobacteriaceae* strains of resistant bacteria (Ballash, et al., 2021). Annually, the federal government conducts testing for a variety of meat products from grocery stores to monitor contamination and resistance trends (Environmental Working Group, 2018). However, meat products containing resistant bacteria are still sold to consumers. Furthermore, the FDA reported 70% of antibiotics used an animal husbandry are medically significant (Dall, 2020). Antibiotic resistance of medically important antibiotics is notable due to its use in human medicine. Without the effectiveness of these antibiotics, our first line of defense in our healthcare system in dismantled. Therefore, a complete ban of all medically significant antibiotics in agriculture should be instilled. In addition, routine tests for antibiotic resistance genes in meat products are recommended instead of the current annual check-ins for the analysis of current trends. Current practices exacerbate the severity of this issue and contribute to the rising prevalence. Despite recent antibiotic classifications as "highly important" made by the CDC and WHO, tetracyclines are still one of the most used antibiotics in agriculture (Environmental Working Group, 2018). Banning medically significant antibiotics and agriculture can reserve antibiotics for our healthcare. As a result, if an infection occurs the patient will have a treatment option available.

To ensure medically significant antibiotics are still effective in our healthcare system, five proposed risks and mitigations are outlined to portray the severity of this issue to current legislators. Please see Appendix L. Gathered from the CDC's categorization of moderate to severe threats, the proposed risks are outlined as follows: drug resistant *Neisseria* gonorrhea, drug resistant *Campylobacter*, Erythromycin-resistant Group A *streptococcus*, Carbapenem-resistant *Enterobacteria*, and Carbapenem-resistant *Acinetobacter*. The main cause for resistance within these bacteria is the failure to reduce these antibiotics in commercial farming. If the reduction of these antibiotics does not occur, the project will fail. This project management method can be an effective tool to visualize the main risks while proposing solutions.

Current funding opportunities are available through the Meat and Poultry Foundation. This organization tests meat products for foodborne illnesses before selling to consumers. Proposing a similar policy intervention monitored by the FDA, could be an adequate solution. Due to the large scale of this project, a funding by the federal government is suggested. Smaller scale farms could receive aid through the Meat and Poultry Foundation to support testing of antibiotic resistant bacteria in meat products.

Policies on Implementation of Organic Practices

Adopting organic practices can be an effective method to reduce antibiotic resistant bacteria in animal products (Sapkota, et al., 2011). Farms that are organically certified follow strict regulations mandated by the US Department of Agriculture. Organic livestock producers encourage the health of their animals by providing sanitary living conditions (USDA, 2015). Organic practices rely on preventative health methods such as genetics, habitat, exercise, nutrition, and stress management (USDA, 2015). Vaccination and veterinary care are common however, antibiotics are prohibited (USDA, 2015). A recent article stated nearly less than one percent of approximately 900 million acres of farmland in the United States implemented organic practices (Bialik and Walker, 2020). Therefore, mandating all industrial farms to implement a yearly 10% increase in organic practices will contribute to the decline of AMR. By 2030 we'd like to see at least 20% of all farms switching to organic practices. To reach this goal, a list of stakeholders mentioned in Appendix M provide an insight on the importance different stakeholders can partake in this milestone. Ranging from education efforts to demanding tighter restrictions from our legislators, this program management diagram categorizes the responsibility of transitioning commercial farms to organic practices. Lastly, there are several grants provide incentives for existing farms to switch over to organic practices. For example, the USDA's Growing Opportunity Grant provides funding for sustainable farming practices. Similarly, the USDA provides assistance with loan programs, crop insurance, marketing strategies, and conservation assistance to support organic agriculture. In addition, the USDA has an organic resource guide which describes the transition to organic practices. With the use of the USDA funding programs we can expect to see an increase in industrial farm switching to organic practices.

Increasing Data and Surveillance

The containment of antimicrobial resistance genes demands effective surveillance programs to identify the extent of the issue across contributing routes of transmission. Routine AMR testing is a key component of data collection and surveillance programs. Successful AMR data and surveillance programs should include a top management approach. This organization would include mobilizing funds, articulating planning methods, recording results, and coordinating surveillance tasks. Please see Appendix N. An outline of this intervention's milestones schedule is provided. This planning method is significant due to its visual representation of project phases. By phase two, developers begin to collect antibiotic use data with veterinary prescriptions from commercial farms. Phase three discusses the identification of farms out of scope of antibiotic use restrictions. Phase four will reprimand any farm out of compliance and issue fines for misuse. Lastly, by phase five the surveillance team will reduce the misuse of antibiotics by effectively implementing data collection and surveillance methods. Surveillance of antibiotic resistance plays a crucial role in providing data for future policymaking as well as assisting in the treatment of antimicrobial resistant patients. Without effective tactics of data and surveillance, existing policies are not enforced and statistical evidence on the pathways of transmission are lacking. Therefore, mandating surveillance in all industrial farms should be routine practice. A failed example is the FDA's Guidance for Industry. Although the policy recommended veterinary oversight and the reduction of antibiotics, it fails to enforce evidence of the policy change. Thus, antibiotics are continually used in animal feed and water without oversight. With this intervention, an amendment of the FDA's Guidance for

Industry should include a surveillance and data collection section. Possible funding opportunities exist through the FDA's annual budget. To mobilize funds for this intervention, the Food and Drug Administration could adjust their user fees to allocate enough funds for surveillance. In addition, a demand made to federal government could potentially authorize a separate budget for data collection and surveillance.

Discussion

There is ample evidence supporting the clear connection between the overuse of antibiotics in industrial farms with rising cases of antimicrobial resistant bacteria in humans. Although several policies have been in place to address the growing concern on AMR, current policies fail to reach their full potential of health equity. Also, current policies failed to implement effective methods that are enforced and consistently disregard the need for immediate action. Throughout this research, four reoccurring themes have been identified as major public health challenges impacts the fight against AMR: contamination, poor sanitation, public perception, and lack of surveillance. All of these themes are rooted on an important public health issue of inequality on access to resources and healthcare. Herein is a description of the public health implications within the four reoccurring themes:

Contamination

Contamination and a lack of urgency to contain the spread of anti-microbial resistant bacteria comprise the first theme. Currently, there are no policies that mandate the testing of AMRs in meat products before sold to consumers. Therefore, frozen, cooked, and fresh meat are all pathways of which AMRs can be transmitted to humans. However, it should be noted that the transfer of AMRs to an individual does not guarantee an infection. Nonetheless, if this individual had a consequent infection and required an antibiotic, the AMR gene could interfere. Individuals who consume meat products produced from industrial farms who routinely use antibiotics in animal feed are at a significant risk of the transfer of AMRs to their body. Furthermore, individuals who cannot afford to purchase organically produced products have the greatest risk. Accessibility to uncontaminated products could be directly associated with an individual's socioeconomic status. There is significant literature acknowledging the lack of accessibility that minorities face with their access to organic products (Schupp, 2019). However, few limitations exist when implementing an intervention to resolve this issue. Firstly, the main challenge is mobilizing funds for testing equipment to all industrial farms and meat processing plants. Significant financial support from the government would be necessary to manage the cost. In addition, routine enforcement and surveillance programs is essential to ensure AMR testing is fulfilled.

Sustainable Practices

In the United States, little is known about the public perception of antibiotic resistance. However, policies surrounding public education can be an effective method in increasing antibiotic resistance awareness. A 2016 study analyzed the views of the American public towards antibiotic resistance and acknowledges the gaps regarding appropriate use. As a result, a significant proportion of the sample believed antibiotics are an effective treatment for cold symptoms (Carter, et al., 2016). In fact, 90% of participants agreed that their body could build immunity to antibiotics over time and respondents perceived this issue could be resolved with a stronger antibiotic (Carter, et al., 2016). Another study found 45% of people could correctly identify what antibiotics could be used for in medicine (Jessop, et al., 2020). Based on this observation, it is evident that an intervention focused on educating the public is necessary to instill sustainable practices for antibiotic use (Appendix F describes the enabling and reinforcing examples of education campaigns). This intervention would collect baseline data to analyze the population's perception of antibiotics before the education course. During the presentation, individuals will learn safe practices with antibiotic use. A few examples include taking the full course of antibiotics, how to dispose of antibiotics, when it is appropriate to take antibiotics, and sustainable methods for food consumption. After participants have completed the course, a survey analyzing their perception of antibiotics will be gathered. The intent of this intervention is to educate the public on the risks of antibiotics and identify a demographic of individuals who are at a greater risk of misinformation. In addition, this intervention could be applied to social workers, healthcare providers, and teachers to convey the importance of education to their pupils. Pamphlets such as Appendix C, D, and E could be useful handouts for this education campaign. Possible funding opportunities could be provided through the Bill and Melinda Gates foundation. This nonprofit organization offers a plethora of grants to combat disease proliferation around the world. This foundation could enable the resources needed to implement this intervention.

Not only does the public perception of intellectual topics define policy, but influence the consumption of antibiotics. If individuals are informed on the risks of antibiotic use, perhaps consumers will refrain from purchasing contained meat products and demand action from their legislators. It is also imperative that the public has basic health literacy to make informed decisions that can affect their health. Arguably, antibiotic use and its risks have been deceptive to the public. Despite the WHO and the CDC's call to action, there are few interventions targeting sustainable practices that individuals could implement resulting in better health outcomes. More disturbingly, the pharmaceutical industry profits extensively off antibiotic use, and in doing so, AMR cases continue to rise. A 2017 estimate of the revenue generated through antibiotic sale is roughly $46 million per year (Plackett, 2020). The main threat that existing interventions experience while focusing on public perception, is the limited ability to broadly inform individuals. During the educational campaign researchers are limited to a small population group. Discovering a solution to this issue is the sole responsibility of policy makers to reduce poor health outcomes on diverse communities.

Poor Sanitation

The United States Department of Agriculture (USDA) reported approximately 9.8 billion land animals were slaughtered in 2020. Due to the high demand of animal products each year, industrial farms are forced to house animals in small, unsanitary conditions. In fact, the average size of an industrial farm is 440 acres, with approximately 700 cows (USDA, 2020). However, some of the largest industrial cow farms can hold up to 150,000 cows (USDA, 2020). This equates to roughly 9 million dairy cows necessary to maintain the demand for milk. In comparison, the average size of an organic cow farm was 330 acres with approximately 79 cows (USDA, 2020). Not to mention, the waste produced from both farming methods are used to fertilize crops which leaches into other environmental sources (Manyi-Loh, et al., 2018)**.** Because of the higher standards of care for cattle in organic farms, organically raised beef is 50% more expensive than industrial produced beef (Lameiras, 2022). The main challenge in addressing this issue is rooted within the large demand of meat and dairy products. Because of the massive consumption of animal products industrial farms have evolved to confined spaces. The difficulty resides in maintaining the demand while implementing organic practices that require spacious living conditions. The routine use of antibiotics is to preserve the health of the animal while maximizing space. More notably, the 50% increase in cost is not attainable for all socioeconomic groups. If all farming converted to organic practices the cost would be exponential, leaving many families without their regular source of protein.

Lack of Surveillance

Data collection and surveillance programs are crucial to contribute to the prevention and management of antimicrobial resistant bacteria (Pruden, et al., 2021). Recent data suggests, estimating the confidence intervals of AMR estimates are only effective in producing biased results (Kalanxhi, et al., 2021). Therefore, without implementing surveillance programs we cannot effectively predict the rising trends of antibiotic resistant bacteria. Utilizing a One Health Approach with the use of surveillance programs we can monitor resistant bacteria within humans, animals, and our environment. Surveillance and data collection is not only fundamental to the development of new antibiotics but also provides evidence in proposing new interventions. Some limitations to this include, cost to mobilize surveillance systems, upkeep and storage of data, and technology failure. However, without the use of surveillance and data systems, the misuse of antibiotics continues the rise of AMR cases.

Conclusion

Gaps addressed within this paper are indicated using the Socioecological model and the One Health Approach. The Socioecological model uses a multilevel approach that combines policies to address the gaps in literature, and labels multitier factors that recognize current policies are part of the institutional problem. The recommendations in this paper for refining our current agricultural system are concise, implement routine testing across waste and meat processing plants, a significant reduction in antibiotic use within agriculture, and increased data and surveillance systems to track antibiotic trends. It is also pertinent that a multilevel approach should be used when recommending new interventions. For example, food stamps and government stipends can provide low-income families with a solution to buy organically grown produce while government funded incentives for farmers who wish to convert to organic methods. The proposed solution will not only result in a reduction of AMR cases but improve the health of diverse populations.

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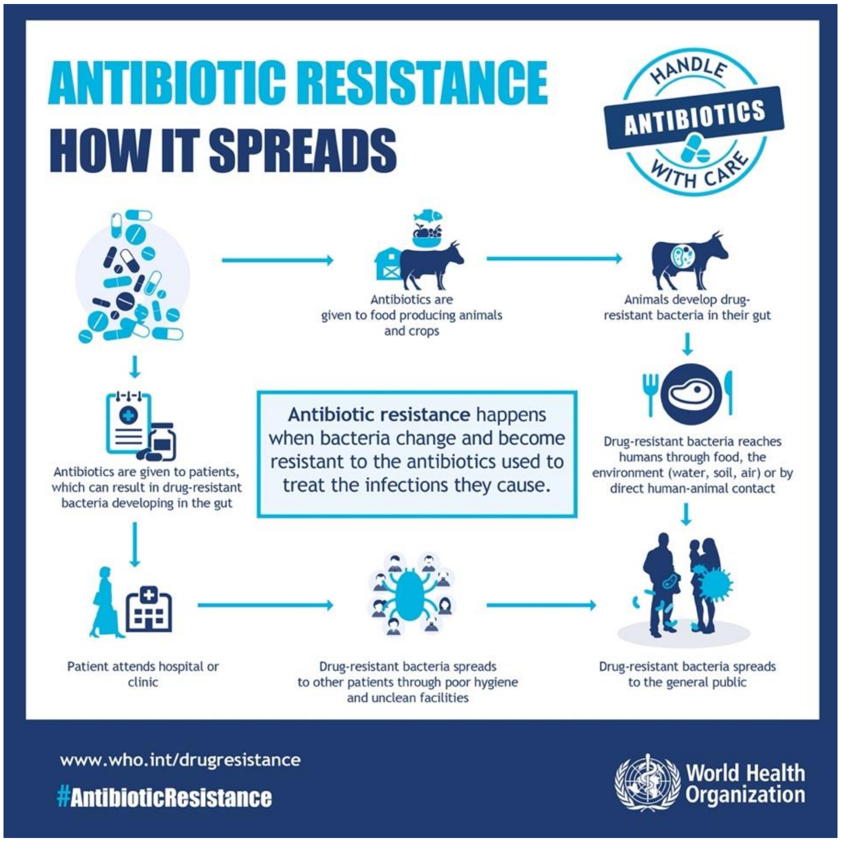
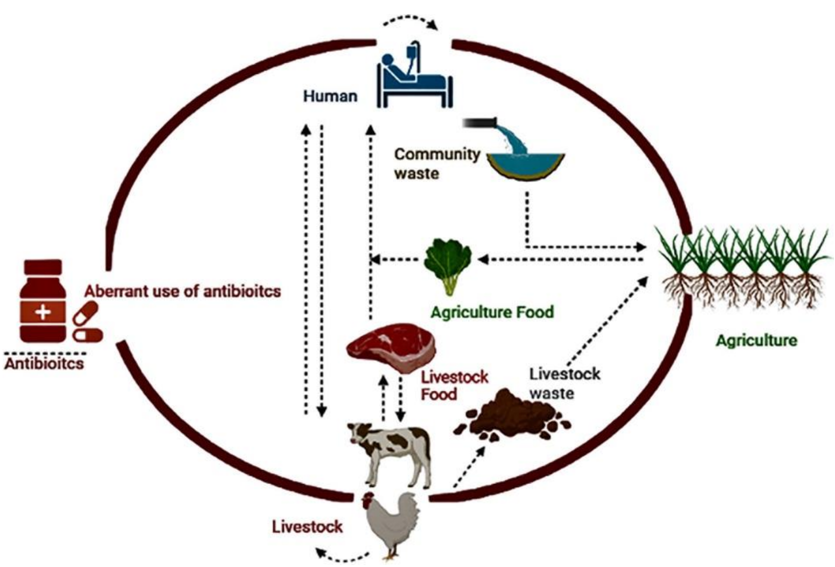
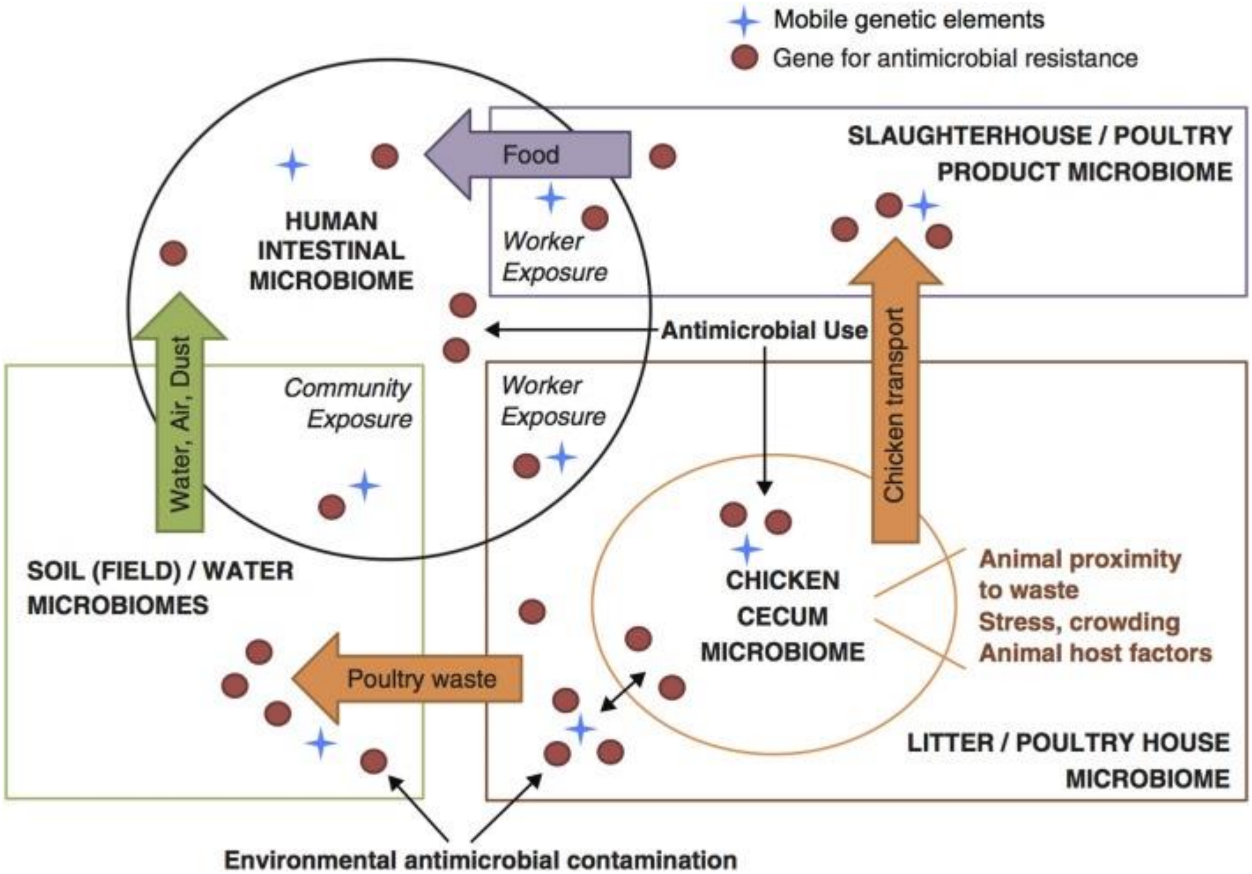
Appendix A. How it Spreads



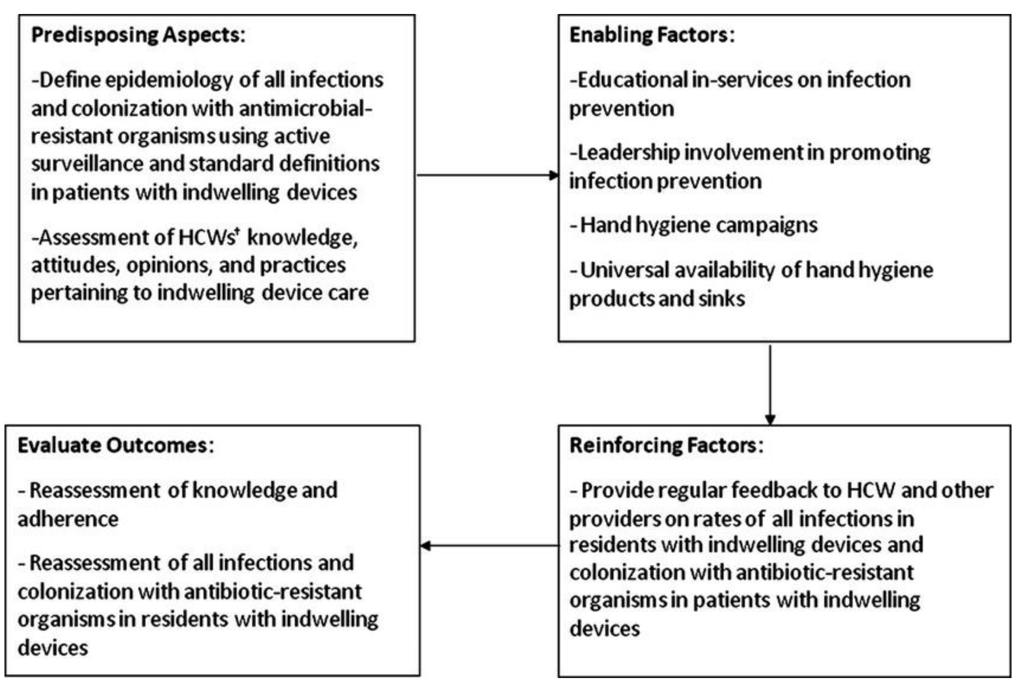
Appendix B. Routes of Transmission



Appendix C. A Conceptual Model of the Pathways of AMR Genes



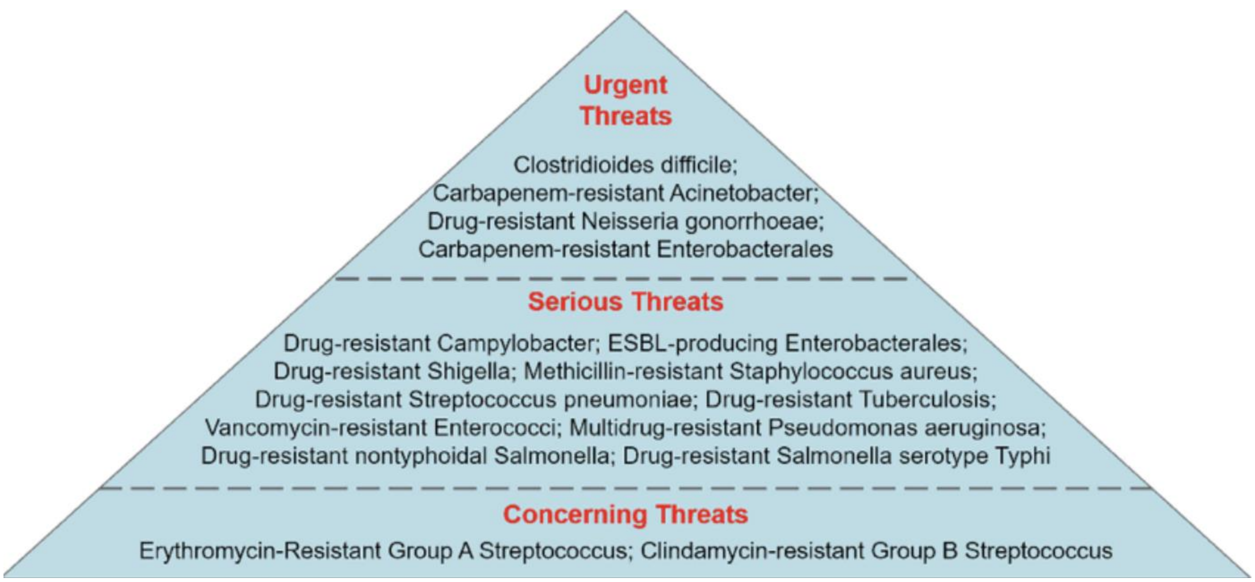
Appendix D. Precede-Proceed Model



Appendix E. USDA's Government Payments to Commercial Farms

	Government payments to farm operator households			
	Countercyclical	Marketing loans	Conservation	Other
Major programs included	PLC, ARC	LDP, MLG	EQIP, CSP, CRP	MFP, disaster and other emergency
Total payments in 2019 ($ billion)	1.8	0.8	2.9	9.3
Average payment in 2019 ($), by farm type				
Commercial	28,093	48,444	21,376	67,807
Intermediate	5,800	10,236	7,043	11,157
Residence	2,660	9,240	7,173	6,470

Appendix F. The CDC's Classification of Antibiotic Resistant Bacteria



Appendix G. MPH Competencies

Policy in Public Health	Advocate for political, social and economic policies and programs that will improve health in diverse populations
Policy in Public Health	Evaluate policies for their impact on public health and health equity
Communication	Communicate audience-appropriate public health content, both in writing and through oral presentation
MPH - Community and Public Health Practice Competencies	Apply project management strategies to improve the quality of programs and services in public health settings
MPH - Community and Public Health Practice Competencies	Identify environmental health risks in vulnerable communities and examine strategies to reduce exposures

Appendix H. Definition of SMART Goals

Appendix I. Wastewater Treatment Plant SMART Goals

SMART Goals

SMART Goal #1	Within the next week, categorize waste from 100% of the commercial farms received at this plant into designated sections to avoid cross contamination between different regions.
SMART Goal #2	In three months, 50% of waste will be tested before being spread to agricultural land.
SMART Goal #3	Annual USDA grant applications will be applied for to ensure funding for this project.

Appendix J. Risks and Mitigations

Serial	Risk ID	Occurrence Date	Risk Details			Risk Assesment					Risk Owner	Risk Materialization Tracking	Risk Response Planning					Risk Status
			Cause Due To...	Risk There is a risk/opportunity that...	Effect This will result in...	Risk Category	Risk Urgency	Probability	Impact	Rank			Strategy	Action	Date By	Action By	Last Risk Revision Date	
1	RXXX	Date	Write the reason you think caused the risk	What is the risk/opportunity that would happen?	How the risk/opportunity will affect the project	Category #1	Urgent	200	2	400			Mitigate	What action will mitigate the risk?	Action Date	Who is taking the action?	revision date (to be updated periodically)	Open
2	R001	Immediate	Did not successfully reduce this antibiotic in commercial farming.	Drug-resistant Neisseria gonnorhoeae	project failure	Category #1	Very Urgent	200	5	1000	PM	Recurrent	Mitigate	Actively prohibt the use of this antibiotic in commercial farming	Immediate	FDA	reoccuring	Open
3	R002	Immediate	Did not successfully reduce this antibiotic in commercial farming.	Drug-resistant Campylobacter	project failure	Category #2	Urgent	200	3	600	PM	Recurrent	Mitigate	Actively prohibt the use of this antibiotic in commercial farming	Immediate	FDA	reoccuring	Open
4	R003	Immediate	Did not successfully reduce this antibiotic in commercial farming.	Erythromycin-resistant Group A Streptococcus	project failure	Category #3	Moderate	200	2	400	PM	Recurrent	Mitigate	Actively prohibt the use of this antibiotic in commercial	Immediate	FDA	reoccuring	Open
5	R004	Immediate	Did not successfully reduce this antibiotic in commercial farming.	Carbapenem-resistant Enterobacterales	project failure	Category #4	Very Urgent	200	5	1000	PM	Recurrent	Mitigate	Actively prohibt the use of this antibiotic in commercial farming	Immediate	FDA	reoccuring	Open
6	R005	Immediate	Did not successfully reduce this antibiotic in commercial farming.	Carbapenem-resistant Ancinetobacter	project failure	Category #5	Very Urgent	200	5	1000	PM	Recurrent	Mitigate	Actively prohibt the use of this antibiotic in commercial	Immediate	FDA	reoccuring	Open

Appendix K. Communication Management Plan

Communication Management Plan

Project Name: **Transitioning to Organic Practices**

Stakeholders	Communications Name	Delivery Method / Format	Producer (who is responsible for the conduct and output of the meeting)	Due / Frequency
Consumers	Education Brief	Mail, social media, and/or community meetings	Environmental health non-profits, health advocates, and healthcare providers	Bi-weekly
Community Groups	Motivation Education: Get Active	Community Meeting	Environmental health non-profits, health advocates	Weekly
Policy Makers	Advocacy for incentives and tighter restrictions	Call to Action	Community leaders and health advocates	Monthly
FDA	Demand a ban on medically significant antibiotics and increase surveillance systems	Call to Action	Consumers, environmental advocates, animal health advocates, and legislatures	Bi-monthly

Appendix L. Summary Milestone Schedule

SUMMARY MILESTONE SCHEDULE

Summary Milestone Schedule – List key project milestones relative to project start.	
Project Milestone	**Target Date (mm/dd/yyyy)**
• Project Start	01/01/2023
• Phase 2 - A workflow checklist within the next week will be completed to ensure staff are prepared to contact all commercial farms in the US by providing methods of data collection and surveillance briefings. - Each farm will be requested to report all antibiotic use with proof of veterinary prescription	01/08/2023
• Phase 3 - In one month, the first data collection sample will be reported. Staff are instructed to review and highlight any commercial farms out of the scope of recommended use.	02/01/2023
• Phase 4- In the three months all staff will fine and reprimand all farms who are not complying with antibiotic standards.	04/01/2023
• Project Complete- By month 6, staff will reduce the misuse of antibiotics in agriculture by implementing a surveillance system.	07/01/2023