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Advanced Insights into Artificial Intelligence Applications in Antibiotic Resistance

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ABSTRACT

To examine key areas and emerging directions in artificial Intelligence (AI) research correlated to Antibiotic resistance. Research literature on AI in the field of Antibiotic resistance was gathered from the Science Citation Index expanded, which is part of the Scopes. This data was analyzed to gain insights into publication years, countries/regions, institutions, citations, and keywords. Co-occurrence network graphs were created using the VOSviewer Library, Publish or Perish, and CiteSpace tools on the online analysis platform. The analysis of AI-related antibiotic sensitivity research (2020–2025) highlights China's guiding contribution, fluctuating magazine trends, disparities in institutional output, and a strong research focus on bacterial resistance, biofilms, and quorum sensing, with bibliometric analysis revealing the dominance of antibiotic resistance as a key topic and citation metrics showing rapidly evolving scientific discussions in microbiology and antimicrobial research. The study identified key focus areas and emerging trends in artificial intelligence for antibiotic resistance and the role of certain bacteria on the patient, suggesting that artificial intelligence will play an increasingly prominent role in antibiotic resistance moving forward.

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1. Background

The discovery of antibiotics in the early twentieth century was a powerful turning point in the battle against bacterial infections. The development of antibiotic research was the result of many years of gradual improvement, beginning with Antonie van Leeuwenhoek's early observations of bacterial structure. This journey continued with John Parkington's mention of the healing belongings of mold in the seventeenth century, the disproof of the abiogenesis theory, and the characterization of infectious diseases [1]. Antibiotics are drugs used in both critical care hospitals and outpatient clinics. While the rational and necessary use stays a challenge, the irrational and excessive usage increases the emergence of multidrug resistant bacteria (MDR), causing higher mortality, longer hospitalization, and high costs for fitness care [2,3].

Antimicrobial resistance (AMR) is the capability of microbes to mitigate the action of antimicrobials, it has been remembered as a global public health emergency [4]. AMR poses an important problem to global health systems and is recognized as one of the top ten public health global threats [5,6]. A prior report to the World Health Organization said that, without more effective interventions, AMR is projected to result in 10 million deaths by 2050. [7,8].

Due to the continued increase of antibiotic resistance and MDR, it is necessary to seek solutions for this puzzle. The current analysis actions have mainly targeted factors that related to bacterial pathogenicity like biofilm, quorum sensing, and other techniques, other models deals with enhancing the knowledge in the usage of antibiotic [9,10]. Accordingly, researchers should concentrate on building and developing molecules with creative target sites. On the other hand, researching and marketing new antibiotics face technical difficulties and economic hardships. These problems include a depletion of devices, infrastructure, and trained individuals [11].

Artificial intelligence (AI) and related tools play a role in combating AMR by enhancing diagnostic accuracy, optimizing antibiotic prescribing, and accelerating the discovery of novel antimicrobial agents. In the realm of antibiotic stewardship, AI-driven systems minimize misuse and reduce the development of resistant bacterial strains. Tools such as the "UTI Smart-Set" have demonstrated significant reductions in antibiotic mismatches. Furthermore, AI enables the rapid identification of therapeutic compounds, predicts key molecular properties, and reduces the time and cost associated with drug discovery and development. It also optimizes drug design, predicts resistance patterns, and repurposes existing compounds, offering

innovative solutions to strengthen the fight against AMR [12,13].

Deep Learning (DL) is a subset of Machine Learning (ML) that utilizes artificial neural networks (ANN). These networks consist of numerous connected neurons organized into layers, simulating the functions of biological neurons. They accept input, process data, and forge creation signals. Within this network, self-evaluation occurs with each input received. Thus, the more varied and high-quality the data, the more accurate the predictive power becomes. As a result, the parameters increasingly develop authentic values, new ways are formed, and the final structure of the algorithm accepts shape [14]. While ML still utilizes human intervention, when the desirable output is unlike the generated result, DL can set itself to achieve the needed criteria. The generation of personalized therapy protocols is achieved through the prediction, identification, and validation of bioactive agents compatible with the patient's molecular background [15]. DL is utilized to create molecules with specific physicochemical properties efficiently and with minimal toxic side effects. [16]. The fight against bacterial antibiotic resistance must be offered critical lookout to avert the current and appearing crisis of treating bacterial infections due to the inefficacy of clinically relevant antibiotics. AI methods and processes can potentially augment the detection and identify antibiotic targets and antagonistic bactericidal and bacteriostatic molecules that are or can be designed as antibiotics [1]. The goal of this review is to emphasize the role of deep learning in addressing antibiotic resistance.

2. Materials and Methods

2.1 Data Source and research process

Data were sourced from the Science Citation Index Expanded (SCI-E) of the Scopes Core Collection on March 6, 2025. The search formula is as follows: (ALL= (deep learning) AND ALL= (Antimicrobial resistance) OR ALL=(AMR)). The Search language was configured to English, and the research works in the field of biology science that were published in the recent five years were chosen. Once the initial criteria were met, two researchers individually screened and examined all the studies. Books, early access publications, data papers, and retracted works were excluded from consideration. The remaining articles were sifted through by reading carefully the titles and abstracts of each piece of literature. The criteria for Manual Exclusion were as follows: 1) no association with AI and Antimicrobial resistance; 2) AI and

Antimicrobial resistance must be the main research subjects. In cases of disagreement, the matter was discussed during a group meeting. The search and analysis process is illustrated in Fig. 1.

2.2 Bibliometric analysis

This study employs three analytical tools to conduct a comprehensive bibliometric analysis of the literature related to various aspects of the subject matter. Initially, the online library analysis platform (<https://bibliometric.com/>) was utilized to visualize cooperative network relationships among countries and regions. In the secondary, VOSviewer 1.6.19.0 from Leiden University in the Netherlands was used. This software focuses on document data, primarily providing functions for co-occurrence clustering and Visualization. This study analyzed the co-occurrence network of keywords across all documents. The different colors on the graph represent various clusters, while the circles denote keywords. The diameter of each circle represents the frequency and correlation of occurrences. Publish and perish app was used to analyze citation data and assess the impact of publications in the related field. In this study, we analyzed the most significant keywords and determined the year and intensity of each keyword.

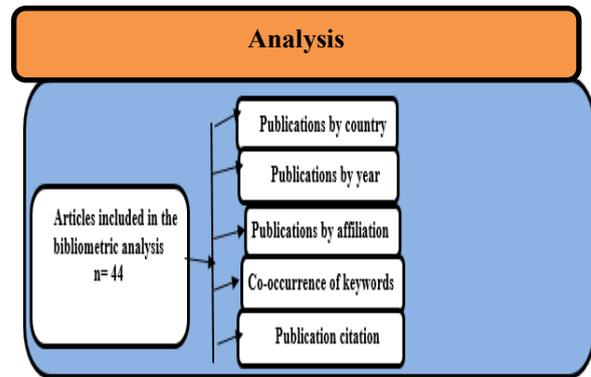
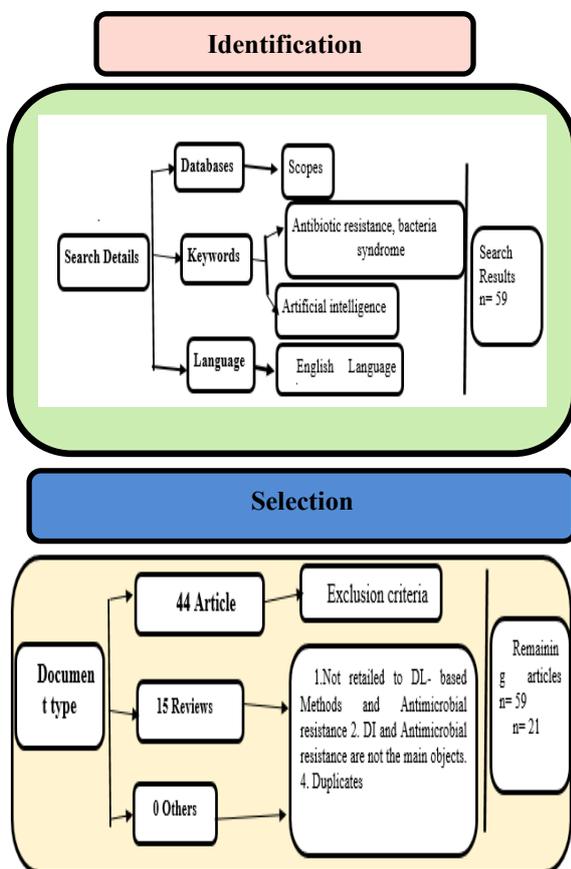


Fig.1 SEQ "Figure" * MERGEFORMAT 1. Flowchart of Document Collection and Selection Process within the Research Framework

3. Results and Discussion

3.1 Publications by country

Figure 2 shows the distribution of scientific articles on AI-related antibiotic sensitivity by country. The research covers the period from 2020 to 2025. China has the highest value at 13, significantly surpassing all other countries, followed by the United States at 8, indicating strong engagement or dominance in the measured field. India, Australia, and the United Kingdom have moderate values (5–6), suggesting a considerable but lower level of involvement. In contrast, Belgium, Germany, Pakistan, the Philippines, and Romania show the lowest values (2–3), highlighting a smaller contribution. These differences may be influenced by factors such as economic capacity, technological advancements, research investment, or policy frameworks. Understanding these variations can help identify potential areas for development and strategic improvements in the respective fields. We should focus enhancing collaboration among all countries globally and transferring various types of knowledge to ensure more effective global.

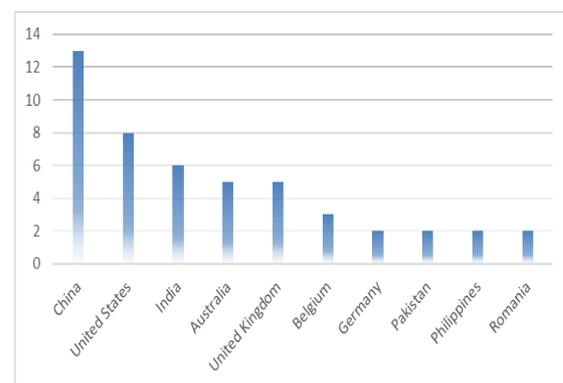


Fig. 2. Document counts by countries/territories efforts in using artificial intelligence to fight antibiotic resistance.

3.2 Publications by year

Figure 3 illustrates a trend over time, depicting fluctuations in the measured parameter from 2020 to 2025. The values were stable at 3 for both 2020 and 2021. In 2022, there was a sharp increase to 10, indicating a significant rise. In 2023, the value slightly decreased to 9, but it then increased again to its highest point of 11 in 2024. However, by 2025, the value experienced a sharp decline, dropping to 5. These variations may be influenced by external factors such as environmental conditions, policy changes, technological advancements, or other relevant influences that may vary based on the context of the data. AI in medical research is anticipated to pour significantly in 2022 and 2024. However, there may be a relative decline in 2025, which could result in a saturation point or a change toward alternative methods for fighting antibiotic resistance. This fall could be influenced by global events, such as pandemics or economic recessions, which may impact research funding and publication rates.

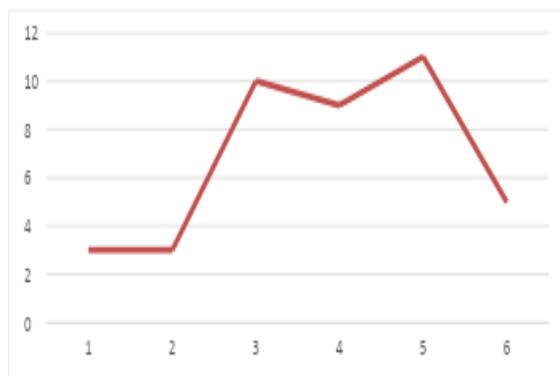


Fig. 3. The yearly publication trends of articles.

3.3 Publications by affiliation

Figure 4 shows the differences in document contributions among institutions. Most entities are represented in blue, indicating that they each contributed two documents. In contrast, one institution, marked in orange, contributed only one document. This color differentiation highlights a potential disparity in research output. While the majority of universities and research centers maintain a consistent level of publication, the highlighted institution may be facing challenges, such as reduced funding, fewer research initiatives, a focus is primarily on clinical practice rather than on academic research. This variation suggests the need for further investigation into the factors affecting research productivity across different institutions.

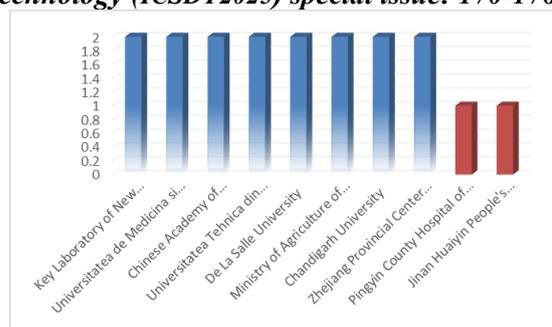


Fig. 4. (4) Comparison of the document counts for 15 affiliations.

3.4 Publications by subject area

Figure 5 displays the number of documents published by various institutions, with most contributing equally two documents, representing approximately 90% of the total, while one institution, highlighted in orange, contributes only 1 document (around 10%). This variation may indicate differences in research priorities, funding, or institutional focus. Universities and research centers, which account for the majority (90%), generally produce more publications. In contrast, hospitals and other institutions, making up the smaller 10%, often prioritize clinical work over academic research. The color distinction highlights this disparity, there is a need for further investigation into the factors that affect research productivity, such as resource availability, collaboration networks, or institutional policies.

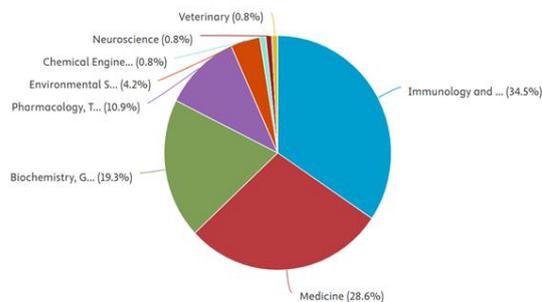


Fig. 5. Analysis of disparities in Institutional contributions to research publications

3.5 Co-occurrence of keywords

Table (1) presents a bibliometric analysis of key research terms, highlighting their frequency and total link strength in academic literature. Antibiotic resistance emerges as the most frequently occurring keyword, 59 times, with the highest total link strength (252), indicating its central role in scientific discussions. The terms "nonhuman" (48 occurrences, link strength of 222) and "article" (43 occurrences, link strength of 203) indicate a significant emphasis on experimental models and published literature in the field. Key microbiological

concepts such as "controlled study" (25 occurrences, link strength of 133), "biofilm" (23 occurrences, link strength of 130), and "quorum sensing" (25 occurrences, link strength of 127) highlight the increasing interest in bacterial communication and persistence mechanisms. *Escherichia coli* (23, 120) highlights its relevance as a model organism in antibiotic resistance studies. Additionally, human (29, 116) signifies research involving human-related infections, while bacterial growth (18, 93) and antibiotic sensitivity (18, 86) emphasize the ongoing exploration of bacterial behavior and drug response. The keyword distribution highlights significant research on bacterial resistance, biofilms, and experimental studies with human and nonhuman models, underscoring the urgent need to tackle antibiotic resistance in microbiology and clinical research.

Table 1. Bibliometric analysis of key research terms in antibiotic resistance studies.

Keywords	occurrences	Total length strength
Antibiotic resistance	59	252
nonhuman	48	222
article	43	203
Controlled study	25	133
biofilm	23	130
Quorum sensing	25	127
<i>Escherichia coli</i>	23	120
human	29	116
Bacteria growth	18	93
Antibiotic sensitivity	18	86

Figure 6 (A & B): Proposes a network visualization of key terms related to antibiotic resistance (AMR), emphasizing the connections between various concepts in microbiology and antimicrobial research. The red nodes represent issues with strong affinities with AMR, such as quorum sensing, biofilm formation, bacterial strains, *Escherichia coli*, and controlled studies, which are crucial factors in bacterial resistance mechanisms. The green nodes indicate connections to human and non-human aspects, including genetics, bacterial proteins, and antimicrobial agents. The intensity of the connections suggests the strength of relationships, with denser red links indicating highly interrelated topics in AMR research. This visualization helps illustrate the intricacy AMR, stressing the interplay between bacterial behavior, clinical studies, and genetic factors in resistance evolution.

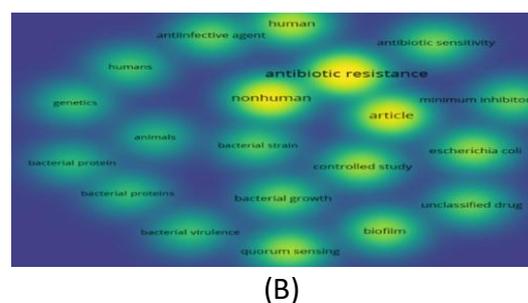
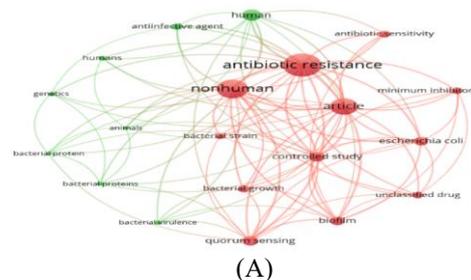


Fig. 6. Keyword Co-occurrence Network in Research Related to antibiotic resistance and AI.

3.6 Publications citations

Table (2) provides a bibliometric analysis of recent scientific publications, showcasing key authors, citation metrics, and research impact. E. Paluch's (2020) analysis in *Applied Microbiology and Biotechnology* has the most elevated citation count (282), with a unique 56.4 citations per year, indicating strong academic impact. S. Ji's (2024) research in the *European Journal of Medicinal Chemistry* has a high citation rate (52 per year) despite being the most recent, meaning immediate recognition. F. Wong's (2023) publication in *science* also shows a significant impact (101 citations, 50.5 per year), supporting its importance in the field. Studies from 2020 to 2024 dominate the table, highlighting contemporary research trends with citation rates reflecting varying levels of influence. The author count remains one per study, indicating single-author contributions. Overall, the table underscores emerging and impactful research, with recent studies gaining recognition rapidly, suggesting active and evolving academic discussions in microbiology, medicinal chemistry, and environmental safety. Studies using AI to antibiotic resistance have garnered significant attention, emphasizing the growing significance of AI in addressing global health challenges. This may signal a change in research priorities toward AI-based solutions, highlighting the need for continued asset in this field.

Table 2. Research Studies on Antibiotic Resistance and Machine Learning: Publication Details, Citations, and Author Metrics.

Authors	year	Source	Cites	Citations within Scopes		Author Count In the paper	Age
				Author and every year			
E. Paluch	2020	Applied Microbiology and Biotechnology	282	56.4	282	1	5
S. Wu	2020	Cellular and Molecular Life Sciences	141	28.2	141	1	5
F. Wong	2023	Science	101	50.5	101	1	2
J.P. Pirnay	2020	Frontiers in Microbiology	70	14	70	1	5
A.A. Rabaan	2022	Antibiotics	56	18.67	56	1	3
M. Pascucci	2021	Nature Communications	56	14	56	1	4
S. Ji	2024	European Journal of Medicinal Chemistry	52	52	52	1	1
K.A. Simanek	2022	Microbiology Spectrum	41	13.67	41	1	3
T. Pacheco	2021	Frontiers in Microbiology	38	9.5	38	1	4
F. Yang	2021	Ecotoxicology and	32	8	32	1	4

5. Conclusion

This study emphasizes the increasing role of artificial intelligence (AI) in tackling antibiotic resistance, especially through applications of deep learning. The findings imply that AI-driven models have significant potential to improve diagnostic precision, predict patterns of bacterial resistance, and optimize antibiotic treatments. However, the successful integration of AI into clinical settings needs complete datasets, ongoing validation, and regulatory oversight to ensure reliability and ethical use. The bibliometric analysis highlights the quick evolution of research in this area, with increasing contributions from different countries and organizations. Moving forward, interdisciplinary collaboration among microbiologists, data scientists, and healthcare professionals will be required to fully harnessing AI's possibility in combating antibiotic resistance. By combining technological improvements with clinical applications, AI can evolve a transformative tool in the global fight against antimicrobial resistance, ultimately improving patient outcomes and public health. Artificial intelligence (AI) in tackling

4. Limitations

While bibliometric analysis offers valuable insights by examining the literature objectively and systematically, our study has some limitations. First, we focused our search on the Science Citation Index Expanded (SCI-E) database within the Scopes, which is a prominent global citation index. However, the limited availability of relevant Data reduced the scope of our analysis. Second, we focused only on English-language articles and manually screened content to remove irrelevant studies. This process may have missed important research published in other languages or non-traditional formats, with possible biases due to researchers' expertise. Finally, our keyword search centered on "AI" and "Antibiotic resistance," which might have excluded some relevant studies. Common terms like Antibiotic resistance and artificial intelligence appeared frequently but added limited new insights. Future research should expand data sources, purify keyword selection, and strengthen the team's interdisciplinary expertise for more comprehensive analysis.

antibiotic resistance, particularly through applications of deep learning. The findings indicate that AI-driven models have significant potential to enhance diagnostic accuracy, predict patterns of bacterial resistance, and optimize antibiotic treatments. However, the successful integration of AI into clinical environments needs comprehensive datasets, ongoing assurance, and regulatory oversight to ensure reliability and ethical use. The bibliometric analysis highlights the rapid development of research in this area, with growing assistance from various countries and institutions. Moving forward, interdisciplinary collaboration among microbiologists, data scientists, and healthcare professionals will be crucial to fully harnessing AI's potential in combating antibiotic resistance. By connecting technological advancements with clinical applications, AI can become a transformative tool in the global fight against antimicrobial resistance, finally improving patient outcomes and public health

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