REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

Antimicrobial Residues from Animal husbandry in Sewage and Sediment: a systematic review

Ashwani Rawat[1]*, Sanjeev Kumar Mandal[2], Preeti Naval[3]
*[1]Assistant Professor, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, India, Email Id- agri.ashwani@dbuu.ac.in, Orcid Id- 0009-0002-0626-2135
[2]Assistant Professor, Department of Computer Sceince and Information Technology, Jain (Deemed to be University), Bangalore, India, Email Id- km.sanjeev@jainuniversity.ac.in, Orcid Id- 0000-0002-5562-2486
[3]Assistant Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India, Email Id- er.preetinaval09@gmail.com, Orcid Id- 0000-0003-2988-7082

Abstract

Assessing Antimicrobial residues in a variety of environmental and animal-related conditions, extensive study explores the complex nature of Antimicrobial residues. The collection, consisting of 650 papers, provides a thorough analysis of the levels of antibiotics in soil, water, livestock and products derived from animals. According to the first search until the final article selection, the steps of the systematic review are carefully navigated, as illustrated in the PRISMA flow diagram. The integration of eighteen further sources improves the analysis to expand and offers useful data, which is significant. The study goes more deeply and presents aggregated data on Antimicrobial residues, emphasizing the need of effective synthesis for understanding environmental effects. The research offers a thorough perspective through data summaries and visual aids, assisting in well-informed decision-making. An emphasis on preventing illness is evident in the treatment distribution study across livestock categories, highlighting the necessity for specialized health and production methods. Moreover, determining the sensitivity and resistance to antibiotics in both human and non-human populations is essential for promoting responsible Antimicrobial use and preventing the emergence of resistance. The importance-based categorization of materials improves the research even more by making it simpler to assign resources and set priorities across different categories. In overall, this research offers significant understanding of the intricate terrain around Antimicrobial residues, guiding sustainable management approaches along with public health and environmental protection tactics.

Keywords: Antimicrobial Residues, Environmental Impact, Livestock, management, Antimicrobial Sensitivity

INTRODUCTION

Antimicrobial residues from animal husbandry techniques have been found in sewage and sediment systems, raising widespread concerns about their impact on the environment. Animals get these antimicrobials which include antibiotics, anti-parasitic and other veterinary medications via a variety of channels, including food, water, or injections. But a large amount of these antibiotics are expelled by animal feces, which go through the agricultural environment via waste disposal and find their way into sewage and sediment systems (1). Sewage systems are essential for controlling the removal of waste from urban and agricultural sources because they act as channels for the movement of pollutants, such as leftover antimicrobials. These residues are found in animal feces that are dumped into sewage systems untreated, which causes antimicrobial compounds to build up in wastewater. These compounds' continued presence in the environment is further facilitated by the partial elimination of these chemicals during sewage treatment operations. As a result, worries about the possible emergence an ecological and human strength are raised (2). Sediment in aquatic habitats acts as a reservoir for antimicrobial leftovers from animal husbandry, in addition to sewage systems. Contaminants from livestock can be carried by runoff from agricultural areas and accumulate in water bodies and sediment layers. Long-term ecological concerns arise from the binding

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

and retention of antimicrobial residues in sediment, which provide a continuous source of exposure for aquatic species (3). The antimicrobial destiny of sediment in the environment is further complicated by the possibility that these residues must change and re-enter the water column. Antimicrobial residues in sewage and sediment present a number of issues, including the development of Antimicrobial resistance, public health and environmental sustainability (4). The possibility for antimicrobial residues to go from these environmental compartments to food crops and into the human food chain is one of the main causes for worry. The possibility of consuming contaminated crops and that is exposed to low concentrations of antimicrobials raises concerns about the long-term consequences on public health, including the degradation of medical treatment effectiveness (5). Veterinary antimicrobial are widely used in livestock and poultry husbandry with the intention of accelerating animal development and treating diseases. The spread is not limited to animal populations; it affects people, other animal species, plants, the environment and the larger ecosystem. The result is contamination of the soil and water. The schematic Figure (1) provides a visual representation of the interrelated influence of this event.

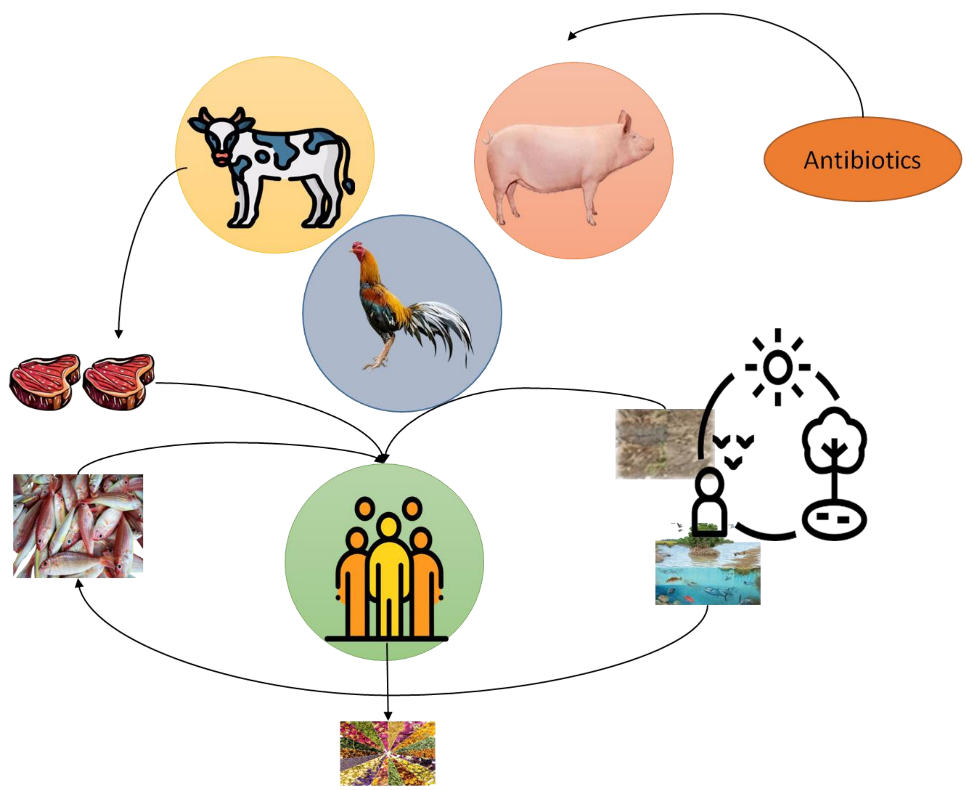

Figure (1). Transmission of AMR from livestock

[Source: https://www.mdpi.com/2079-6382/10/5/539]

Antimicrobial resistance is a worldwide health concern that is exacerbated by the environmental persistence of antibacterial residues. Low concentrations of antibiotics in the environment expose microorganisms over time, putting selection pressure on the survival and spread of resistance strains. The potential for the transmission of Antimicrobial resistance genes among bacteria is increased by this process, which affects terrestrial and aquatic ecosystems in addition to the initial animal source (6). The intricate problems caused by antimicrobial residues in animal husbandry need a comprehensive response owing to the interconnectedness of ecosystems and the transit of pollutants via different environmental compartments. A comprehensive approach that covers the whole agricultural

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

production and waste management chain is needed to lessen the effects of Antimicrobial residues in sewage and sediment (7). Improved sewage treatment procedures efficiently remove antimicrobial residues, sustainable agricultural methods that reduce the need for preventative antimicrobial usage and improved waste management strategies to guarantee correct disposal of animal waste. In order to monitor environmental concentrations, enforce adherence to antimicrobial usage standards and evaluate the efficacy of mitigation options, regulatory actions and monitoring systems are necessary (8). Animal husbandry-related antimicrobial residues in sewage and sediment pose a serious environmental threat with far-reaching effects on both ecological and human health. The interdependence of aquatic, agricultural and human systems demands a coordinated, interdisciplinary approach for solving this problem (9). Working together to create and execute sustainable methods that protect human health and animal welfare is necessary to address this problem in the agricultural, environmental and health domains. To lessen the negative impacts of Antimicrobial residues on our ecosystems and preserve the efficacy of antimicrobial medications, continuing research, policy development and international collaboration are essential owing to the complexity of this issue (10).

The research (11) discussed the increasing concern about Antimicrobial usage throughout the world, which has resulted in microbial populations that is under selection pressure and Antimicrobial resistance genes (ARGs) emerging. ARG reduction is improved by tertiary treatments, such as sophisticated oxidative procedures. When it comes to maximizing the effectiveness of treatments for removing ARG from animal feces, operational factors including temperature, hydraulic retention duration and sunlight penetration are critical. The research (12) investigated exactly happened to medications during anaerobic digestion in 29 biogas plants located in three different countries, with a focus on antibiotics (tetracyclines, sulfonamides and fluoroquinolones). The study focuses on input materials like sewage sludge as well as animal manures and it finds that 81% of substrates and 83% of digestates contain antibiotics. Notable amounts of antibiotics, especially ciprofloxacin and tetracycline, are found in sewage sludge. Most substrates showed somewhat reduced Antimicrobial concentrations during digestion. The study (13) conducted an extensive review of existing literature pertaining to five veterinary antibiotics amoxicillin, enrofloxacin, sulfadiazine, tetracycline, and trimethoprim commonly employed in animal production. The identified significant risk to soil and surface water, as indicated by predicted environmental concentrations (PECs), underscores the pressing necessity for regulatory measures to mitigate potential adverse effects stemming from antimicrobial residues in the soil. The research (14) examined the use of antibiotics in Indian aquaculture, cattle and poultry with an emphasis on animal Antimicrobial resistance and the spread of resistance genes across environmental niches. It explores the categorization, processes, dangers and advantages of antibiotics. The research (15) focused on the paucity of systematic information on the risk factors and Antimicrobial source distribution in peri-urban waterways. This study describes 16 antibiotics found in water and sediment in Beijing's Chaobai River and links them to environmental conditions. Strategies for preventing and controlling pollution are informed by assessments of the Eco toxicological hazards, mixture toxicity and synergistic effects of Antimicrobial combinations.

The research (16) examined more than 170 publications on the prevalence of antibiotics in China's environment as part of an extensive examination of the literature. The results showed that, apart from the atmosphere, 110 antibiotics were found, of which 28 were considered widely distributed. The frequency of certain antibiotics, such as tetracycline, ofloxacin and sulfamethoxazole, was highlighted using cluster analysis, which found seven dominating antibiotics across all environmental compartments. Major river basins were found to have different median amounts of antibiotics; the Haihe River Basin had greater quantities. The research (17) examined an Antimicrobial and ARG. Test results showed elevated amounts of ARG and antibiotics up to 20 kilometers downstream from the WWTP. The river system functions as an ARG reservoir even when human Antimicrobial usage is minimal. The research (18) evaluated Antimicrobial residues in rivers that were discharged from sewage sources, including as wastewater treatment facilities, aquaculture farms and livestock farms. Concentrations were found in sediment and water

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

samples, ranging from not detectable to 1039.53 ng g−1 and 530.05 ng L−1, correspondingly. According to a principal component analysis, aquaculture and cattle farms contributed 21.2% and wastewater treatment facilities, 66.8%, respectively. The aquatic ecosystems medium risk was found to be caused by ciprofloxacin, highlighting the significance of environmental management and the prevention of Antimicrobial pollution in Shanghai. The research (19) explored into the manner that antibiotics affected Lake Titicaca's drinking water, trout tissues and aquatic ecology. High amounts of nine antibiotics, including tetracyclines, sulfonamides and fluoroquinolones, were found in surface water and soil after monitoring of these substances. Antimicrobial contamination in the lake has originated from aquaculture. The research (20) proved to track zoonotic bacteria, resistance genes and Antimicrobial residues while biological nitrogen was being removed from swine dung. Over the course of six time periods on two farms, seven antibiotics, nine resistance genes and two bacteria were monitored. The study identified antibiotics that had been used over the previous three months. Doxycycline was found and sulfadiazine was recovered in the majority of samples. While there was a decrease in residues in the storage lagoon as compared to the liquid fraction, there was no significant difference seen.

METHODS AND MATERIALS

The PRISMA research flow diagram shows the steps involved with conducting a systematic review, from the initial search and screening phase to the final selection of articles for inclusion in the comprehensive review. The data we collected consisted of 18 articles shown in Figure (2) that reported Antimicrobial residue levels in a variety of contexts, such as the environment, soil, aquatic and terrestrial animal tissues, livestock (cattle, sheep, pigs, horses, chickens, rabbits and goats), wastewater as well as animal-derived products (milk and eggs).

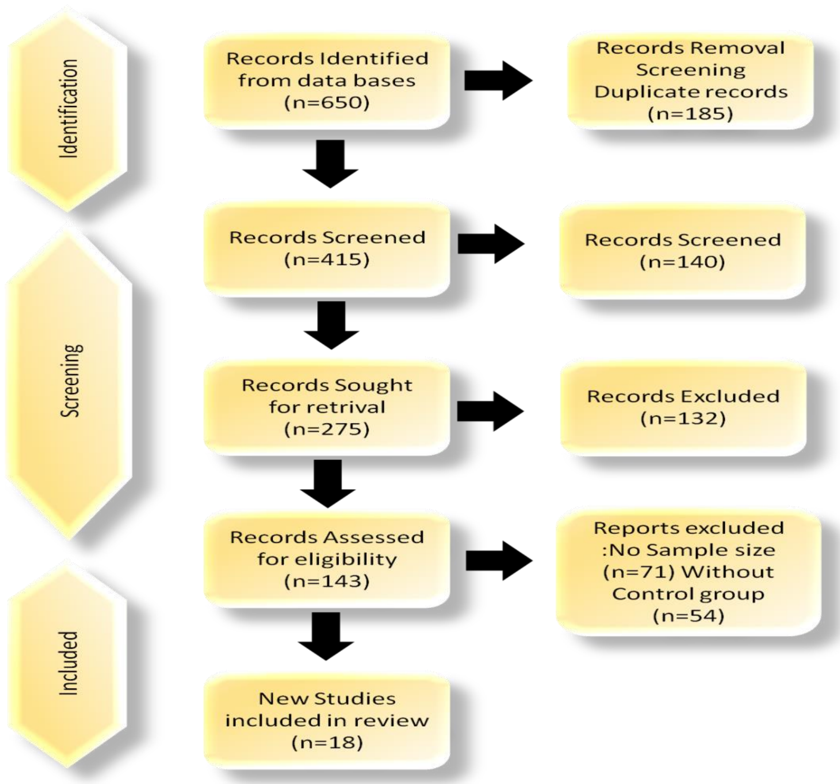

Figure (2). Flow of PRISMA (Source:Author)

During the identification stage of this research, 650 entries in total were found in different databases. After 185 duplicate entries were eliminated throughout a thorough screening procedure, 415 unique records were left for further evaluation. Following the next round of screening, 140 records were examined; 275 of them were chosen to be retrieved. At the eligibility evaluation step, 132 records were excluded for a diversity of cause, including a lack of a control group (54 records) and an inadequate sample size (71 records). In the final phase, 143 records were evaluated for eligibility. Reports without a control group or one with an unspecified sample size were not included in the final inclusion. As a result, eighteen more studies were found to be eligible for inclusion in the thorough review, adding significant knowledge to the corpus of previous research on the topic. The selection of solid and relevant research for the ensuing phases of analysis and synthesis was guaranteed by this methodical procedure.

Presentation of aggregated data on antimicrobial residues in sewage and sediment

A methodical and significant synthesis of data from many investigations is required for the presenting of aggregated data on Antimicrobial residues in sewage and sediment (21). Through this procedure, important information on the kinds, amounts and distribution of antimicrobial residues originating from animal husbandry activities will be distilled. In this context, efficiency pertains to the seamless arrangement and dissemination of this copious amount of data, which enables a thorough comprehension of the environmental effect. The use of statistical summaries is essential for achieving this efficiency (22). Quantitative studies of aggregated data are performed to compute averages, trends and variances in Antimicrobial concentrations. Hotspot of contamination, probable regions of concern and common antimicrobial agents has been identified using this quantitative method. The efficiency of data transmission is further improved by graphic representations, such as charts and maps, which provide visual clarity that is easier to understand and absorb than raw numerical data. Contextualizing the quantitative results is part of the presentation's narrative section. The tale of Antimicrobial residues in sewage and sediment is interwoven in this narrative, emphasizing subtleties, anomalies and possible causes of variation. Incorporating a qualitative component into the quantitative data allows for a more comprehensive comprehension of the dynamics of the environment. For example, the story might clarify relationships between certain geographic regions, particular animal husbandry techniques and the persistence of particular Antimicrobial residues (23). Their ability to understand the present situation regarding antimicrobial residues in sewage along with sediment, make educated judgments that create plans for reducing threats to the environment and public health is enhanced. When it comes to antimicrobial residues from animal husbandry techniques in sewage and sediment, efficiency in this context means reducing complexity into insightful understandings that motivate action (24).

Environmental Impact Assessment (EIA)

An environmental impact assessment (EIA) is a methodical procedure that entails assessing the possible consequences on the environment of a certain project, activity, or material (25). When we discuss Antimicrobial residues, we mean EIA, which is the study of the effects of these residues on aquatic ecosystems and the habitats around them. The objective is to get a thorough understanding and forecast the potential effects of antimicrobial residues on the biodiversity, ecological balance and general health of these ecosystems (26). The evaluation usually takes a multidisciplinary approach, considering variables including the kinds and amounts of antimicrobial residues, the features of the impacted ecosystems and the susceptibilities of the local flora and fauna. It includes many different elements, such as the environment's physical, chemical and biological components as well as possible direct and indirect impacts on species and habitats. An environmental impact assessment would provide insight into how antimicrobial residues from animal husbandry in sewage and sediment might change the makeup of microbial communities, affect the wellbeing of aquatic life and possibly interfere with ecosystem function (27). It could investigate the channels by which Antimicrobial residues travel through the ecosystem, such sedimentation or water movement. This procedure is essential for environmentally sustainable management and it is mandated by law for

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

actions that might have a large negative impact on the environment. When it comes to antimicrobial residues specifically, an EIA helps to direct interventions to reduce adverse effects on aquatic ecosystems and surrounding environments while advancing our knowledge of the substances' wider effects beyond their immediate presence (28). The process, which is mandated by regulations for actions that have a substantial negative, is essential for sustainable environmental management. An environmental impact assessment, in the particular instance of antimicrobial residues, aids in directing interventions to reduce adverse effects on aquatic ecosystems and surrounding environments that advances our knowledge of the substances' wider effects beyond their immediate presence (29).

Ecological Impact of Antimicrobial Residues in Aquatic Environments

The ecological effects of antimicrobial residues in aquatic habitats require a thorough examination of the consequences for biodiversity, water quality and the complex network of ecological interactions (30). This thorough examination includes the surrounding habitats that are impacted by these contaminants in addition to the water-based ecosystems themselves. Through examining the changes in microbial communities have possible perturbations to the nutrient cycle and the bioaccumulation of Antimicrobial residues in aquatic species (31). The complex processes that affect these ecosystems' overall health. Comprehending the wider ecological ramifications is essential for developing practical approaches for reducing the environmental effect, conserving biodiversity and defending the fragile equilibrium that supports aquatic life and its environs (32). The establishment of sustainable practices and well-informed decision-making for the management of antimicrobial residues in aquatic environments are both facilitated by this comprehensive approach.

These Impacts includes many dimensions:

- Studying the effects of Antimicrobial residues on fish, invertebrates along with other aquatic creatures' variety, abundance and behavior. Assessing possible alterations to food chains and ecological connections in the aquatic ecosystem is part of approach (33).
- Assessing those antimicrobial residues can change the physical and chemical properties of the aquatic environment, such as the parameters of the water quality and the composition of the sediment and how this affects the health of the ecosystem as a whole (34).
- Investigating those Antimicrobial residues alter the microbial populations in watery settings. Examining changes in the make-up and capabilities of bacteria and other microbes is part of the aforementioned, since they are essential to the cycling of nutrients and the preservation of ecological equilibrium (35).
- Evaluating the bioaccumulation process, this is the gradual build-up of antimicrobial residues in the tissues of aquatic life. This is especially important to comprehend how these compounds go up the food chain and perhaps impact creatures at higher tropic levels, including those humans eat (36).
- Examining the ways in which antimicrobial residues can interfere with or modify essential functions in aquatic environments, such the cycling of nutrients, primary production and decomposition. The ecosystem as a whole to be affected in a cascade of ways by changes to these processes (37).
- Exploring that long-term exposure to antimicrobial residues might cause aquatic ecosystems to adapt or recover. Predicting long-term effects and directing conservation and management activities need an understanding of these ecosystems' resilience (38).

Field investigations, lab tests and modeling techniques are used in these examinations to collect information on the existence, trajectory and consequences of Antimicrobial residues. Informed policies, regulations and mitigation methods to safeguard aquatic ecosystems and the surrounding environment can be developed with its significant insights on the larger environmental effects.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

Treatment Distribution in Livestock

The frequency percentages represent the treatment kinds' prevalence across various cattle groups. Disease prevention accounts for 84.5 percent of cattle cases, while fattening techniques comprise 3.1% of instances. Disease prevention accounts for 90.7% of therapies in the case of goats, compared to 1% and 8.2% for fattening and other treatments. Similarly, sheep (87.8%) place a high priority on preventing sickness, with 3.1% going toward fattening practices.

Table (1). Distribution of Treatment Types among Livestock

[**Source:** https://www.frontiersin.org/articles/10.3389/fvets.2020.00055/full]

Types	**Frequency percentage**		
	Treatment	**Disease prevention**	**Fattening**
Cattle	84.5	11.3	3.1
Goat	90.7	8.2	1
Sheep	87.8	10.2	3.1

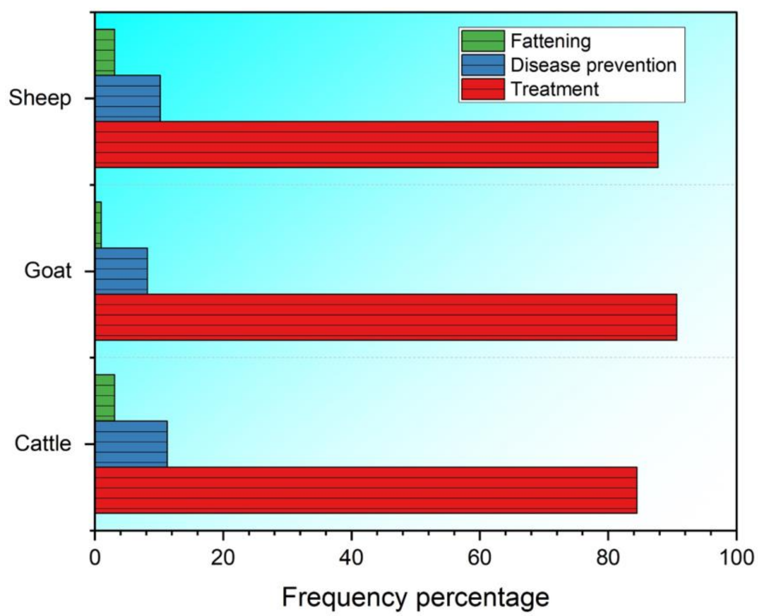

Figure (3). Frequency Percentage of Treatment Types in Livestock

[**Source**: https://www.frontiersin.org/articles/10.3389/fvets.2020.00055/full]

Table (1) and Figure (3) provide an overview of the most common treatment approaches used in each livestock category, revealing that production goals and health maintenance measures are prioritized. Designing focused

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

treatments and sustainable livestock management techniques that complement the unique requirements and traits of every animal category requires an understanding of the distribution of treatment types.

Differentiated Livestock Management Treatment Methods

The distribution of various treatment methods across different livestock groups is shown in Table (2) as frequency percentages. 6.2% of cattle get treatments that are not described, 64.8% of cattle receive measures to avoid illness and 50% of cattle undergo fattening procedures. In goats, 28.4% are engaged in fattening, 65.7% get illness prevention and 6% receive additional treatments. Comparably, among sheep, 42.9% are fattened, 65.8% get illness prevention and 8.7% receive no treatment entirely.

Table (2). Treatment Types across Livestock Categories

[**Source:** https://www.frontiersin.org/articles/10.3389/fvets.2020.00055/full]

Types	Frequency percentage		
	Treatment	**Disease prevention**	**Fattening**
Cattle	6.2	64.8	50
Goat	6	65.7	28.4
Sheep	8.7	65.8	42.9

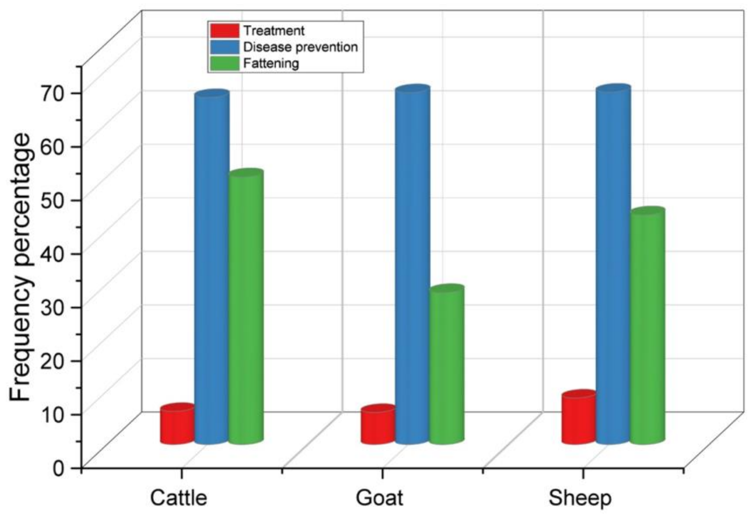

Figure (4). Treatment Distribution in Livestock

[**Source**: https://www.frontiersin.org/articles/10.3389/fvets.2020.00055/full]

Figure (4) illustrates the general availability of disease preventive techniques by demonstrating the range of treatment options used across cattle species. Recognizing these distributions serves a pivotal role in providing

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

gained livestock management, enabling the formulation of focused plans for health care and production that are customized to the individual requirements of every animal group.

Antimicrobial Sensitivity and Resistance Analysis

The percentages of susceptibility and resistance to several antibiotics in human and non-human populations are shown in table (3). For an instance, cephalothin exhibits 100% sensitivity, meaning that resistance cannot be observed in either human or non-human subject. Conversely, gentamycin exhibits 30% resistance and 67% sensitivity in humans as well as 23% resistance and 86% sensitivity in non-human animals.

Table (3). Percentage of Antimicrobial Sensitivity and Resistance

[**Source:** https://www.researchgate.net/figure./Antibiotic-resistance-patterns-of-E-coli-from-humans-and-non-humans-sources_fig3_46150522]

Antibiotics	% of sensitivity			
	Resistance humans	Susceptible humans	Resistance non-humans	Susceptible non-humans
Cephalothin	100	0	100	0
Penicillin G	98	4	83	18
Kanamycin	96	5	95	8
Sulthothiazole	96	5	72	28
Tetracycline	95	6	64	43
Nalidixic acid	94	8	83	14
Gentamycin	30	67	23	86
Ciprofloxacin	4	94	5	91
Chloramphenicol	3	97	18	82
Neomycin	2	96	9	89

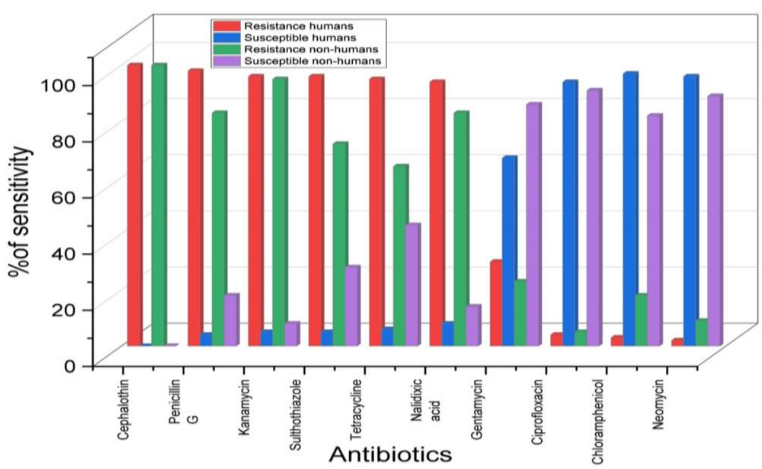

Figure (5). Antimicrobial Sensitivity and Resistance Distribution
[**Source:** https://www.researchgate.net/figure./Antibiotic-resistance-patterns-of-E-coli-from-humans-and-non-humans-sources_fig3_46150522]

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

Figure (5) illustrates the results, which emphasize the potential effect on human and animal health by highlighting differences in Antimicrobial susceptibility. It is worth noting that human susceptibility rates to certain antibiotics, such ciprofloxacin and chloramphenicol, are greater than those of non-human species. Given the consequences for the development of Antimicrobial resistance in diverse populations, it is important to comprehend these patterns to utilize antibiotics with knowledge in both veterinary and medical settings.

Importance Categorization across Entities

Table (4) provides a degree of value to entities according to their relevance in certain categories. The categories have designations ranging from Very High significance (I) through Low Importance (IV) and the distribution of entities in each significance level is shown by the appropriate number values.

Table (4). Importance Levels across Categories

[**Source:** Author]

Category	Very high Importance I	High Importance II	Medium Importance III	Low Importance IV
Pets	38	64	5	2
Live stock	2	24	38	37
Humans	29	68	4	2
Feedlot Cattle	1	2	6	88

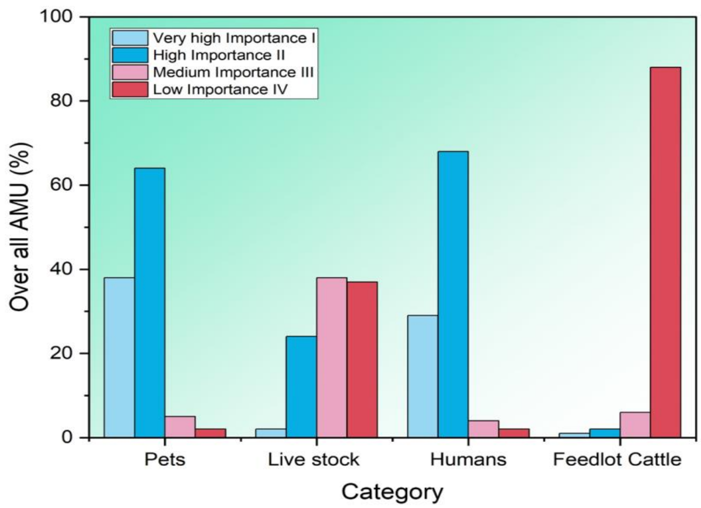

Figure (6). Distribution of Importance Levels

[**Source:** Author]

For example, 38 entities are classified as Very High Importance, 64 as High Importance, 5 as Medium Importance and 2 as Low Importance in the "Pets" category. Comparably, "Livestock" comprises 24 entities of High Importance, 38 entities of Medium Importance and 37 entities of Low Importance. This categorization gives an organized picture of an important each category's constituents are thought to be, giving valuable information for allocating resources and establishing concerns as shown in Figure (6).

CONCLUSION

The complex network of Antimicrobial residues is uncovered by this research, from their occurrence in diverse settings to their effects on distinct species, to sum up. A strong grasp of Antimicrobial dynamics is ensured by the inclusion of additional papers, which improve the review's comprehensiveness. An emphasis on disease prevention is placed by the treatment distribution analysis, which highlights the need of focused health initiatives in livestock management. Analyzing patterns of Antimicrobial sensitivity and resistance shows subtle differences between human and non-human populations, which are important to maximize the use of antibiotics and prevent problems with resistance. Setting priorities and allocating resources between entities is made easier by the organized viewpoint that the significance category offers. The research promotes an interdisciplinary strategy that integrates quantitative and qualitative investigations as we negotiate the intricacies of Antimicrobial residues. This comprehensive knowledge is essential for developing sustainable management strategies, making well-informed decisions, reducing possible environmental concerns and protecting public health.

REFERENCES

[1] Guo, X., Feng, C., Gu, E., Tian, C., & Shen, Z. (2019). Spatial distribution, source apportionment and risk assessment of antibiotics in the surface water and sediments of the Yangtze Estuary. Science of the Total Environment, 671, 548-557. https://doi.org/10.1016/j.scitotenv.2019.03.393

[2] Bombaywala, S., Mandpe, A., Paliya, S., & Kumar, S. (2021). Antimicrobial resistance in the environment: A critical insight on its occurrence, fate, and eco-toxicity. Environmental Science and Pollution Research, 28, 24889-24916. https://doi.org/10.1007/s11356-021-13143-x

[3] Serwecińska, L. (2020). Antimicrobials and antibiotic-resistant bacteria: a risk to the environment and to public health. Water, 12(12), 3313. https://doi.org/10.3390/w12123313

[4] Rashid, A., Mazhar, S. H., Zeng, Q., Kiki, C., Yu, C. P., & Sun, Q. (2020). Simultaneous analysis of multiclass Antimicrobial residues in complex environmental matrices by liquid chromatography with tandem quadrupole mass spectrometry. Journal of chromatography B, 1145, 122103. https://doi.org/10.1016/j.jchromb.2020.122103

[5] Kimera, Z. I., Mgaya, F. X., Mshana, S. E., Karimuribo, E. D., & Matee, M. I. (2021). Occurrence of extended spectrum beta lactamase (ESBL) producers, quinolone and carbapenem resistant Enterobacteriaceae isolated from environmental samples along Msimbazi River basin ecosystem in Tanzania. International Journal of Environmental Research and Public Health, 18(16), 8264. https://doi.org/10.3390/ijerph18168264

[6] Kairigo, P., Ngumba, E., Sundberg, L. R., Gachanja, A., & Tuhkanen, T. (2020). Occurrence of antibiotics and risk of Antimicrobial resistance evolution in selected Kenyan wastewaters, surface waters and sediments. Science of The Total Environment, 720, 137580. https://doi.org/10.1016/j.scitotenv.2020.137580

[7] Voigt, A. M., Ciorba, P., Döhla, M., Exner, M., Felder, C., Lenz-Plet, F., ... & Faerber, H. A. (2020). The investigation of Antimicrobial residues, Antimicrobial resistance genes and antibiotic-resistant organisms in a drinking water reservoir system in Germany. International journal of hygiene and environmental health, 224, 113449. https://doi.org/10.1016/j.ijheh.2020.113449

[8] Wang, L., Li, H., Dang, J., Guo, H., Zhu, Y. E., & Han, W. (2021). Occurrence, distribution, and partitioning of antibiotics in surface water and sediment in a typical tributary of Yellow River, China. Environmental Science and Pollution Research, 28, 28207-28221. https://doi.org/10.1007/s11356-021-12634-1

[9] Kimera, Z. I., Mshana, S. E., Rweyemamu, M. M., Mboera, L. E., & Matee, M. I. (2020). Antimicrobial use and resistance in food-producing animals and the environment: an African perspective. Antimicrobial Resistance & Infection Control, 9, 1-12. https://doi.org/10.1186/s13756-020-0697-x

[10] Milaković, M., Vestergaard, G., González-Plaza, J. J., Petrić, I., Kosić-Vukšić, J., Senta, I., ... & Udiković-Kolić, N. (2020). Effects of industrial effluents containing moderate levels of Antimicrobial mixtures on the abundance of Antimicrobial resistance genes and bacterial community composition in exposed creek sediments. Science of the Total Environment, 706, 136001. https://doi.org/10.1016/j.scitotenv.2019.136001
[11] Pereira, A. R., Paranhos, A. G. D. O., de Aquino, S. F., & Silva, S. D. Q. (2021). Distribution of genetic elements associated with Antimicrobial resistance in treated and untreated animal husbandry waste and wastewater. Environmental Science and Pollution Research, 28, 26380-26403. https://doi.org/10.1007/s11356-021-13784-y
[12] Lehmann, L., & Bloem, E. (2021). Antimicrobial residues in substrates and output materials from biogas plants–Implications for agriculture. Chemosphere, 278, 130425. https://doi.org/10.1016/j.chemosphere.2021.130425
[13] Menz, J., Olsson, O., & Kümmerer, K. (2019). Antimicrobial residues in livestock manure: Does the EU risk assessment sufficiently protect against microbial toxicity and selection of resistant bacteria in the environment?. Journal of hazardous materials, 379, 120807. https://doi.org/10.1016/j.jhazm at.2019.120807
[14] Sivagami, K., Vignesh, V. J., Srinivasan, R., Divyapriya, G., & Nambi, I. M. (2020). Antimicrobial usage, residues and resistance genes from food animals to human and environment: An Indian scenario. Journal of Environmental Chemical Engineering, 8(1), 102221. https://doi.org/10.1016/j.jece.2018.02.029
[15] Zhang, Y., Chen, H., Jing, L., & Teng, Y. (2020). Ecotoxicological risk assessment and source apportionment of antibiotics in the waters and sediments of a peri-urban river. Science of the total environment, 731, 139128. https://doi.org/10.1016/j.scitotenv.2020.139128
[16] Huang, F., An, Z., Moran, M. J., & Liu, F. (2020). Recognition of typical Antimicrobial residues in environmental media related to groundwater in China (2009− 2019). Journal of Hazardous Materials, 399, 122813. https://doi.org/10.1016/j.jhazmat.2020.122813
[17] Sabri, N., Schmitt, H., Van der Zaan, B., Gerritsen, H. W., Zuidema, T., Rijnaarts, H. H. M., & Langenhoff, A. A. M. (2020). Prevalence of antibiotics and Antimicrobial resistance genes in a wastewater effluent-receiving river in the Netherlands. Journal of environmental chemical engineering, 8(1), 102245. https://doi.org/10.1016/j.jece.2018.03.004
[18] Li, D., Shao, H., Huo, Z., Xie, N., Gu, J., & Xu, G. (2021). Typical antibiotics in the receiving rivers of direct-discharge sources of sewage across Shanghai: Occurrence and source analysis. RSC advances, 11(35), 21579-21587. https://doi.org/10.1039/D1RA02510D
[19] Vilca, F. Z., Galarza, N. C., Tejedo, J. R., Cuba, W. A. Z., Quiróz, C. N. C., & Tornisielo, V. L. (2021). Occurrence of residues of veterinary antibiotics in water, sediment and trout tissue (Oncorhynchus mykiss) in the southern area of Lake Titicaca, Peru. Journal of Great Lakes Research, 47(4), 1219-1227. https://doi.org/10.1016/j.jglr.2021.04.012
[20] Van den Meersche, T., Rasschaert, G., Haesebrouck, F., Van Coillie, E., Herman, L., Van Weyenberg, S., ... & Heyndrickx, M. (2019). Presence and fate of Antimicrobial residues, Antimicrobial resistance genes and zoonotic bacteria during biological swine manure treatment. Ecotoxicology and environmental safety, 175, 29-38. https://doi.org/10.1016/j.ecoenv.2019.01.127
[21] Pan, X., Chen, Z., Zhai, W., Dong, L., Lin, L., Li, Y., & Yang, Y. (2023). Distribution of antibiotic resistance genes in the sediments of Erhai Lake, Yunnan-Kweichow Plateau, China: Their linear relations with nonpoint source pollution discharges from 26 tributaries. Environmental Pollution, 316, 120471. https://doi.org/10.1016/j.envpol.2022.120471
[22] Harrower, J., McNaughtan, M., Hunter, C., Hough, R., Zhang, Z., & Helwig, K. (2021). Chemical fate and partitioning behavior of antibiotics in the aquatic environment—a review. Environmental toxicology and chemistry, 40(12), 3275-3298. https://doi.org/10.1002/etc.5191
[23] Han, Q. F., Zhao, S., Zhang, X. R., Wang, X. L., Song, C., & Wang, S. G. (2020). Distribution, combined pollution and risk assessment of antibiotics in typical marine aquaculture farms surrounding the Yellow Sea, North China. Environment International, 138, 105551. https://doi.org/10.1016/j.envint.2020.105551
[24] Al Salah, D. M. M., Laffite, A., & Poté, J. (2019). Occurrence of bacterial markers and antibiotic resistance genes in sub-Saharan rivers receiving animal farm wastewaters. Scientific Reports, 9(1), 14847. https://doi.org/10.1038/s41598-019-51421-4
[25] Lu, P., Fang, Y., Barvor, J. B., Neth, N. L. K., Fan, N., Li, Z., & Cheng, J. (2019). Review of antibiotic pollution in the seven watersheds in China. Polish Journal of Environmental Studies, 28(6), 4045-4055. https://doi.org/10.15244/pjoes/99061

[26] Peng, Q., Song, J., Li, X., Yuan, H., Liu, M., Duan, L., & Zuo, J. (2020). Pharmaceutically active compounds (PhACs) in surface sediments of the Jiaozhou Bay, north China. Environmental Pollution, 266, 115245. https://doi.org/10.1016/j.envpol.2020.115245

[27] Ekwanzala, M. D., Lehutso, R. F., Kasonga, T. K., Dewar, J. B., & Momba, M. N. B. (2020). Environmental dissemination of selected antibiotics from hospital wastewater to the aquatic environment. Antibiotics, 9(7), 431. https://doi.org/10.3390/antibiotics9070431

[28] Chen, L., Li, H., Liu, Y., Cui, Y., Li, Y., & Yang, Z. (2020). Distribution, residue level, sources, and phase partition of antibiotics in surface sediments from the inland river: a case study of the Xiangjiang River, south-central China. Environmental Science and Pollution Research, 27, 2273-2286. https://doi.org/10.1007/s11356-019-06833-0

[29] Xie, H., Hao, H., Xu, N., Liang, X., Gao, D., Xu, Y., ... & Wong, M. (2019). Pharmaceuticals and personal care products in water, sediments, aquatic organisms, and fish feeds in the Pearl River Delta: Occurrence, distribution, potential sources, and health risk assessment. Science of the total Environment, 659, 230-239. https://doi.org/10.1016/j.scitotenv.2018.12.222

[30] Zhang, L., Bai, J., Zhang, K., Wang, Y., Xiao, R., Campos, M., ... & Jorquera, M. A. (2023). Occurrence, bioaccumulation and ecological risks of antibiotics in the water-plant-sediment systems in different functional areas of the largest shallow lake in North China: Impacts of river input and historical agricultural activities. Science of The Total Environment, 857, 159260. https://doi.org/10.1016/j.scitotenv.2022.159260

[31] Wang, J., Wei, H., Zhou, X., Li, K., Wu, W., & Guo, M. (2019). Occurrence and risk assessment of antibiotics in the Xi'an section of the Weihe River, northwestern China. Marine Pollution Bulletin, 146, 794-800. https://doi.org/10.1016/j.marpolbul.2019.07.016

[32] Chen, H., Bai, X., Li, Y., Jing, L., Chen, R., & Teng, Y. (2019). Characterization and source-tracking of antibiotic resistomes in the sediments of a peri-urban river. Science of The Total Environment, 679, 88-96. https://doi.org/10.1016/j.scitotenv.2019.05.063

[33] Anh, H. Q., Le, T. P. Q., Da Le, N., Lu, X. X., Duong, T. T., Garnier, J., ... & Nguyen, T. A. H. (2021). Antibiotics in surface water of East and Southeast Asian countries: A focused review on contamination status, pollution sources, potential risks, and future perspectives. Science of The Total Environment, 764, 142865. https://doi.org/10.1016/j.scitotenv.2020.142865

[34] Chow, L. K., Ghaly, T. M., & Gillings, M. R. (2021). A survey of sub-inhibitory concentrations of antibiotics in the environment. Journal of Environmental Sciences, 99, 21-27. https://doi.org/10.1016/j.jes.2020.05.030

[35] Fouz, N., Pangesti, K. N., Yasir, M., Al-Malki, A. L., Azhar, E. I., Hill-Cawthorne, G. A., & Abd El Ghany, M. (2020). The contribution of wastewater to the transmission of antimicrobial resistance in the environment: implications of mass gathering settings. Tropical medicine and infectious disease, 5(1), 33. https://doi.org/10.3390/tropicalmed5010033

[36] Zou, M., Tian, W., Zhao, J., Chu, M., & Song, T. (2022). Quinolone antibiotics in sewage treatment plants with activated sludge treatment processes: a review on source, concentration and removal. Process Safety and Environmental Protection, 160, 116-129. https://doi.org/10.1016/j.psep.2022.02.013

[37] Bombaywala, S., Dafale, N. A., Jha, V., Bajaj, A., & Purohit, H. J. (2021). Study of indiscriminate distribution of restrained antimicrobial resistome of different environmental niches. Environmental Science and Pollution Research, 28, 10780-10790. https://doi.org/10.1007/s11356-020-11318-6

[38] Reichert, G., Hilgert, S., Alexander, J., de Azevedo, J. C. R., Morck, T., Fuchs, S., & Schwartz, T. (2021). Determination of antibiotic resistance genes in a WWTP-impacted river in surface water, sediment, and biofilm: Influence of seasonality and water quality. Science of the Total Environment, 768, 144526. https://doi.org/10.1016/j.scitotenv.2020.144526