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Report on Singapore's Antimicrobial Resistance Research Landscape 2009- 2019

ANTIMICROBIAL RESISTANCE COORDINATING OFFICE
NATIONAL CENTRE FOR INFECTIOUS DISEASES
SINGAPORE

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EXECUTIVE SUMMARY

Antimicrobial resistance occurs when microorganisms such as bacteria, viruses, fungi and parasites evolve under selection pressure and develop mechanisms to circumvent the action of medicines. A key driver of resistance is the misuse of antimicrobials in humans, animals and agriculture worldwide. As a result of increasing resistance, infections caused by antimicrobial resistant microorganisms are more difficult to treat and pose a significant challenge to healthcare systems. Without concrete actions to mitigate the threat of antimicrobial resistance, our lives and economy would be affected, with an estimated 10 million dying from drug-resistant infections per year by 2050 [1].

The accelerated development of antimicrobial resistance and the concomitant lower return in investments for the development of antimicrobials by pharmaceutical companies had led to slower rates of research and development into newer antimicrobials. In the development of new antibiotics, most research is now undertaken by academic institutions [2].

In 2015, the Global Action Plan on Antimicrobial Resistance published by the World Health Organization set clear objectives to guide national and international efforts against antimicrobial resistance. Among these objectives was to strengthen our knowledge and evidence base through surveillance and research that would guide our actions and investments towards AMR.

An understanding of the current state of antimicrobial resistance research in Singapore is needed to develop clear rationales for national actions and research investments. Therefore, a review of the antimicrobial resistance research in Singapore was conducted.

A systematic literature review approach was undertaken to retrieve relevant research articles from databases and assembled to review the trends in research. Although antimicrobial resistance research in Singapore had shown an upward trend since 2009 (including the contribution of samples and data to regional research efforts and participation in international collaborations), some domains of research remained less popular. These included research in antimicrobial resistance transmission, the social and economic impact of antimicrobial resistance, and on the knowledge, attitudes and practices of the population on antimicrobial resistance. Furthermore, it identified a need to strengthen our knowledge and evidence base from the animal, environment and food sectors, due to the disproportionate number of research articles identified.

Through this review, research that may have contributed towards national guidelines or institutional practice were also identified, as well as the contribution of existing research towards Singapore's National Strategic Action Plan on Antimicrobial Resistance. Opportunities and recommendations for future research were also proposed based on the gaps identified from this review. These include the development of a national antimicrobial resistance research agenda in One Health, ensuring relevance of future antimicrobial resistance research to the National Strategic Action Plan, adopting a Delphi consensus to identify and prioritise research topics of significance to Singapore, dedicated grant calls for antimicrobial resistance research proposals from the One Health sectors, and ensuring sustained funding to drive the national antimicrobial resistance research agenda in One Health.

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REPORT ON SINGAPORE'S ANTIMICROBIAL RESISTANCE RESEARCH LANDSCAPE FROM 2009 TO 2019

(I) AIM

1. To provide an overview of the types of antimicrobial resistance (AMR) research conducted in Singapore during the period of January 2009 to December 2019.

(II) BACKGROUND

2. AMR is a globally recognised threat to human health, animals and the environment. The May 2015 World Health Assembly adopted the Global Action Plan on AMR with five objectives to address this global crisis [3].

3. In response, Singapore's National Strategic Action Plan (NSAP) on AMR was published on 1 Nov 2017, setting the framework for a national response to AMR, especially bacterial resistance to antibiotics. The plan aims to reduce the emergence and prevent the spread of drug resistant organisms through five core strategies: (1) Education; (2) Surveillance and Risk Assessment; (3) Research; (4) Prevention and Control of Infection; and (5) Optimisation of Antimicrobial Use [4].

4. The third core strategy, Research, aims to provide a better understanding of AMR and to provide information and evidence to support the other core strategies [4].

5. A priority area of action in AMR research highlighted in the NSAP is to understand the AMR research landscape in Singapore. This would identify and prioritise the research needs to ensure that key questions and evidence gaps are addressed to drive the national AMR agenda [4]. The review of Singapore's AMR research landscape was performed by the Antimicrobial Resistance Coordinating Office (AMRCO) at the National Centre for Infectious Diseases (NCID). The findings are presented in this report.

(III) METHODOLOGY

6. A comprehensive search strategy was adopted to retrieve articles from databases that index AMR research articles. Details on the identification of the final list of research articles, including the study selection and eligibility criteria, are described in Annex A. Each research article was read in full to enable its assignment to the appropriate sector and research domain, and for a summary of the research conducted in each domain to be included in this report.

7. Research domains were determined through an expert consultation conducted in 2017. Domain definitions were further defined and refined throughout the process of this landscape review (Textbox 1). When research could potentially span multiple domains, they were assigned by consensus to the most appropriate single domain that represented its main research focus.

8. The research articles were also assigned to the appropriate One Health sector that the research was from (i.e. animal, environment, food or human). Assignment was based on the source of the isolate/sample or the application of the research. Articles were assigned to multiple sectors where suitable and appropriate.

9. The research articles were also assigned to the relevant NSAP core strategy where they contributed further information to advance the AMR agenda.

Textbox 1. Definition of research domains.

Knowledge, Attitudes, Practices [5, 6]

- Studies that investigated and/or discussed the level of understanding of AMR and antimicrobial use (AMU) by different populations, the individual perception and reaction towards AMR and AMU, and the actions that they take as a result.

Social and Economic Impacts

- Studies that analysed the impact of AMR on the community, the impact of AMR on healthcare costs, and the cost effectiveness of interventions against AMR. Social determinants of health were also considered.

Transmission [7]

- Studies that investigated the spread of AMR microorganisms or genes.

Microbiology

- Laboratory-based studies that investigated a specific aspect of the resistant microorganism that contributed to its resistance profile, increasing existing insights and knowledge.

Diagnostics [8]

- Studies that developed, investigated, or validated methods for identifying the presence of AMR or antimicrobials, or monitored the effect of interactions of antimicrobials with resistant microorganisms.

Intervention

- Studies that developed tools or methods to curb the spread or transmission of AMR pathogens and/or investigated their efficacy.

Surveillance

- Studies that reported the prevalence of AMR (microorganisms or genes), or presence of antimicrobials detected and their quantities. Studies that reported antimicrobial consumption are also included.

Public Health and Epidemiology

- Studies that performed systematic or data-driven analyses of the distribution (frequency, pattern) and determinants (causes, risk factors) of AMR in specific populations; Studies that analysed the impact of AMR on the health of a population as a whole.

Therapeutics

- Studies that developed and investigated new therapy(ies) for treating AMR, including but not limited to:
    - Drug repurposing;
    - Screening libraries for potential lead compounds;
    - Synthesis of compound series with antimicrobial activity against AMR microorganisms;
    - Investigating the mechanisms of action of the therapeutic / mechanisms of resistance mounted by the microorganisms;
    - Comparison of treatments in patients with conditions or infections caused by AMR microorganisms; or
    - Clinical trials.

(IV) SINGAPORE'S AMR RESEARCH LANDSCAPE

10. The review of Singapore's AMR research landscape identified a total of 741 articles that could be divided into three main categories:
    a. Research studies conceived and led by investigators in Singapore (N=551);
    b. Research studies conceived and led by investigators from foreign institutions, with a Singapore-based researcher involved (N=128); or
    c. Research studies where Singapore contributed samples or data to increase knowledge across regions about AMR or AMU (N=62).

11. Annex B lists all articles identified from this review. Each article was assigned to the relevant research domain, the One Health[i] sector, and the core strategy to which the research findings contributed knowledge or evidence.

(A) AMR Research from Singapore, 2009-2019

Overview of Research Trends

12. The number of research articles conceived and led by investigators in Singapore increased from 17 in 2009 to 73 in 2019 (Annex C, Figure 1).

13. In terms of domain distribution of the research conducted, *Therapeutics* had the most number of research articles, followed by *Public Health and Epidemiology,* and *Surveillance*; Domains with the least articles were *Transmission, Social and Economic Impacts* (*SEI*) and *Knowledge, Attitudes, Practices* (*KAP*) (Annex B, Figure 2). All other research domains also saw regular annual publications except for the latter three (Annex C, Figure 2).

14. For research from a single sector, the *Human* sector (N=490) had the highest number of research articles, followed by the *Environment* sector (N=27). For cross-sector studies, research that straddled the *Human* and *Environment* sectors had the most articles (N=14) (Annex C, Figure 3A).

15. An increasing trend in the number of articles published from the *Human* sector was observed, from 15 in 2009 to 57 in 2019. AMR research published from the other sectors was sparse, until 2017, when more articles from the *Environment* and *Food* sectors were published (Annex B, Figure 3B).

[i] The One Health High-Level Expert Panel recently updated the definition of One Health as "an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent. The approach mobilises multiple, disciplines, and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for healthy food, water, energy, and air, taking action on climate change and contributing to sustainable development. In Singapore, the One Health sectors include the human, animal, food and environment sectors.

Microorganisms of Interest, 2009-2019

16. AMR bacteria and their related genes were most studied compared to other microorganisms, with more gram-negative than gram-positive bacteria in the studies published between 2009 to 2019. Other AMR microorganisms (fungi, virus or parasites) had fewer studies across the same period under review (Annex C, Figure 4).

17. The World Health Organization (WHO) priority pathogen list for therapeutics highlighted three categories of AMR microorganisms to be prioritised for the research and development of novel therapeutics[ii]. Articles in the *Therapeutics* domain showed that there was already interest by researchers from Singapore to prioritise the development of novel therapeutics targeting the above categories. (Annex C, Table 1). Most of the *Therapeutics* studies were on carbapenem-resistant *Pseudomonas aeruginosa*, or carbapenem-resistant, extended-spectrum beta-lactamase (ESBL)-producing Enterobacterales in the Priority 1 category, and on MRSA[iii] and VISA/VRSA[iv] in the Priority 2 category.

AMR Research Output by Institutions, 2009-2019

18. There was significant research conducted by clinicians from public healthcare institutions (PHIs) between 2009 to 2019 on AMR, with most publications from the tertiary hospitals (Singapore General Hospital, National University Hospital, Tan Tock Seng Hospital), and some from the regional general hospitals (Changi General Hospital, Ng Teng Fong General Hospital, Khoo Teck Puat Hospital, KK Women's and Children's Hospital) (Annex C, Table 2).

19. Research on AMR from institutes of higher learning (IHLs) was dominated by National University of Singapore and Nanyang Technological University, and a small number of publications from the Duke-NUS Medical School, Singapore Institute of Technology, Singapore University of Technology & Design, and the polytechnics (Ngee Ann Polytechnic, Republic Polytechnic and Singapore Polytechnic). Research institutes (RIs) and ministries/agencies in Singapore also conducted AMR research, but had fewer publications compared to the PHIs and IHLs (Annex C, Table 2).

20. Research from the respective institutions were reflective of their research interests and fields of expertise. PHIs published more research that were in the *Surveillance* and *Public Health and Epidemiology* domains, while IHLs and RIs had strong expertise in *Therapeutics* and *Microbiology* research. PHIs and IHLs showed similar levels of expertise or interests in *Intervention* research (Annex C, Figure 5).

21. Lastly, most of the AMR research between 2009 and 2019 were funded by grants from or managed by ministries/agencies. Other sources of funding included grants from healthcare clusters, IHLs, or were funded internally (Annex C, Table 3).

[ii] "WHO publishes list of bacteria for which new antibiotics are urgently needed." 27 February 2017. Link: https://www.who.int/news/item/27-02-2017-who-publishes-list-of-bacteria-for-which-new-antibiotics-are-urgently-needed

[iii] *Staphylococcus aureus*, methicillin-resistant

[iv] *Staphylococcus aureus*, vancomycin-intermediate or vancomycin-resistant

22. A summary of the research from each domain is elaborated in Annex D.

(B) Involvement in Multinational Research Efforts

23. Singapore was also involved in multinational research efforts to address AMR, either through the contribution of samples or data, both in the region or globally, or in international collaborations, providing their expertise in research led by their foreign counterparts. When compared with research published by investigators from Singapore, Singapore's involvement in multinational research also increased (Annex E, Figure 1).

Contributing Samples to Multinational Studies

24. Between 2009 and 2019, Singapore contributed samples or data to 62 studies. No trend was observed in the studies published between 2009 and 2019 (Annex E, Figure 1 "*Sample contribution"*; Annex F).

25. There were 57 studies from the human sector, four studies from the environment sector, and one human-animal cross-sector study.

26. Majority of the articles identified (N=55) were assigned to the *Surveillance* and *Public Health and Epidemiology* domains. The remaining articles were distributed across *Therapeutics* (N=2), *Transmission* (N=2), *Diagnostics* (N=2) and *Microbiology* (N=1).

International Collaborations on AMR, 2009-2019

27. Investigators based in Singapore participated in 128 collaborations between 2009 to 2019, and the trend in collaborations showed an increase from three studies in 2009 to 25 studies in 2019 (Annex E, Figure 1 "International collaborations").

28. International collaborations on AMR research showed a similar distribution in terms of the research domain assignment with research from Singapore (Annex E, Figure 2).

29. Researchers in Singapore collaborated with research groups from the high- (17 countries), upper middle- (4 countries) and lower middle- (6 countries) income countries. Countries with more than 10 research collaborations included Australia, the United States, the United Kingdom, Denmark and China (Annex E, Figure 3).

(V) AMR RESEARCH RELEVANT TO POLICY OR PRACTICE

30. The review of Singapore's AMR research landscape identified the following research topics that were relevant to Singapore's public health policies and practices. Some of the findings provided information on pneumococcal immunisation, and for improving practices in the hospital to prevent the spread of infections caused by AMR microorganisms.

(A) Pneumococcal Immunisation

31. There were three research articles that studied the pneumococcal disease burden and antibiotic resistance rates, as well as how the introduction of PCV-7, and subsequently PCV-13 and PPSV-23 impacted the disease burden.

32. Overall findings showed that the introduction of PCV-7 was followed by concomitant replacement of vaccine serotypes by non-vaccine serotypes circulating in the population. Furthermore, baseline resistance rates were high. Penicillin non-susceptible serotypes, especially in 19A, was observed following introduction of PCV-7. Resistance to erythromycin was also found to be gradually increasing [9].

33. In addition, mortality rates due to pneumococcal disease were high, at 19% and 3% of hospitalised elderly and children, respectively. Of the serotypes found in the study by Martinez-Vega et al. [9], 30% of serotypes identified were not covered by vaccines that were licensed in Singapore at the time of the study in 2013.

34. The period of the three studies coincided with the time at which PCV-7 and/or PCV-13 were introduced. However, it was unclear whether these studies directly contributed to the decision to have the PCV-7 immunisation programme implemented, and subsequently replaced by the newly approved and licensed PCV-13. Global experiences and data gathered from the US and Europe may have had some impact, since these countries reported the emergence of non-vaccine serotypes after introducing PCV-7, especially the high prevalence of the 19A serotype [10].

35. A nationwide pneumococcus surveillance programme was started in 2009 with the National Public Health Laboratory, along with mandatory reporting of invasive pneumococcal disease by clinicians [11]. This facilitated the evaluation of the effectiveness of the pneumococcal immunisation programme in reducing pneumococcal disease burden.

36. The overall high mortality rates also reflected the need to increase vaccine coverage for pneumococcal disease. PCV-13 is included in the National Childhood Immunisation Schedule. In the elderly, PCV-13 and PPSV-23 are recommended.

(B) Interventions in Healthcare Institutions

37. Several studies identified from this review focused on the impact of interventions implemented at PHIs. These could be divided into (1) interventions aimed at improving hand hygiene as part of infection prevention and control (IPC)

practices; and (2) engineering interventions to reduce the spread of AMR transmission when the source was identified.

Hygiene Practices at Healthcare Institutions

38. There were four studies that sought to assess the impact of institutional workflows that aimed to reduce hospital-associated infections by AMR microorganisms. These included the addition of intranasal octenidine to daily antiseptic bathing [12], alcohol hand-rubbing practices [13, 14] and the use of ward level targets to improve hand hygiene compliance rates [15]. The outcomes from the inclusion of these institutional practices reduced infection rates; hand hygiene compliance rates also improved with sustained results.

39. In a study that investigated *Elizabethkingia meningoseptica* infections, clinical staff were found to misuse hand hygiene sinks to dispose patient secretions or rinse re-usable patient care items. An urgent education programme was instituted to change the practice with temporary improvement reported. Room design and staff workflows were recommended to be optimised for patient safety as such lapses in procedures could put patients at risk [16].

Engineering Interventions at Healthcare Institutions

40. Three articles included in the review were on interventions aimed at removing the environmental source to curb AMR transmissions. The changes that were implemented were either already part of institutional workflows, or implemented after findings showed that the changes were beneficial:

    a. Absence of carbapenem-resistant *Acinetobacter baumannii* (CRAB) found outside patients' wards showed that appropriate cleaning of high- and low-touch surfaces, provision of dedicated blood pressure cuffs for patients and increased accessibility to alcohol-based hand rubs were effective. A pilot project to use real-time whole genome sequencing (WGS) combined with epidemiological linkage analysis to track CRAB as they emerged also facilitated early institution of infection control measures to reduce further transmission [17].

    b. Molecular typing analysis of MRSA and *Acinetobacter* spp. showed clonally related strains circulated between patients, the hands of healthcare professionals and the environment. As enhanced cleaning demonstrated reduced MRSA infections, systematic cleaning programmes were recommended to evaluate the hygiene standards in healthcare environments [18].

    c. Following a *Pseudomonas aeruginosa* outbreak in a haematology ward, investigations showed that sinks with multiple grooves could harbour biofilms and were difficult to disinfect adequately. Changing the sink drainage system to one without grooves successfully terminated the outbreak. Thus, the institution replaced sinks in all clinical areas that housed immunosuppressed patients [19].

(VI) IDENTIFYING OPPORTUNITIES FOR AMR RESEARCH

41. This review of Singapore's AMR research landscape was the first to include the One Health sectors, in addition to the human sector. Besides providing the first overall glimpse into the current research emphasis, it also highlighted the areas where more research could be conducted.

(A) Research Relevant to the NSAP Core Strategies to Further Singapore's AMR Agenda

42. Besides Research, Singapore's NSAP on AMR consists of four other core strategies: Education; Surveillance and Risk Assessment; Prevention and Control of Infection; and Optimisation of Antimicrobial Use. Through this landscape review, we identified research currently in progress with potential to contribute relevant knowledge to these core strategies. At the same time, it also allowed us to propose research that would be needed but have yet to be conducted in Singapore (Annex G).

Education

43. Findings from research articles assigned to the *Knowledge, Attitudes, Practices* domain contributed important insights, as well as identified appropriate education materials that were needed to improve the population's knowledge and to correct the current misconceptions pointed out by the studies.

44. Information from relevant *Surveillance* or *Public Health and Epidemiology* studies could also provide a proxy measure on whether the relevant education interventions had any positive impact on AMR or AMU.

45. The development of content and use of the appropriate modality for education or public awareness campaigns is an important process, and robust and comprehensive user design and testing prior to launch are recommended. There were studies on interventions to increase knowledge but these were few; the mixed or poor outcomes reported also indicated that more work was required [20, 21]. Social and communication science approaches, which would consider how information is perceived by a different audiences, could be applied when developing the content in public outreach campaigns, as suggested by Huttner et al [22]. Based on this review, such studies were not identified.

Surveillance and Risk Assessment

46. Surveillance is an important part of public health efforts for prompt response to potential threats to public, animal and environmental health, to mitigate and prevent detrimental impacts, and for measuring the outcomes of programmes and initiatives launched as part of the NSAP. Almost all research articles that were assigned to the *Surveillance* and *Public Health and Epidemiology* domains were relevant to this core strategy. Studies in the *Transmission* domain could also contribute information to risk assessments, through provision of updated information by which resistant pathogens may spread.

47. Publications from the animal, environment and food sectors should be encouraged due to the low numbers identified in this review and to demonstrate the inter-relationship of AMR in One Health. From the environment and food sectors in particular, research to identify potential sources of AMR would be necessary, as their roles as reservoirs of *de novo* antimicrobial resistance development are not fully elucidated.

48. Integrated surveillance of AMR across the One Health sectors is a priority highlighted in Singapore's NSAP. In relation to this, researchers could further develop or harmonise existing diagnostic tools to aid integrated surveillance. Where possible, the development of diagnostic tools should also move from single sector application to potential cross-sector applications. Methodological studies for sample collection should also be followed-up, as one research had demonstrated that different combinations of anatomical sites gave rise to different sensitivities for the identification of target AMR pathogens [23]. Such lessons learnt from one sector could be applied to other sectors.

Research

49. Research within the NSAP is framed with the objective of improving our understanding of AMR. The research articles identified from this review largely satisfied this objective as the findings contributed towards our knowledge and understanding of AMR from multiple dimensions.

50. Moving forward, knowledge and evidence base acquired through such research should be applied and translated by the research community. An example would be the further development of promising novel treatment or intervention strategies that target drug-resistant microorganisms for practical applications.

Prevention and Control of Infection

51. Prevention and control of infection minimise the incidences and associated risks of emergence and spread of AMR. Most research studies in the *Intervention* domain provided information or engineered novel methods relevant to this core strategy. Studies from *Social and Economic Impacts*, such as a review of screening and isolation programme, also provided evidence of their effectiveness [24].

52. However, studies on vaccines to reduce infection by AMR pathogens were few. There were three studies that correlated the emergence of AMR *Streptococcus pneumoniae* following the introduction of the relevant vaccines. Although timely, they were unlikely to impact policies on vaccine implementation, but provided data that supported them.

53. There was also a lack of research identified from the animal sector. While guidelines were recently developed for pet vaccination and husbandry, and for prudent use of antimicrobials in companion animals (to include references NParks 2020 and 2021), their impact on AMR in animals are still unknown. Therefore, monitoring the uptake of pet vaccination and AMU rates in the animal sector are recommended. Coupled with surveillance of AMR in animals, data correlation would provide useful information that contribute to advancing Singapore's agenda on AMR.

Optimisation of Antimicrobial Use

54. Although research relevant to this core strategy could be identified from almost all research domains, majority of the research were also from the human sector. Research to optimise AMU in the animal sector could be strengthened, with similar studies conducted in the human sector replicated in animals where appropriate.

55. A regulatory framework for veterinary drug registration and supply chain control is under development. When implemented, AMU could be monitored to contribute towards surveillance of the usage trends of antimicrobials, as well as encourage a parallel optimal prescription and usage by veterinarians and pet owners.

56. A cornerstone of improving AMU would be through education. However, only two studies were identified from this review. Poor or mixed outcomes were obtained from current educational efforts to improve AMU. Though there were limitations mentioned in the studies conducted, they provided avenues for improvement of similar studies in the future.

(B) Opportunities in One Health AMR Research

57. Three research domains that had the least research output or articles provided opportunities for future research. These were *Transmission*, *Social and Economic Impacts*, and *Knowledge, Attitudes, Practices* on AMR. Another observation made was the small number of research articles from the animal, environment and food sectors, as well as the number of cross-sector research. While AMR research from the environment, food and animal sectors were increasingly being published from 2017, this was only 7.8% of the articles from the human sector. Research from the other sectors should be encouraged to increase our understanding and provide evidence-based approaches for addressing AMR. Cross-sector research is also needed to increase our knowledge of the interrelatedness of AMR across the One Health sectors.

(C) Others

58. Separately, some of the research articles also highlighted existing challenges that researchers faced in order to drive research to address AMR. These challenges provide opportunities for development into future research questions or topics. Such development could take the approach by Tudor Car et al. [25], where challenges identified from a review of the literature were formulated into potential research questions to highlight the areas of need to the research community.

(VII) RECOMMENDATIONS

59. Recommendations proposed are aligned with the opportunities identified from Section (VI), which echo opportunities proposed by others [1, 26]

(A) National Research Agenda on AMR in One Health

60. **A national AMR research agenda that incorporates One Health could be formulated to advance Singapore's AMR agenda.** This landscape review not only identified research that were relevant to each of the NSAP core strategies in Section VI (A), it also identified opportunities. A list of research questions or topics could be formulated to address the gaps; some of these research questions are currently being collated from this review (Annex G), and additional questions will be obtained through expert solicitation from the One Health sectors for comprehensiveness. The final list will contribute to the development of Singapore's AMR research agenda with emphasis on the priority topics to be funded for research.

61. **Future AMR research in Singapore should also consider their relevance to the NSAP core strategies.** This review showed that research articles identified could contribute valuable information and insights to multiple NSAP core strategies (Annex B). Therefore, the planning for future research relevant to the advancement of Singapore's AMR agenda should take this aspect into consideration to maximise the potential of each research proposal.

62. **A Delphi consensus [27] could be adopted as part of a priority setting exercise to identify research topics that are of significance to Singapore's One Health AMR research agenda.** The Tripartite collaboration between WHO, Food and Agricultural Organization of the United Nations and the World Organisation for Animal Health is working towards the development of a global research agenda on AMR, and had invited stakeholders to participate in a survey on research questions for OH AMR research that was launched from Jul – Sep 2021 [28]. Singapore could take guidance from this approach to identify relevant research questions that are suitable for Singapore's needs.

(B) Funding for AMR Research from the One Health Sectors

63. Most of the current research addresses AMR from a human perspective. To emphasise the interrelatedness of all One Health sectors and AMR, **grant calls dedicated to AMR research proposals from the One Health sectors should continue**. AMR genes from the environment known to impact human health include ESBL and New Delhi metallo-beta-lactamase (NDM-1) genes [29, 30]. These two genes show that there is a feedback loop between infection, antibiotic use and the development of antibiotic resistance [31]. Identifying and understanding the transmission of such genes from the environment, food and animal sectors would be necessary for planning mitigation measures. Such research is needed to expand our knowledge.

64. **Further funding to drive the national AMR research agenda in One Health is needed.** The One Health AMR Research Programme (OHARP) [v] was conceived to drive cross-sectoral research collaborations on AMR and to identify and dedicate research funding to the priority domains identified through an expert consultation conducted in 2017. Through grant calls launched in 2021 and 2022, four grants were awarded to specific projects that addressed cross-sector transmission of AMR, and knowledge, attitudes and practices of Singaporeans towards AMR. Separately, a social and economic impact study was also commissioned in 2022. With the success achieved, further funding would also be needed to invest in the priority research questions or topics identified from this review.

[v] One Health Antimicrobial Research Programme (OHARP) Grant. Website link: https://www.nmrc.gov.sg/grants/competitive-research-grants/one-health-antimicrobial-resistance-research-programme-(oharp)-grant

(VIII) CONCLUSION

65. This report provides the first comprehensive review of Singapore's AMR research landscape on the types of AMR research conducted in Singapore, and their findings, between 2009 and 2019. Recommendations made were based on the gaps and opportunities identified from current research and presented for adoption to drive the national AMR research agenda.

66. Being the first time that the AMR research in Singapore was surveyed, this review used key word search of relevant databases to identify as many of the relevant research or review articles as possible. With increasing emphasis of the One Health approach in AMR, Singapore's AMR research landscape is expected to evolve as the research focus further develops and matures. Thus, AMRCO will conduct regular reviews and provide updates based on the information collated. Future reviews may also expand and improve the current processes used to increase comprehensiveness where needed.

67. Lastly, as we limited the review to published articles from Singapore, some areas of research that have the potential to advance Singapore's AMR agenda may have been excluded. An example is the development of viable alternatives to reduce overall use of antimicrobials in livestock, which is an area with limited research in Singapore. Future reviews should also compare with AMR research conducted globally and consider how these research could impact on Singapore's NSAP on AMR.

(IX) List of Annexes:

Annex A Details of identification of research articles.
Annex B List of relevant research articles identified from this landscape review.
Annex C Figures and tables describing overview of AMR research from Singapore.
Annex D Summary of AMR research from Singapore, grouped according to research domains.
Annex E Figures describing involvement of researchers in multinational research efforts to address AMR.
Annex F Summary of the types of AMR research that Singapore contributed samples or data to.
Annex G Mapping research relevant to NSAP core strategies and opportunities for future research.

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Annex A. Details of identification of research articles *(Section III)*

Search strategy

Search strategy for NCBI Pubmed, and adapted accordingly for Embase (Ovid), Scopus, Cumulative Index to Nursing and Allied Health Literature (CINAHL, Ebsco), Global Health (Ovid), Medline (Ovid) and Web of Science.

1 (((((((anti*) OR (anti-b*)) OR (anti-m*)) OR (anti-f*)) OR (anti-v*)) OR (microb*)) OR (antimicrob*)) OR (anti-microb*)
2 ((resistant) OR (resistance)) OR (resist*)
3 #1 OR #2
4 (Singapore) OR (Singaporean)
5 #3 AND #4
6 #5 AND (("2009/01/01)"[Date – Publication] : "2019/12/31"[Date – Publication]))

Eligibility criteria

The table lists the criteria when considering an article for inclusion in this landscape review.

	Include	Exclude
Year of publication	2009 to 2019, inclusive	Preprints and Epub ahead of print between 2009 to 2019
Content type	Research articles Review articles	Editorials Poster/Conference abstracts Commentary Opinion pieces Guidelines Reports Book or Book Chapters
Country	Studies conducted by authors whose primary affiliation is with a Singapore/local institution Studies with samples or data from Singapore	Studies not conducted or involving authors whose primary affiliation is with a Singapore/local institution
Research scope	Research focused on addressing AMR, including but not limited to the following: - Identifying methods to reduce/prevent AMR - Treating infections due to AMR microorganisms - Developing methods to improve the removal of antimicrobials - Understanding the levels of AMU or AMR	Studies describing research on general infectious diseases without an AMR focus

Annex B. Relevant research articles identified from review of Singapore's antimicrobial resistance research landscape, 2009-2019

Table 1. List of AMR research and review articles published by researchers from Singapore between 2009 and 2019.
Articles were assigned to the most relevant research domain, sector(s) and their contribution to the NSAP core strategy(ies).

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2009, Chan KS [32]	Human	Surveillance	Surveillance & Risk Assessment
2009, Chuwa EWL [33]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2009, Deepak RN [34]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2009, Donaldson AD [35]	Human	Therapeutics	Research
2009, Fan C [36]	Environment	Microbiology	Research
2009, Fong RKC [37]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2009, Ho YM [38]	Human	Microbiology	Research
2009, Koh TH [39]	Human, Animal	Public Health and Epidemiology	Surveillance & Risk Assessment
2009, Lee CC [40]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2009, Lim T-P [41]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2009, Liu L [42]	Human	Therapeutics	Research
2009, Luan J [43]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2009, Prabakaran M [44]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2009, Tan TY [45]	Human	Diagnostics	Research
2009, Teo JWP [46]	Human	Microbiology	Research
2009, Tin S [47]	Human	Therapeutics	Research
2009, Wang S-Q [48]	Human	Therapeutics	Research
2010, Cheow WS [49]	Human	Therapeutics	Research
2010, Cheow WS [50]	Human	Therapeutics	Research
2010, Ch'ng J-H [51]	Human	Microbiology	Research
2010, Ding C [52]	Environment	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Donaldson AD [53]	Human	Surveillance	Surveillance & Risk Assessment
2010, Gan LSH [54]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2010, Ho J [55]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment; Research
2010, Hsu L-Y [56]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Hsu L-Y [57]	Human	Therapeutics	Research
2010, Husain N [58]	Human	Therapeutics	Research
2010, Inoue M [59]	Human	Therapeutics	Research
2010, Jayaraman P [60]	Human	Therapeutics	Research
2010, Koh TH [61]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Koh TH [62]	Human	Surveillance	Surveillance & Risk Assessment
2010, Kurup A [63]	Human	Intervention	Surveillance & Risk Assessment; Prevention & Control of Infection
2010, Lim LG [64]	Human	Diagnostics	Research
2010, Lim PL [65]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Liu R [66]	Human	Diagnostics	Research
2010, Ng ES-T [67]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2010, Nzila A [68]	Human	Therapeutics	Research
2010, Ong DCT [69]	Human	Diagnostics	Research
2010, Rottmann M [70]	Human	Therapeutics	Research
2010, Samy RP [71]	Human	Therapeutics	Research
2010, Soe WM [72]	Human	Therapeutics	Research
2010, Soe WM [73]	Human	Therapeutics	Research
2010, Sun Y-J [74]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Tan TY [75]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Tan TY [76]	Human	Surveillance	Surveillance & Risk Assessment
2010, Vasoo S [10]	Human	Surveillance	Surveillance & Risk Assessment
2010, Wijaya L [77]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Wong L [78]	Human	Therapeutics	Research
2010, Zhou C [79]	Human	Therapeutics	Research
2011, Bahadin J [80]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Chan HLE [81]	Human	Surveillance	Surveillance & Risk Assessment
2011, Chantratita N [82]	Human	Therapeutics	Research

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2011, Cheow WS [83]	Human	Therapeutics	Research
2011, Ch'ng J-H [84]	Human	Therapeutics	Research
2011, Fan C [85]	Environment	Microbiology	Research
2011, Hsu L-Y [86]	Human	Surveillance	Surveillance & Risk Assessment
2011, Husain N [87]	Human	Therapeutics	Research
2011, Kyaw BM [88]	Human	Therapeutics	Research
2011, Kyaw BM [89]	Human	Therapeutics	Research
2011, Lee CY [90]	Human	Therapeutics	Research
2011, Lee HK [91]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2011, Leung GYC [92]	Human	Therapeutics	Research
2011, Liew YX [93]	Human	Surveillance	Surveillance & Risk Assessment
2011, Liew YX [94]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2011, Liew YX [95]	Human	Surveillance	Surveillance & Risk Assessment
2011, Lim PL [96]	Human	Surveillance	Surveillance & Risk Assessment
2011, Lim T-P [97]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2011, Lim T-P [98]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2011, Lingegowda PB [99]	Human	Therapeutics	Research
2011, Mirza H [100]	Human, Animal	Diagnostics	Research; Optimisation of Antimicrobial Use
2011, Mok S [101]	Human	Therapeutics	Research
2011, My NH [102]	Human	Therapeutics	Research
2011, Nederberg F [103]	Human	Therapeutics	Research
2011, Ng LSY [104]	Human, Environment	Intervention	Research; Prevention & Control of Infection
2011, Ong DCT [105]	Human	Diagnostics	Research
2011, Pada SMK [106]	Human	Social and Economic Impacts	Research
2011, Phua CK [107]	Human	Therapeutics	Research
2011, Saeidi N [108]	Human	Therapeutics	Research
2011, Samy RP [109]	Human	Therapeutics	Research
2011, Sim SH [110]	Human, Environment	Therapeutics	Research
2011, Soe WM [111]	Human	Therapeutics	Research
2011, Suhaila M [112]	Human	Therapeutics	Research
2011, Tan TY [113]	Human	Diagnostics	Research
2011, Teo BW [114]	Human	Intervention	Surveillance & Risk Assessment; Prevention & Control of Infection
2011, Teo BW [115]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Teo JWP [116]	Human	Surveillance	Surveillance & Risk Assessment
2011, Vasoo S [11]	Human	Surveillance	Surveillance & Risk Assessment
2011, Xing B [117]	Human	Therapeutics	Research
2012, Bai Y [118]	Human	Therapeutics	Research
2012, Balm MND [119]	Human	Surveillance	Surveillance & Risk Assessment
2012, Cai Y [120]	Human	Surveillance	Surveillance & Risk Assessment
2012, Chen C [121]	Human, Environment	Intervention	Research; Prevention & Control of Infection
2012, Chen T [122]	Human	Intervention	Research; Prevention & Control of Infection
2012, Chen Y-T [123]	Human	Surveillance	Surveillance & Risk Assessment
2012, Cheong CSJ [124]	Human	Surveillance	Surveillance & Risk Assessment
2012, Chew KK [125]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2012, Chien JMF [126]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2012, Choudhury S [127]	Human	Surveillance	Surveillance & Risk Assessment
2012, Choudhury S [128]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2012, Chow ALP [23]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2012, Chow ALP [129]	Human	Intervention	Prevention & Control of Infection
2012, Cui Y [130]	Human	Therapeutics	Research
2012, Du H [131]	Human	Microbiology	Research
2012, Fukushima K [132]	Human	Therapeutics	Research
2012, Han N [133]	Human	Therapeutics	Research
2012, Huang Y [134]	Human	Therapeutics	Research
2012, Kanagarajan V [135]	Human	Therapeutics	Research
2012, Koh TH [136]	Human	Surveillance	Surveillance & Risk Assessment
2012, Koh TH [137]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2012, Kyaw BM [138]	Human	Therapeutics	Research
2012, Win M-K [139]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Lee ASG [140]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2012, Lee CK [141]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2012, Liew YX [142]	Human	Intervention	Optimisation of Antimicrobial Use
2012, Liew YX [143]	Human	Intervention	Optimisation of Antimicrobial Use
2012, Ling ML [14]	Human	Intervention	Prevention & Control of Infection
2012, Lye DCB [144]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Ng ES-T [145]	Human	Social and Economic Impacts	Research
2012, Poon LM [146]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Sarathy JP [147]	Human	Microbiology	Research
2012, Shao Q [148]	Human	Intervention	Research; Prevention & Control of Infection
2012, Teo JQM [149]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Teo JQM [150]	Human	Intervention	Optimisation of Antimicrobial Use
2012, Teo JWP [151]	Human	Surveillance	Surveillance & Risk Assessment
2012, Vasoo S [152]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Venkatachalam I [153]	Human	Surveillance	Surveillance & Risk Assessment
2012, Verrall AJ [154]	Human	Therapeutics	Research
2012, Wozniak M [155]	Human	Therapeutics	Research
2012, Yeo C-L [156]	Human	Intervention	Optimisation of Antimicrobial Use
2012, Zou G [157]	Human	Microbiology	Research
2013, Ang TL [158]	Human	Therapeutics	Research
2013, Balm MND [159]	Human	Surveillance	Surveillance & Risk Assessment
2013, Balm MND [160]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Balm MND [161]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Balm MND [16]	Human	Transmission	Surveillance & Risk Assessment; Prevention & Control of Infection
2013, Chee CBE [162]	Human	Transmission	Surveillance & Risk Assessment
2013, Chin W [163]	Human	Therapeutics	Research
2013, Ch'ng J-H [164]	Human	Therapeutics	Research
2013, Chong C-W [165]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Chow WL [166]	Environment	Intervention	Research; Prevention & Control of Infection
2013, Chua SL [167]	Human	Therapeutics	Research
2013, Fisher DA [168]	Human	Intervention	Prevention & Control of Infection
2013, Fukushima K [169]	Human	Therapeutics	Research
2013, Goh S [170]	Human	Transmission	Research
2013, Grant D [171]	Human	Transmission	Surveillance & Risk Assessment
2013, Heng YK [172]	Human	Therapeutics	Research
2013, Hon PY [173]	Human	Diagnostics	Research
2013, Koh J-J [174]	Human	Therapeutics	Research
2013, Koh TH [175]	Human	Surveillance	Surveillance & Risk Assessment
2013, Lee GH [176]	Human	Therapeutics	Research
2013, Lee GH [177]	Human	Therapeutics	Research
2013, Lee LK [178]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Li Y [179]	Human	Intervention	Research; Prevention & Control of Infection
2013, Liew YX [180]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Lim CLL [181]	Human	Public Health	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2013, Lim S-G [182]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2013, Ling ML [19]	Human, Environment	Transmission	Surveillance & Risk Assessment; Prevention & Control of Infection
2013, Marimuthu K [183]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Molton JS [184]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Ng VWL [185]	Human	Therapeutics	Research
2013, Ong ZY [186]	Human	Intervention	Research; Prevention & Control of Infection
2013, Qiu G [187]	Environment	Intervention	Research
2013, Russell B [188]	Human	Diagnostics	Research
2013, Samy RP [189]	Human	Therapeutics	Research
2013, Samy RP [190]	Human	Therapeutics	Research
2013, Sarathy JP [191]	Human	Microbiology	Research
2013, Sarathy JP [192]	Human	Microbiology	Research
2013, Seah J [193]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2013, Shao Q [194]	Human	Diagnostics	Research
2013, Sim JHC [195]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Soon MML [196]	Human	Social and Economic Impacts	Research
2013, Tan PS [197]	Human	Therapeutics	Research
2013, Tan SY-Y [198]	Human	Microbiology	Research
2013, Tan TY [18]	Human, Environment	Transmission	Surveillance & Risk Assessment
2013, Teo JQM [199]	Human	Surveillance	Surveillance & Risk Assessment
2013, Teo JWP [200]	Human	Surveillance	Surveillance & Risk Assessment
2013, Teo JWP [201]	Human	Surveillance	Surveillance & Risk Assessment
2013, Vasudevan A [202]	Human	Therapeutics	Research
2013, Vasudevan A [203]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Verrall AJ [204]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Win M-K [205]	Human	Diagnostics	Research
2013, Xia E [206]	Human	Surveillance	Surveillance & Risk Assessment
2013, Xiong P [207]	Human	Intervention	Research; Prevention & Control of Infection
2013, Yang Y [208]	Human	Therapeutics	Research
2013, Yokokawa F [209]	Human	Therapeutics	Research
2013, Yuan X [210]	Human	Intervention	Research; Prevention & Control of Infection
2013, Zou H [211]	Human	Therapeutics	Research
2014, Bandyopadhyay S [212]	Human	Therapeutics	Research
2014, Bayen S [213]	Environment	Diagnostics	Surveillance & Risk Assessment; Research
2014, Castillo CFG [214]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Chen HH [215]	Human	Therapeutics	Research
2014, Ch'ng J-H [216]	Human	Therapeutics	Research
2014, Chow JY [217]	Human	Intervention	Research; Prevention & Control of Infection
2014, Coady DJ [218]	Human	Therapeutics	Research
2014, Deng C-L [219]	Human	Therapeutics	Research
2014, Deng Y [220]	Human	Therapeutics	Research
2014, Gopal P [221]	Human	Therapeutics	Research
2014, Hon PY [222]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Jauneikaite E [223]	Human	Surveillance	Surveillance & Risk Assessment
2014, Khara JS [224]	Human	Therapeutics	Research
2014, Koh TH [225]	Human	Surveillance	Surveillance & Risk Assessment
2014, La M-V [226]	Human	Surveillance	Surveillance & Risk Assessment
2014, Lescar J [227]	Human	Therapeutics	Research
2014, Li X [228]	Human	Intervention	Research; Prevention & Control of Infection
2014, Liu S [229]	Human	Therapeutics	Research
2014, Loh CCY [230]	Human	Diagnostics	Research
2014, Mani V [231]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2014, Marimuthu K [232]	Human	Surveillance	Surveillance & Risk Assessment
2014, Marimuthu K [233]	Human	Intervention	Prevention & Control of Infection
2014, Marimuthu K [234]	Human	Intervention	Prevention & Control of Infection
2014, Mok S [235]	Human	Therapeutics	Research
2014, Ng TM [236]	Human	Intervention	Optimisation of Antimicrobial Use
2014, Ng TM [237]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Ng VWL [238]	Human	Therapeutics	Research
2014, Ong ZY [239]	Human	Therapeutics	Research
2014, Samy RP [240]	Human	Therapeutics	Research
2014, Seah XFV [241]	Human	Intervention	Optimisation of Antimicrobial Use
2014, Shekar S [242]	Human	Therapeutics	Research
2014, Singhal A [243]	Human	Therapeutics	Research
2014, Song M [244]	Human	Therapeutics	Research
2014, Tan MW [245]	Human	Public Health and Epidemiology	Research; Optimisation of Antimicrobial Use
2014, Tan TT [246]	Human, Environment	Transmission	Surveillance & Risk Assessment
2014, Tan YE [247]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2014, Tang SS [248]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Teo JWP [249]	Human, Environment	Transmission	Surveillance & Risk Assessment
2014, Teo JWP [250]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2014, Vasudevan A [251]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2014, Venkatachalam I [252]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Wang Y [253]	Human	Therapeutics	Research
2014, Wen H [254]	Human	Microbiology	Research
2014, Wozniak M [255]	Human	Diagnostics	Research
2014, Wu Z [256]	Human	Microbiology	Research
2014, Yeoh LY [257]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Young BE [258]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Zhou YP [259]	Human	Transmission	Surveillance & Risk Assessment
2014, Zhou YP [260]	Human	Therapeutics	Research
2015, Anusha S [261]	Human	Therapeutics	Research
2015, Cai Y [262]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2015, Chee CBE [263]	Human	Transmission	Surveillance & Risk Assessment; Research
2015, Cheng J [264]	Human	Therapeutics	Research
2015, Cherng BPZ [265]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2015, Ch'ng JH [266]	Human	Microbiology	Research
2015, Choudhury S [267]	Human	Therapeutics	Research
2015, Chow ALP [268]	Human	Knowledge, Attitudes, Practices	Education; Optimisation of Antimicrobial Use
2015, Chow ALP [269]	Human	Intervention	Optimisation of Antimicrobial Use
2015, Chua AP-G [270]	Human	Therapeutics	Research
2015, Chua NGS [271]	Human	Therapeutics	Research
2015, Chung SJ [272]	Human	Therapeutics	Research
2015, Duan R [273]	Human	Therapeutics	Research
2015, Feng G [274]	Human	Therapeutics	Research
2015, Gopal P [275]	Human	Therapeutics	Research
2015, Harris PNA [276]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2015, Harris PNA [277]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2015, Harris PNA [278]	Human	Intervention	Prevention & Control of Infection
2015, Haver HL [279]	Human	Therapeutics	Research
2015, Ho HJ [13]	Human	Intervention	Prevention & Control of Infection
2015, Hsu L-Y [280]	Human	Transmission	Surveillance & Risk Assessment
2015, Koh J-J [281]	Human	Therapeutics	Research
2015, Koh J-J [282]	Human	Therapeutics	Research
2015, Koh TH [283]	Human, Environment	Surveillance	Surveillance & Risk Assessment
2015, Kumar A [284]	Human, Environment	Microbiology	Research
2015, Lau QY [285]	Human	Therapeutics	Research
2015, Lau QY [286]	Human	Therapeutics	Research
2015, Lau QY [287]	Human	Therapeutics	Research
2015, Lee HK [288]	Human	Surveillance	Surveillance & Risk Assessment
2015, Lew KY [289]	Human	Intervention	Optimisation of Antimicrobial Use
2015, Li J [290]	Human	Therapeutics	Research
2015, Liew YX [291]	Human	Intervention	Optimisation of Antimicrobial Use
2015, Liew YX [292]	Human	Social and Economic Impacts	Research
2015, Lim K [293]	Human	Intervention	Research; Prevention & Control of Infection
2015, Lim T-P [294]	Human	Therapeutics	Research
2015, Lim T-P [295]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2015, Ling ML [296]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2015, Loo LW [297]	Human	Intervention	Optimisation of Antimicrobial Use
2015, Lu S [298]	Human	Intervention	Research; Prevention & Control of Infection
2015, Manjunatha UH [299]	Human	Therapeutics	Research
2015, Ng C [300]	Environment	Surveillance	Surveillance & Risk Assessment
2015, Ng LSY [301]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2015, Ng PS [302]	Human	Therapeutics	Research
2015, Ng TM [303]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2015, Paton NI [304]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2015, Phoon YW [305]	Human	Surveillance	Surveillance & Risk Assessment
2015, Samy RP [306]	Human	Therapeutics	Research

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2015, Samy RP [307]	Human	Therapeutics	Research
2015, Seneviratne CJ [308]	Human	Surveillance	Surveillance & Risk Assessment
2015, Tan S [309]	Human	Therapeutics	Research
2015, Tang SSL [310]	Human	Surveillance	Surveillance & Risk Assessment
2015, Teng CB [311]	Human	Intervention	Optimisation of Antimicrobial Use
2015, Teo JWP [312]	Human	Surveillance	Surveillance & Risk Assessment
2015, Vasoo S [313]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2015, Vasoo S [314]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2015, Vasudevan A [315]	Human	Social and Economic Impacts	Research
2015, Win M-K [24]	Human	Social and Economic Impacts	Research; Prevention & Control of Infection
2015, Yi X [316]	Environment	Diagnostics	Surveillance & Risk Assessment; Research
2015, Yoon BK [317]	Human	Therapeutics	Research
2016, Ang TL [318]	Human	Surveillance	Surveillance & Risk Assessment
2016, Ariyasu S [319]	Human	Diagnostics	Research
2016, Arora S [320]	Human	Therapeutics	Research
2016, Ashajyothi C [321]	Human	Therapeutics	Research
2016, Aung KT [322]	Food	Surveillance	Surveillance & Risk Assessment
2016, Aung TT [323]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Boudhar A [324]	Human	Therapeutics	Research
2016, Boudhar A [325]	Human	Therapeutics	Research
2016, Cai B [326]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Cai Y [327]	Human	Intervention	Optimisation of Antimicrobial Use
2016, Cai Y [328]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2016, Cai Y [329]	Human	Therapeutics	Research
2016, Cao Y [330]	Human	Therapeutics	Research
2016, Chen YT [331]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Chen Y-T [332]	Human	Transmission	Research
2016, Chia G [333]	Human	Intervention	Prevention & Control of Infection
2016, Chow ALP [334]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2016, Chow ALP [335]	Human	Intervention	Optimisation of Antimicrobial Use
2016, Chua SL [336]	Human	Therapeutics	Research
2016, Fisher DA [337]	Human, Environment	Intervention	Prevention & Control of Infection
2016, Ghode P [338]	Human	Therapeutics	Research
2016, Gopal P [339]	Human	Therapeutics	Research
2016, Hemu X [340]	Human	Therapeutics	Research
2016, Ho HJ [341]	Human	Transmission	Surveillance & Risk Assessment
2016, Husain N [342]	Human	Therapeutics	Research
2016, Isenman H [343]	Human	Intervention	Prevention & Control of Infection
2016, Isenman H [344]	Human	Intervention	Prevention & Control of Infection
2016, Khara JS [345]	Human	Therapeutics	Research
2016, Khong WX [346]	Human	Transmission	Surveillance & Risk Assessment
2016, Khong WX [347]	Human	Transmission	Surveillance & Risk Assessment; Research
2016, Koh J-J [348]	Human	Therapeutics	Research
2016, Kong YL [349]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2016, Lakshminarayanan R [350]	Human	Therapeutics	Research
2016, Le T-H [351]	Environment	Surveillance	Surveillance & Risk Assessment
2016, Lee SH [352]	Human	Therapeutics	Research
2016, Li M [353]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Lim EJZ [354]	Food	Surveillance	Surveillance & Risk Assessment
2016, Lim MY-X [355]	Human	Therapeutics	Research
2016, Lim WS [356]	Human	Therapeutics	Research
2016, Low A [357]	Environment	Surveillance	Surveillance & Risk Assessment
2016, Mandakhalikar KD [358]	Human	Intervention	Research; Prevention & Control of Infection
2016, Marimuthu K [359]	Human	Intervention	Prevention & Control of Infection
2016, Ng TM [360]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Pan DST [361]	Human	Knowledge, Attitudes, Practices	Education
2016, Seneviratne CJ [362]	Human	Microbiology	Research
2016, Song CT [363]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2016, Su CT-T [364]	Human	Therapeutics	Research
2016, Teng CP [365]	Human	Therapeutics	Research
2016, Teo JQM [366]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2016, Teo JWP [367]	Human	Surveillance	Surveillance & Risk Assessment
2016, Teo JWP [368]	Human	Diagnostics	Research
2016, Tran NH [369]	Environment	Diagnostics	Surveillance & Risk Assessment; Research
2016, Tran NH [370]	Environment	Intervention	Research
2016, Truong T [371]	Human	Therapeutics	Research
2016, Tun ZM [372]	Human	Knowledge, Attitudes, Practices	Education
2016, Wee KB [373]	Human	Therapeutics	Research
2016, Wong EHH [374]	Human	Therapeutics	Research
2016, Wong JGX [375]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2016,Teo JQM [376]	Human	Surveillance	Surveillance & Risk Assessment
2017 Lee MHM [20]	Human	Intervention	Education
2017 Zhang J [377]	Food, Environment	Intervention	Research
2017, Ang MLT [378]	Human	Therapeutics	Research
2017, Aung KT [379]	Food, Environment	Surveillance	Surveillance & Risk Assessment
2017, Aw J [380]	Human	Diagnostics	Research
2017, Aziz DB [381]	Human	Therapeutics	Research
2017, Cai Y [382]	Human	Surveillance	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2017, Cai Y [383]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2017, Chee CBE [384]	Human	Therapeutics	Research
2017, Chen S [385]	Human	Diagnostics	Research
2017, Chew KL [386]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Chew KL [387]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Chew KL [388]	Human	Public Health	Surveillance & Risk Assessment
2017, Chew KL [389]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2017, Chin JSF [390]	Human	Diagnostics	Research
2017, Chong SM [391]	Food, Animal	Surveillance	Surveillance & Risk Assessment
2017, Chow ALP [392]	Human	Transmission	Surveillance & Risk Assessment
2017, Gopal P [393]	Human	Therapeutics	Research
2017, Gopal P [394]	Human	Therapeutics	Research
2017, Hou Z [395]	Human	Therapeutics	Research
2017, Hsu L-Y [396]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Hsu L-Y [397]	Human, Animal	Transmission	Surveillance & Risk Assessment
2017, Khara JS [398]	Human	Therapeutics	Research
2017, Kityo Cissy [399]	Human	Therapeutics	Research
2017, Lee TH [400]	Human	Knowledge, Attitudes, Practices	Education
2017, Li PQ [401]	Human	Diagnostics	Research
2017, Lin S [402]	Human	Therapeutics	Research
2017, Lin S [403]	Human	Therapeutics	Research
2017, Lin S [404]	Human	Therapeutics	Research
2017, Liu S [405]	Human	Therapeutics	Research
2017, Loo LH [406]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Marimuthu K [407]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Ng C [408]	Environment	Surveillance	Surveillance & Risk Assessment
2017, Ng SMS [409]	Human	Therapeutics	Research
2017, Ng SMS [410]	Human	Therapeutics	Research
2017, Ng SMS [411]	Human	Therapeutics	Research
2017, Paton NI [412]	Human	Diagnostics	Research
2017, Peng J [413]	Human	Therapeutics	Research
2017, Pu Y [414]	Human	Therapeutics	Research
2017, Rashid R [415]	Human	Microbiology	Research
2017, Samy RP [416]	Human	Therapeutics	Research
2017, Seneviratne CJ [417]	Human	Therapeutics	Research
2017, Tan JH [418]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2017, Tan JPK [419]	Human	Therapeutics	Research
2017, Tan TY [420]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Tan TY [421]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2017, Teo JQM [422]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Venkatesh M [423]	Human	Therapeutics	Research
2017, Wang A [424]	Human	Microbiology	Research

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2017, Wang J [425]	Human	Therapeutics	Research
2017, Wang K [426]	Human	Microbiology	Research
2017, Yee M [427]	Human	Therapeutics	Research
2017, Yew PYM [428]	Human	Therapeutics	Research
2017, Yi X [429]	Environment	Intervention	Research
2017, Zhong G [430]	Human	Therapeutics	Research
2017, Zhou C [431]	Human	Intervention	Research; Prevention & Control of Infection
2018, Aziz DB [432]	Human	Therapeutics	Research
2018, Baek J-S [433]	Human, Environment	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Balne PK [434]	Human	Intervention	Research; Prevention & Control of Infection
2018, Budigi Y [435]	Human	Therapeutics	Research
2018, Cai Q [436]	Environment	Intervention	Research
2018, Cai Y [437]	Human	Diagnostics	Surveillance & Risk Assessment; Research; Optimisation of Antimicrobial Use
2018, Chan HL [438]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2018, Chan LY [439]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2018, Chan MKL [440]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2018, Chew KL [441]	Human	Diagnostics	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2018, Chew KL [442]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Chiang RZ-H [443]	Human	Therapeutics	Research
2018, Chiew CJ [444]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment; Prevention & Control of Infection
2018, Chilambi GS [445]	Human	Therapeutics	Research
2018, Chin W [446]	Human	Therapeutics	Research
2018, Chow ALP [12]	Human	Intervention	Prevention & Control of Infection
2018, Chuang L [447]	Human	Therapeutics	Optimisation of Antimicrobial Use
2018, Ding Y [448]	Human	Transmission	Research
2018, Ding Y [449]	Food	Microbiology	Research
2018, Gao J [450]	Human	Diagnostics	Research
2018, Haller L [451]	Environment	Surveillance	Surveillance & Risk Assessment
2018, Hartantyo SHP [452]	Animal	Surveillance	Surveillance & Risk Assessment
2018, Heng ST [453]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Ho ZJM [454]	Human	Transmission	Surveillance & Risk Assessment
2018, Htun HL [455]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Hu B [456]	Human	Therapeutics	Research
2018, Kalimuddin S [457]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Koh J-J [458]	Human	Therapeutics	Research
2018, Koh TH [459]	Human	Microbiology	Research
2018, Lakshimarayanan R [460]	Human	Therapeutics	Research
2018, Lau QY [461]	Human	Therapeutics	Research
2018, Le T-H [462]	Environment	Intervention	Research
2018, Lee GH [463]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2018, Li J [464]	Human	Therapeutics	Research
2018, Lim CLL [465]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Lim T-P [466]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Lim YH [467]	Human	Therapeutics	Research
2018, Lou W [468]	Human	Therapeutics	Research
2018, Mendez AR [469]	Human, Environment	Intervention	Research; Prevention & Control of Infection
2018, Ng C [470]	Environment	Surveillance	Surveillance & Risk Assessment
2018, Ng C [471]	Environment	Surveillance	Surveillance & Risk Assessment
2018, Ng C [472]	Environment	Microbiology	Surveillance & Risk Assessment
2018, Ng DHL [17]	Human, Environment	Transmission	Surveillance & Risk Assessment
2018, Ng SMS [473]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Ng SMS [474]	Human	Therapeutics	Research
2018, Obuobi S [475]	Human	Therapeutics	Research

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2018, Ong CH [476]	Human	Diagnostics	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2018, Parmar A [477]	Human	Therapeutics	Research
2018, Rocamora FM [478]	Human	Microbiology	Research
2018, Selcuk A [479]	Human	Surveillance	Surveillance & Risk Assessment
2018, Sinha S [480]	Human	Therapeutics	Research
2018, Su CT-T [481]	Human	Therapeutics	Research
2018, Su W [482]	Human	Microbiology	Research
2018, Tan BH [483]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Tan D [484]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2018, Tan YE [485]	Human	Surveillance	Surveillance & Risk Assessment
2018, Tang YW [486]	Human	Therapeutics	Research
2018, Teo JWP [487]	Human	Microbiology	Research; Optimisation of Antimicrobial Use
2018, Teo JWP [488]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2018, Tong JX [489]	Human	Therapeutics	Research
2018, Xu HV [490]	Human	Intervention	Research; Prevention & Control of Infection
2018, Yang SS [491]	Human	Therapeutics	Surveillance & Risk Assessment; Research; Optimisation of Antimicrobial Use
2018, Yason JA [492]	Human	Therapeutics	Research
2018, Yeo CK [493]	Human	Therapeutics	Research
2018, Yuan W [494]	Food	Intervention	Research; Prevention & Control of Infection
2018, Zhang Z [495]	Human	Diagnostics	Research
2018, Zhu L [496]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Zwe YH [497]	Food	Surveillance	Surveillance & Risk Assessment
2019, Arfan G [498]	Human	Therapeutics	Research
2019, Aung KT [499]	Food, Animal	Surveillance	Surveillance & Risk Assessment
2019, Bae K [500]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2019, Bazan EL [501]	Human	Therapeutics	Research
2019, Bharadwaj S [502]	Human	Intervention	Prevention & Control of Infection
2019, Chan JC [503]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2019, Chan YY [504]	Human	Knowledge, Attitudes, Practices	Education
2019, Chen H [505]	Human, Environment	Transmission	Research
2019, Chen WK [506]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Chew KL [507]	Human	Transmission	Surveillance & Risk Assessment
2019, Chew KL [508]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2019, Chiu JKH [509]	Human	Diagnostics	Research
2019, Choudhury S [510]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2019, Chua AQ [511]	Human	Public Health and Epidemiology	Education; Surveillance & Risk Assessment; Research; Prevention & Control of Infection; Optimisation of Antimicrobial Use
2019, Dupont C [512]	Human	Therapeutics	Research
2019, Ero R [513]	Human	Therapeutics	Research
2019, Fong J [514]	Human	Intervention	Research; Prevention & Control of Infection
2019, Guo S [515]	Food	Surveillance	Surveillance & Risk Assessment
2019, Guo S [516]	Food	Microbiology	Surveillance & Risk Assessment; Research
2019, Guo S [517]	Food	Microbiology	Surveillance & Risk Assessment; Research
2019, Ho HJ [518]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Ho PL [519]	Human	Therapeutics	Research
2019, Htun HL [520]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Keerthisinghe TP [521]	Environment	Intervention	Research
2019, Ko KKK [522]	Human	Surveillance	Surveillance & Risk Assessment
2019, Kyaw BM [21]	Human	Intervention	Education; Research; Prevention & Control of Infection
2019, La M-V [523]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment

Article ID	Sector(s)	Research Domain	Core Strategy(ies)
2019, Lee SY [524]	Human	Diagnostics	Surveillance & Risk Assessment; Research
2019, Legido-Quigley H [525]	Human	Public Health and Epidemiology	Education; Surveillance & Risk Assessment; Research; Prevention & Control of Infection; Optimisation of Antimicrobial Use
2019, Leung CM [526]	Human	Intervention	Research; Prevention & Control of Infection
2019, Li D [527]	Food	Intervention	Research; Prevention & Control of Infection
2019, Li M [528]	Human	Therapeutics	Research
2019, Liu H [529]	Environment	Microbiology	Research
2019, Loke HY [530]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Loo LW [531]	Human	Intervention	Optimisation of Antimicrobial Use
2019, Marimuthu K [532]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Martinez-Vega R [9]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Mayandi V [533]	Human	Therapeutics	Research
2019, Mo Y [534]	Human	Knowledge, Attitudes, Practices	Education
2019, Mo Y [535]	Human	Social and Economic Impacts	Education
2019, Ng C [536]	Environment	Intervention	Surveillance & Risk Assessment; Research
2019, Ngo T-M [537]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2019, Obuobi, S [538]	Human	Therapeutics	Research
2019, Octavia S [539]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Pada, SMK [15]	Human	Intervention	Prevention & Control of Infection
2019, Pang X [540]	Food	Intervention	Research
2019, Quek WM [541]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2019, Ryanputra D [542]	Human	Therapeutics	Research
2019, Selcuk A [543]	Human	Surveillance	Surveillance & Risk Assessment
2019, Singh SR [544]	Human	Public Health and Epidemiology	Education; Surveillance & Risk Assessment; Research; Prevention & Control of Infection; Optimisation of Antimicrobial Use
2019, Sorayah R [545]	Human	Therapeutics	Research
2019, Stewardson AJ [546]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Su CT-T [547]	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2019, Tan GSE [548]	Human	Transmission	Surveillance & Risk Assessment; Research
2019, Tan YE [549]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Tay MYF [550]	Food, Human	Surveillance	Surveillance & Risk Assessment
2019, Teo JQM [551]	Human	Therapeutics	Research
2019, Teo JQM [552]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Teo SW [553]	Human	Therapeutics	Research
2019, Tong JX [554]	Human	Therapeutics	Research
2019, Tran NH [555]	Environment	Surveillance	Surveillance & Risk Assessment
2019, Vasoo S [556]	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2019, Yang C [557]	Human	Therapeutics	Research
2019, Yi X [558]	Environment	Surveillance	Surveillance & Risk Assessment
2019, Yi X [559]	Environment	Surveillance	Surveillance & Risk Assessment
2019, Yuan Y [560]	Human	Therapeutics	Research
2019, Yuan Y [561]	Human	Therapeutics	Research
2019, Zhang EX [562]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Zhang J [563]	Food, Environment	Intervention	Research
2019, Zhang K [564]	Human	Therapeutics	Research
2019, Zhang L [565]	Environment	Intervention	Research
2019, Zheng S-W [566]	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Zhou C [567]	Human	Intervention	Research; Prevention & Control of Infection

Table 2. List of AMR research or review articles published between 2009 and 2019 where Singapore either contributed samples or data, or had researchers involved as part of the research team led by their overseas counterparts.
Articles were assigned to the most relevant research domain, sector(s) and their contribution to the NSAP core strategy(ies).

Article ID	Lead or collaborating country	Sector(s)	Research Domain	Core Strategy(ies)
Contributing samples to multinational studies				
2009, Bouchillon SK [568]	USA	Human	Surveillance	Surveillance & Risk Assessment
2009, Chuang C-H [569]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2009, Hawser SP [570]	Switzerland	Human	Surveillance	Surveillance & Risk Assessment
2009, Hurt AC [571]	Australia	Human	Surveillance	Surveillance & Risk Assessment
2009, Ko W-C [572]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2009, Lee H-Y [573]	Taiwan South Korea	Human	Surveillance	Surveillance & Risk Assessment
2009, Mendes RE [574]	USA	Human	Surveillance	Surveillance & Risk Assessment
2009, Yau W [575]	Australia	Human	Surveillance	Surveillance & Risk Assessment
2010, Christiansen KJ [576]	UK	Human	Surveillance	Surveillance & Risk Assessment; Research
2010, Farrell DJ [577]	USA	Human	Surveillance	Surveillance & Risk Assessment
2010, Higgins PG [578]	Germany	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2010, Hsueh P-R [579]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2011, Chen Y-H [580]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2011, Chung DR [581]	South Korea	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Hurt AC [582]	Australia	Human	Surveillance	Surveillance & Risk Assessment
2011, Hurt AC [583]	Australia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Lee MY [584]	South Korea	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Roberts JA [585]	USA	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2011, Wang H [586]	China Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2012, Bouchillon SK [587]	USA	Human	Surveillance	Surveillance & Risk Assessment
2012, Kiratisin P [588]	Thailand	Human	Surveillance	Surveillance & Risk Assessment
2012, Lin Y-T [589]	Taiwan	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Lu P-L [590]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2012, Namdari H [591]	USA	Human	Surveillance	Surveillance & Risk Assessment
2012, Yang Y [592]	China (Hong Kong SAR)	Environment	Surveillance	Surveillance & Risk Assessment
2013, Holden MTG [593]	UK Germany Ireland	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2013, Kim DH [594]	South Korea	Human	Transmission	Surveillance & Risk Assessment
2013, Leang S-K [595]	Australia	Human	Surveillance	Surveillance & Risk Assessment
2013, Mendes RE [596]	USA	Human	Surveillance	Surveillance & Risk Assessment
2013, Sader HS [597]	USA	Human	Surveillance	Surveillance & Risk Assessment
2013, Sheng W-H [598]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2014, Ginn AN [599]	Australia	Human	Diagnostics	Surveillance & Risk Assessment; Research
2015, Holt KE [600]	Australia UK	Human, Animal	Public Health and Epidemiology	Surveillance & Risk Assessment
2015, Pfaller MA [601]	USA	Human	Surveillance	Surveillance & Risk Assessment
2016, Jean S-S [602]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2016, Tan TY [603]	Singapore	Human	Surveillance	Surveillance & Risk Assessment
2016, Torumkuney D [604]	UK	Human	Surveillance	Surveillance & Risk Assessment
2017, Blackwell GA [605]	Australia	Human	Transmission	Surveillance & Risk Assessment; Research
2017, Blackwell GA [606]	Australia	Human	Microbiology	Surveillance & Risk Assessment; Research
2017, Chang Y-T [607]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment

Article ID	Lead or collaborating country	Sector(s)	Research Domain	Core Strategy(ies)
2017, Cheong HS [608]	South Korea	Human	Surveillance	Surveillance & Risk Assessment
2017, Jean S-S [609]	Taiwan	Human	Surveillance	Surveillance & Risk Assessment
2017, Karlowsky JA [610]	US	Human	Surveillance	Surveillance & Risk Assessment
2017, Ma L [611]	China (Hong Kong SAR)	Environment	Surveillance	Surveillance & Risk Assessment
2018, Harris PNA [612]	Australia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Harris PNA [613]	Australia	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Khor WC [614]	Malaysia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Mendis SM [615]	Singapore USA	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Pfaller MA [616]	USA	Human	Surveillance	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2018, Versporten A [617]	Belgium	Human	Surveillance	Surveillance & Risk Assessment
2018, Vilaichone RK [618]	Thailand	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Yarbrough ML [619]	USA	Human	Diagnostics	Research; Prevention & Control of Infection
2019, Blot S [620]	Belgium	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Chen SL [621]	Singapore	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, George CRR [622]	Australia	Human	Surveillance	Surveillance & Risk Assessment
2019, Hendriksen RS [623]	Denmark	Environment	Surveillance	Surveillance & Risk Assessment
2019, Hsia Y [624]	UK	Human	Surveillance	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2019, Hsia Y [625]	UK	Human	Surveillance	Surveillance & Risk Assessment; Optimisation of Antimicrobial Use
2019, Hu YJ [626]	China (Hong Kong SAR)	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Luo Y [627]	China USA	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Ma L [628]	China (Hong Kong SAR)	Environment	Surveillance	Surveillance & Risk Assessment
2019, Papadopoulos A [629]	Greece	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
International Research Collaborations on AMR, 2009-2019				
2009, Cervantes S [630]	USA	Human	Diagnostics	Research
2009, Tam VH [631]	USA	Human	Therapeutics	Research
2009, Valvatne H [632]	Norway	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Dhorda M [633]	France	Human	Transmission	Surveillance & Risk Assessment; Research
2011, Leitsch D [634]	Australia	Human	Therapeutics	Research
2011, Massi MN [635]	Indonesia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2011, Siswantoro H [636]	Australia	Human	Therapeutics	Research
2012, Apisarnthanarak A [637]	Thailand	Human, Environment	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Brunner R [638]	Switzerland	Human	Therapeutics	Research
2012, Cervantes S [639]	USA	Human	Diagnostics	Research
2012, Dunn LA [640]	Australia	Human	Therapeutics	Research
2012, Guiton PS [641]	USA	Human	Intervention	Research; Prevention & Control of Infection
2012, Ho KKK [642]	Australia	Human	Intervention	Research; Prevention & Control of Infection
2012, Köser CU [643]	UK	Human	Diagnostics	Research; Prevention & Control of Infection
2012, Lee M [644]	South Korea	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2012, Shields RK [645]	USA	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2012, Zhang L [646]	China	Human	Microbiology	Research

Article ID	Lead or collaborating country	Sector(s)	Research Domain	Core Strategy(ies)
2013, Barraud N [647]	Australia	Human	Therapeutics	Research
2013, Bowers DR [648]	Singapore USA	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2013, Chiang W-C [649]	Denmark	Human	Therapeutics	Research
2013, Ciesielczuk H [650]	UK	Human	Diagnostics	Research
2013, Jakobsen TH [651]	Denmark	Human	Microbiology	Research
2013, Kelesidis T [652]	USA	Human	Surveillance	Surveillance & Risk Assessment
2013, Liu Y [653]	Denmark	Human	Therapeutics	Research
2013, Richmond GE [654]	UK	Human	Diagnostics	Research
2013, Wang H [655]	Denmark	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2013, Yepuri NR [656]	Australia	Human	Intervention	Research; Prevention & Control of Infection
2013, Zhang Y [657]	USA	Animal, Environment	Surveillance	Surveillance & Risk Assessment
2013, Zhang Y [658]	USA	Animal, Environment	Surveillance	Surveillance & Risk Assessment
2014, Apisarnthanarak A [659]	Thailand	Human	Intervention	Surveillance & Risk Assessment; Prevention & Control of Infection
2014, Butler J [660]	Australia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Duan S [661]	USA	Human	Microbiology	Research
2014, Karunakaran R [662]	Malaysia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Kelesidis T [663]	USA	Human, Animal	Transmission	Surveillance & Risk Assessment; Research
2014, Lai C-C [664]	Taiwan	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2014, Landelle C [665]	Switzerland	Human, Environment	Intervention	Prevention & Control of Infection
2014, Stryjewski ME [666]	Argentina	Human	Therapeutics	Research
2014, Veiga MI [667]	Portugal	Human	Microbiology	Surveillance & Risk Assessment
2015, Aamodt H [668]	Norway	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2015, Baranovich T [669]	USA	Human	Therapeutics	Research
2015, Farrukee R [670]	Australia	Human	Therapeutics	Research
2015, Malmquist NA [671]	France	Human	Therapeutics	Research
2015, Matsunaga S [672]	Japan	Human	Diagnostics	Research
2015, Nguyen D [673]	Australia	Human	Therapeutics	Research
2015, Regmi SM [674]	Thailand	Human	Surveillance	Surveillance & Risk Assessment
2015, Rhee S-Y [675]	USA	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2015, Soetaert K [676]	Belgium	Human	Therapeutics	Research
2015, Zowawi HM [677]	Australia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2016, Arribas JR [678]	Spain	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Auburn S [679]	Australia	Human	Diagnostics	Research
2016, Coker OO [680]	Thailand	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2016, Cunningham SA [681]	USA	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2016, Grigg MJ [682]	Australia	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Hanafi A [683]	Malaysia	Human	Microbiology	Research
2016, Harris RC [684]	UK	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2016, Mac Aogáin M [685]	Ireland	Human	Surveillance	Surveillance & Risk Assessment
2016, Nguyen T-K [686]	Australia	Human	Therapeutics	Research
2016, Nilsson M [687]	Denmark	Human	Microbiology	Research
2016, Phyo AP [688]	Thailand	Human	Therapeutics	Research
2016, Richmond GE [689]	UK	Human	Microbiology	Research
2016, Stenvang M [690]	Denmark	Human	Therapeutics	Research

Article ID	Lead or collaborating country	Sector(s)	Research Domain	Core Strategy(ies)
2017, Atarashi K [691]	Japan	Human	Microbiology	Research
2017, Basilico N [692]	Italy	Human	Therapeutics	Research
2017, Bazaka K [693]	Australia	Human	Therapeutics	Research
2017, Belousoff MJ [694]	Australia	Human	Therapeutics	Research
2017, Bhuyan GS [695]	Bangladesh	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Chang MJ [696]	Republic of Korea (South Korea)	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2017, Chen F [697]	China	Human	Therapeutics	Research
2017, Cunningham SA [698]	USA	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2017, Gowrisankar G [699]	India	Environment	Microbiology	Research
2017, Gunawan C [700]	Australia	Human	Intervention	Research; Prevention & Control of Infection
2017, Howlin RP [701]	UK	Human	Therapeutics	Research
2017, Hutchison C [702]	China	Human	Social and Economic Impacts	Research
2017, Kathirvel S [703]	India	Human	Knowledge, Attitudes, Practices	Education
2017, Lamoth F [704]	USA	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2017, Landier J [705]	Thailand	Human	Therapeutics	Research
2017, Liao J-H [706]	Taiwan	Human	Microbiology	Research
2017, Thai VC [707]	Vietnam	Human	Therapeutics	Research
2018, Ahmed W [708]	Australia	Environment	Surveillance	Surveillance & Risk Assessment
2018, Antonoplis A [709]	USA	Human	Therapeutics	Research
2018, Beattie RE [710]	USA	Environment	Surveillance	Surveillance & Risk Assessment
2018, Chen C [711]	USA	Human	Therapeutics	Research
2018, Allix-Béguec C [712]	UK	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2018, Dunn DT [713]	UK	Human	Diagnostics	Research
2018, Fang T [714]	China	Environment	Surveillance	Surveillance & Risk Assessment
2018, Germond A [715]	Japan	Human	Microbiology	Research
2018, Grigg MJ [716]	Australia	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Hoppe A [717]	UK	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Jiang Y [718]	China	Environment	Surveillance	Surveillance & Risk Assessment
2018, Kano R [719]	Japan	Animal	Therapeutics	Research
2018, Malkawi R [720]	UK	Human	Therapeutics	Research
2018, Mather AE [721]	Vietnam	Human	Transmission	Surveillance & Risk Assessment; Research
2018, Merchant S [722]	USA	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Nordström R [723]	Sweden	Human	Therapeutics	Research
2018, Oonsivilai M [724]	Cambodia	Human	Diagnostics	Research; Optimisation of Antimicrobial Use
2018, Ravensdale JT [725]	Australia	Human	Surveillance	Surveillance & Risk Assessment
2018, Stockdale AJ [726]	UK	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Subedi D [727]	Australia	Human	Microbiology	Research
2018, Subedi D [728]	Australia	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2018, Subedi D [729]	Australia	Human	Transmission	Surveillance & Risk Assessment; Research
2018, Tzou PL [730]	USA	Human	Diagnostics	Surveillance & Risk Assessment; Research; Optimisation of Antimicrobial Use
2018, Vente A [731]	Germany	Human	Therapeutics	Research; Optimisation of Antimicrobial Use
2018, Zhou C [732]	China	Human	Intervention	Research; Prevention & Control of Infection
2019, Brunton LA [733]	UK	Environment	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Capci A [734]	Germany	Human	Therapeutics	Research
2019, Chen Y [735]	China	Environment	Surveillance	Surveillance & Risk Assessment

Article ID	Lead or collaborating country	Sector(s)	Research Domain	Core Strategy(ies)
2019, Chen Y [736]	China	Environment	Surveillance	Surveillance & Risk Assessment
2019, Faksri K [737]	Thailand	Human	Diagnostics	Research
2019, González A [738]	Spain	Human	Therapeutics	Research
2019, González A [739]	Spain	Human	Therapeutics	Research
2019, Jabbar A [740]	Pakistan	Human	Public Health and Epidemiology	Surveillance & Risk Assessment
2019, Juhas M [741]	Switzerland	Human	Therapeutics	Research
2019, Li H [742]	Denmark	Food	Transmission	Surveillance & Risk Assessment; Research
2019, Li H [743]	Denmark	Food	Surveillance	Surveillance & Risk Assessment
2019, Limmathurotsakul D [744]	Thailand	Human, Animal, Food	Knowledge, Attitudes, Practices	Education
2019, Long S [745]	China	Human	Diagnostics	Research
2019, Nilsson M [746]	Denmark	Human	Therapeutics	Research
2019, Nilsson M [747]	Denmark	Human	Therapeutics	Research
2019, Pei M [748]	China	Environment	Intervention	Research
2019, Penesyan A [749]	Australia	Human	Therapeutics	Research
2019, Phelan JE [750]	UK Philippines	Human	Microbiology	Research
2019, Ram M R [751]	Malaysia	Human	Therapeutics	Research
2019, Safi H [752]	USA	Human	Microbiology	Research
2019, Sosibo SC [753]	South Africa	Human	Therapeutics	Research
2019, Subedi D [754]	Australia	Human	Microbiology	Research
2019, Thompson JA [755]	UK	Human	Therapeutics	Research
2019, Yang DL [756]	China	Human	Therapeutics	Research
2019, Zhang N [757]	China	Environment	Surveillance	Surveillance & Risk Assessment

Annex C. AMR Research from Singapore, 2009-2019 *(Section IV(A))*

Figure 1. AMR Research – Annual Publication Trend 2009-2019.

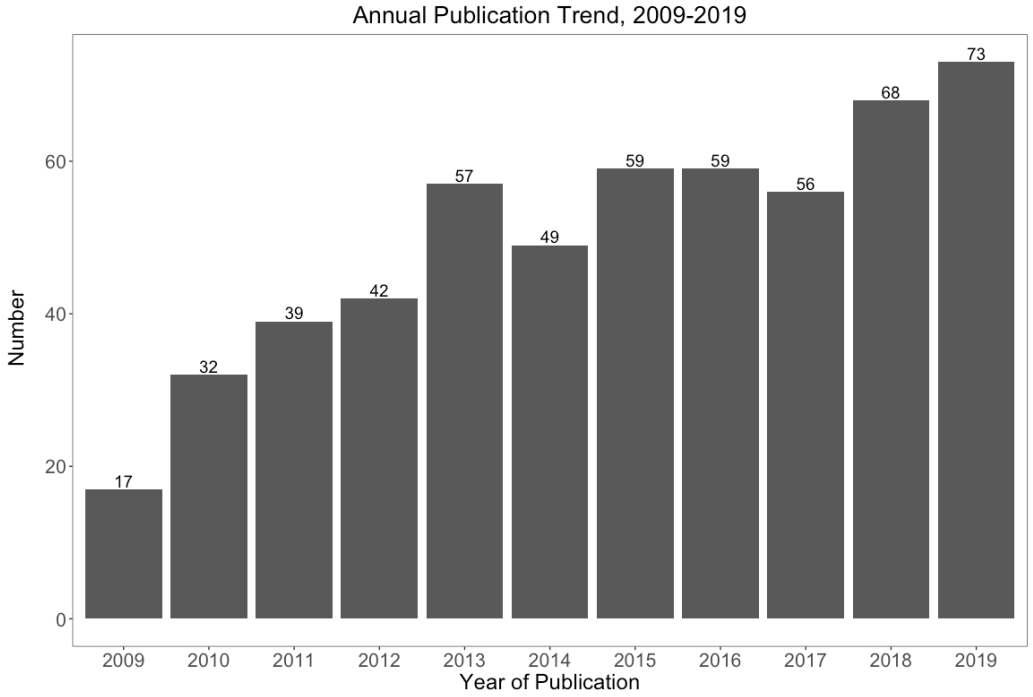
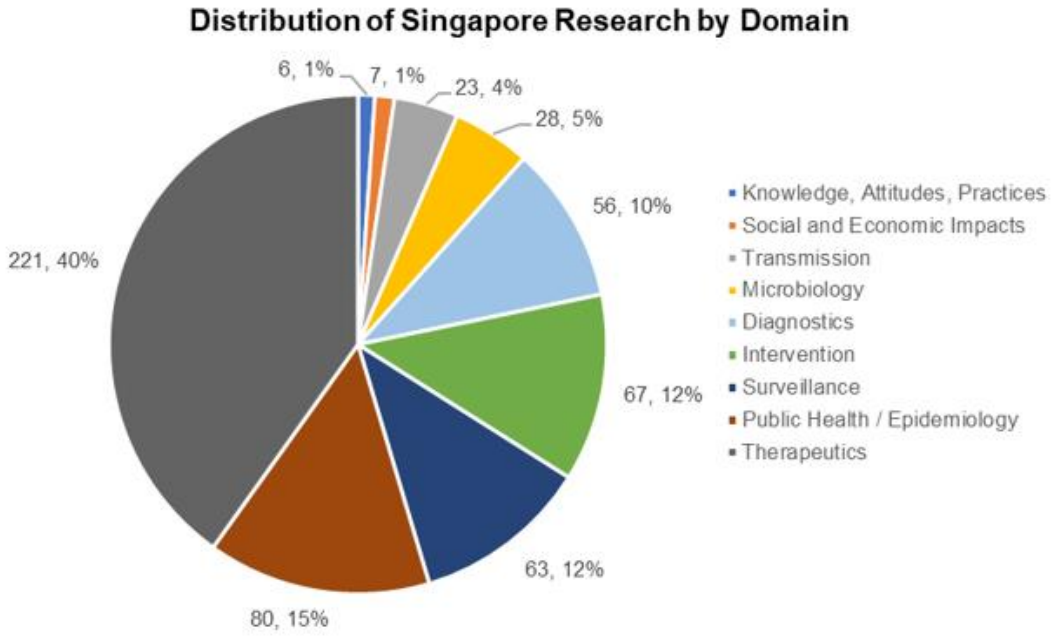


Figure 2. Distribution of AMR research by research domain.

(A) Overall distribution of AMR research by research domain.



(B) Annual trend of publication by research domain, 2009-2019.

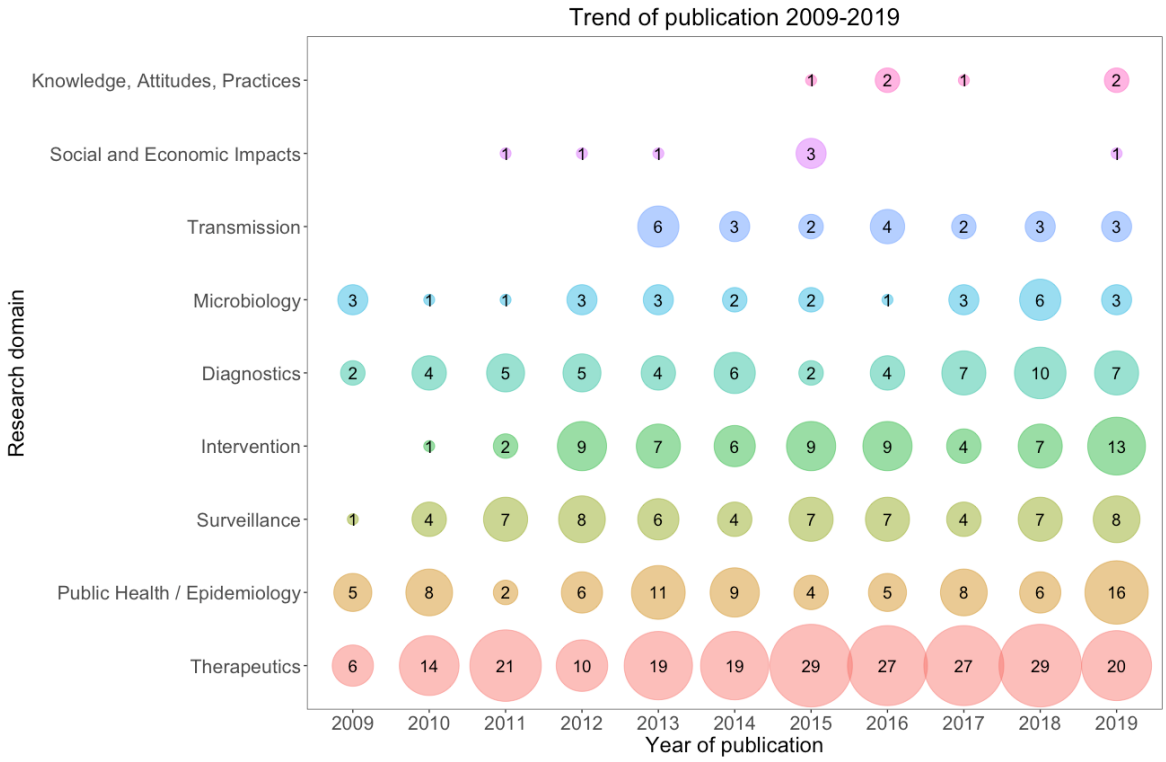
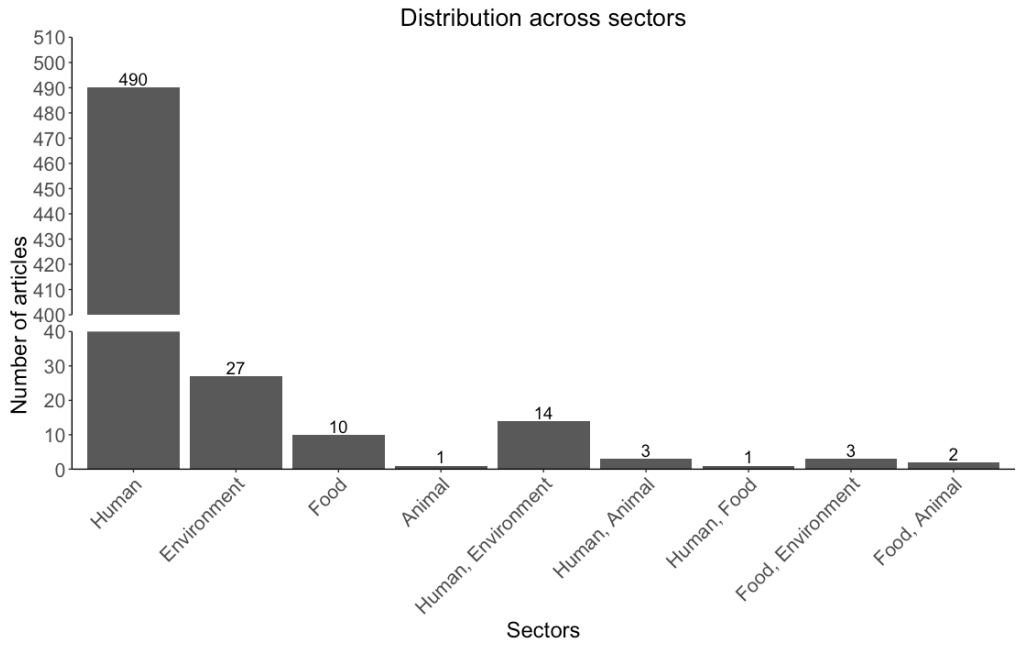


Figure 3. AMR Publication from One Health sectors.

(A) Total publication across One Health sectors.



(B) Annual publication trend from One Health sectors.

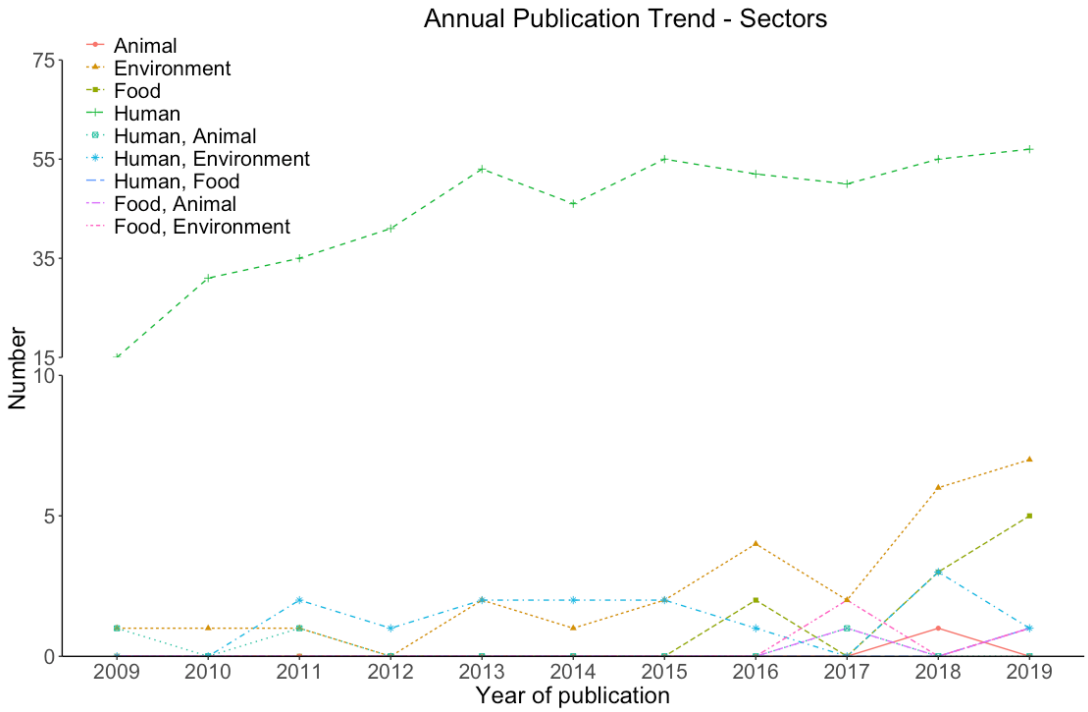


Figure 4. Microorganisms studied between 2009 to 2019.

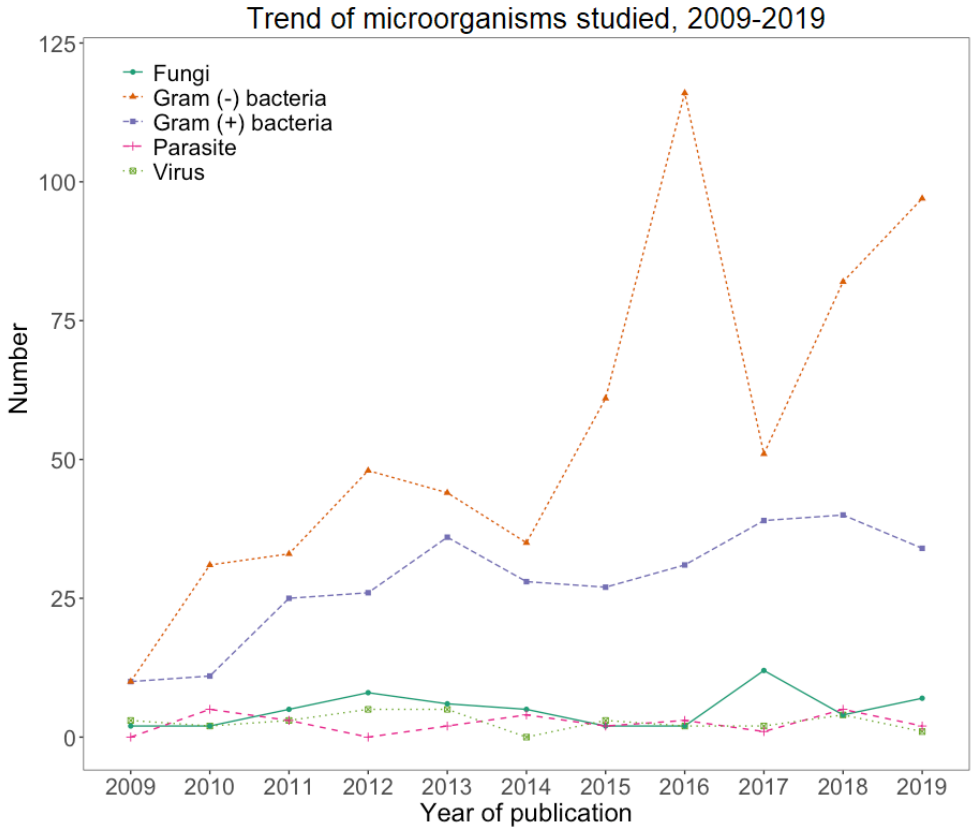


Figure 5. Institutions and their areas of research.

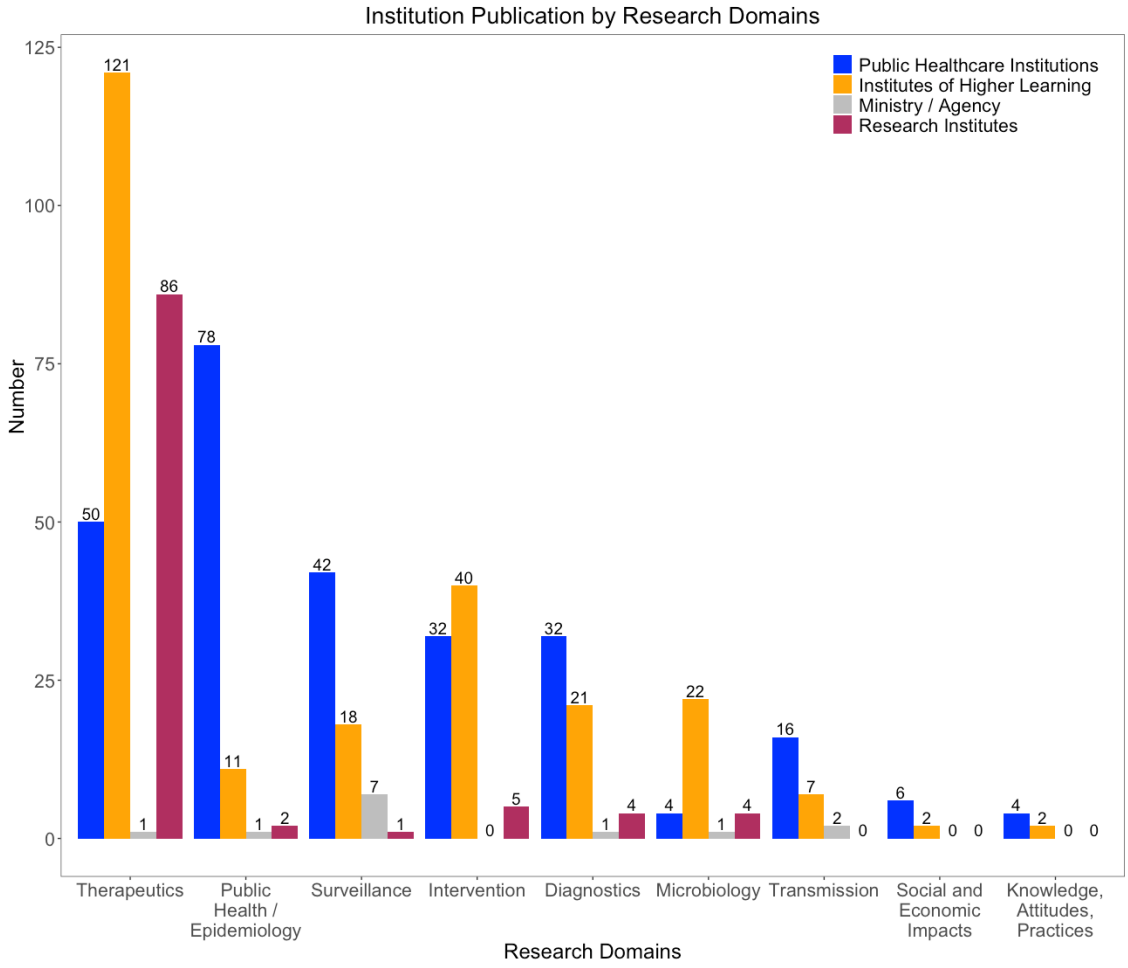


Table 1. Number of research articles in the Therapeutics domain that corresponded to WHO's priority pathogens' list for research and development of novel therapeutics[vi].

AMR Pathogen	**Number of articles**
Priority 1: Critical	
Acinetobacter baumannii, carbapenem-resistant	11
Pseudomonas aeruginosa, carbapenem-resistant	43
Enterobacterales, carbapenem-resistant, ESBL-producing	40
Priority 2: High	
Enterococcus faecium, vancomycin-resistant	9
Staphylococcus aureus, methicillin-resistant, vancomycin-intermediate and resistant	59
Helicobacter pylori, clarithromycin-resistant	2
Campylobacter spp., fluoroquinolone-resistant	0
Salmonellae, fluoroquinolone-resistant	2
Neisseria gonorrhoeae, cephalosporin-resistant, fluoroquinolone-resistant	0
Priority 3: Medium	
Streptococcus pneumoniae, penicillin-non-susceptible	1
Haemophilus influenzae, ampicillin-resistant	0
Shigella spp., fluoroquinolone-resistant	0

[vi] WHO publishes list of bacteria for which new antibiotics are urgently needed

Table 2. Volume of AMR research output by institutions, 2009-2019.

Singapore Institutions (by groups)	Number of articles
Institutes of Higher Learning	245
Duke-NUS Medical School	11
Nanyang Technological University	85
National University of Singapore	140
Ngee Ann Polytechnic	2
Republic Polytechnic	2
Singapore Institute of Technology	2
Singapore Polytechnic	1
Singapore University of Technology & Design	2
Ministry / Agency	13
Research institutes	102
Public Healthcare Institutions	260
Healthcare Cluster: National Healthcare Group	75
Khoo Teck Puat Hospital	1
National Skin Centre	2
Tan Tock Seng Hospital / National Centre for Infectious Diseases	72
Healthcare Cluster: National University Health System	83
National University Hospital	80
Ng Teng Fong General Hospital / Jurong Community Hospital	3
Healthcare Cluster: Singapore Health Services (SingHealth)	102
Bedok Polyclinic	1
Changi General Hospital	17
Eastern Health Alliance	1
KK Women's and Children's Hospital	4
National Cancer Centre Singapore	5
Singapore General Hospital	74

Table 3. Sources of funding and the number of research articles funded each, 2009-2019.

Source of funding	**Number of articles**
Ministry/Agency	344
Healthcare cluster grants	44
IHL funding	52
Public Healthcare Institutions Internal Funding	18
Others	2

Annex D. Summary of AMR research from Singapore in each research domain *(Section IV(A))*

1. *Knowledge, Attitudes, Practices.* Studies in this domain were only published from 2015 and conducted in the human sector. Amongst healthcare professionals, factors associated with antibiotic prescription and acceptance of computer-generated recommendations were studied. In non-healthcare professionals, the overall knowledge of antibiotic use was poor, and factors associated with higher antibiotic use were also identified, such as ethnicity, housing type, lower education and higher social economic status. Such studies in different population groups could provide insights for the development of appropriate or effective education interventions for the respective audiences, to improve their awareness and response toward AMR.

2. *Social and Economic Impacts.* AMR infections resulted in higher median medical costs to hospitals and patients, arising from an increased length of stay and post-discharge care costs. AMR infections also caused higher mortality rates in patients. There were a few studies that compared the cost-effectiveness of AMR interventions, such as screen and isolate programmes and recommendations by hospitals' antimicrobial stewardship programme (ASP). In terms of the social and psychological impact of AMR, one study found that isolation programmes led to emotional trauma, depression and anxiety in patients

3. *Transmission.* Another key area of research was to identify sources for the transfer or spread of AMR microorganisms and antibiotic resistance genes (ARGs). Studies identified from this review covered environmental sources, nosocomial, vector-borne or zoonotic transmission as transmission pathways for microorganisms. For MRSA and tuberculosis, transmission often occurred at venues with prolonged close contact, such as gaming centres, prisons or schools. International travel could also contribute to transmission or introduction of new AMR strains. At the molecular level, phage transduction, plasmid transconjugation or acquisition, and the presence of mobile genetic elements were identified as possible contributors to increased transmission. Insights from these studies provided avenues for the development of appropriate intervention strategies to control the spread of AMR.

4. *Diagnostics.* To enhance detection of AMR, research on diagnostics identified from this review had concentrated on developing more robust tools that would improve the turnaround time, accuracy and reliability of existing methods. Diagnostic tools were also developed to measure the presence of antimicrobials or residues from environmental samples. In general, diagnostic tools could be further segregated into assay-based methods, genetic approaches, imaging or spectrometry. In addition to developing detection technologies, studies that evaluated predictive scoring methods for patient cohorts and sample collection methods to increase sensitivity of AMR detection were also identified.

5. *Intervention.* Research to mitigate the transmission or development of AMR was primarily done in the human, environment and food sectors. Infection

prevention and control (IPC) strategies – including active surveillance and decontamination, control bundles, use of gloves – and ASP recommendations reduced the nosocomial spread of AMR. Bioengineering methods were also developed to disrupt growth of AMR microorganisms, using biomaterials and photodynamic inactivation that could be applied to catheters or building surfaces. Specific to the environment sector, the removal of AMR pathogens and genes from waste treatment was studied and optimised, while in the food sector, methods to prevent biofilm growth through ultra-violet (UV) treatment or novel compounds were studied. Unfortunately, this landscape review identified only one study each targeted at patients and healthcare professionals to improve antibiotic prescribing.

6. *Public Health and Epidemiology.* Overall, studies in this domain aimed to identify the impact of AMR on the health of a population as a whole, as well as expand surveillance efforts through identifying potential risk factors of AMR in target populations, treatment outcomes and adverse outcomes when treating patients for AMR infections. Research identified in this domain was also diverse, covering the spectrum of developing risk evaluation tools, modelling microbial population response, longitudinal studies to map the changes in drug susceptibilities of microbes, identifying associations between resistance factors and resistance rates, correlating AMR with genetic polymorphisms, and changes in minimum inhibition concentration values. Semi-structured interviews were also used to elicit expert opinion in the social, political, cultural and behavioural spheres.

7. *Surveillance.* Surveillance studies reported the prevalence of AMR microorganisms from the One Health sectors, the abundance of resistance genes in the environment, the genetic relatedness of resistance genes in the human sector, the susceptibility profiles of microorganisms, and antimicrobial usage in healthcare settings. Clinicians also reported emerging cases of resistant microorganisms identified from hospitals, demonstrating that passive surveillance is ongoing and an essential component of healthcare professional duties. Studies that described the presence of AMR microorganisms or antimicrobial content from the environment were also identified.

8. *Therapeutics.* Articles assigned to this domain comprised of laboratory-based basic research, bioinformatics research, clinical research, and reviews. Laboratory-based basic research was diverse, and comprised the identification and development of novel compounds or from drug libraries that had promising activities against AMR microorganisms or biofilms, or repurposing existing approved drugs for treatment of AMR infections. Some studies elucidated the mechanisms of action of therapeutics, or ways the microorganisms developed resistance. Bioinformatics approaches were also used to model mechanisms of resistance *in silico*, or used to model pharmacokinetics-pharmacodynamics responses using retrospective clinical data. In terms of clinical research, retrospective clinical data were analysed to understand appropriateness of antimicrobial therapy, or where possible, identify when culture-guided step-down therapies or the use of effective narrow spectrum or empirical therapeutics based on *in vitro* combination testing could be recommended. However, majority of these studies often employed retrospective analyses and

were limited by sample size and patient demographics. Lastly, reviews on therapeutics summarised the current status of research on therapeutics or treatments against AMR microorganisms.

9. *Microbiology.* Articles assigned to this domain were research that generated further insights on AMR and generally investigated a particular aspect of the microorganism to gain such understanding. These included analysing the dynamics of biofilm formation in a co-culture of two bacteria species, correlating genetics to resistance phenotypes, studying the stages of AMR development in bacteria, and studying novel responses or novel mutations in resistant microorganisms, which could provide avenues for the identification of novel targets for therapeutics development.

Annex E. Involvement in Multinational Research Efforts to Address AMR *(Section IV(B))*

Figure 1. Multinational AMR research – annual publication trend 2009-2019.

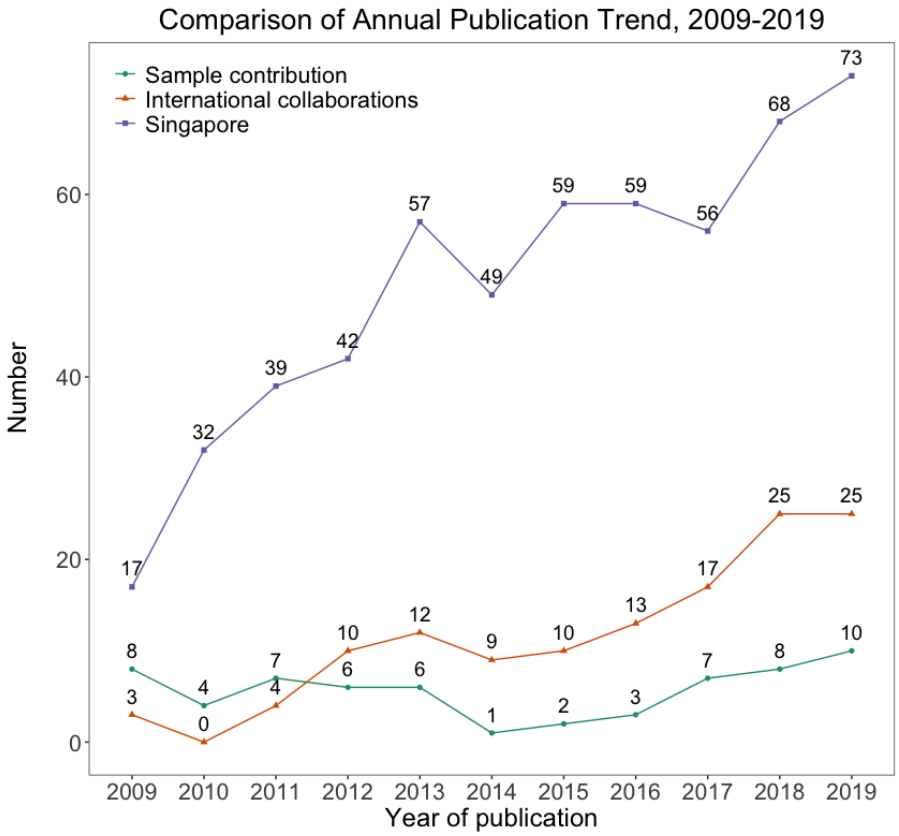


Figure 2. Domain distribution of collaborative AMR research.

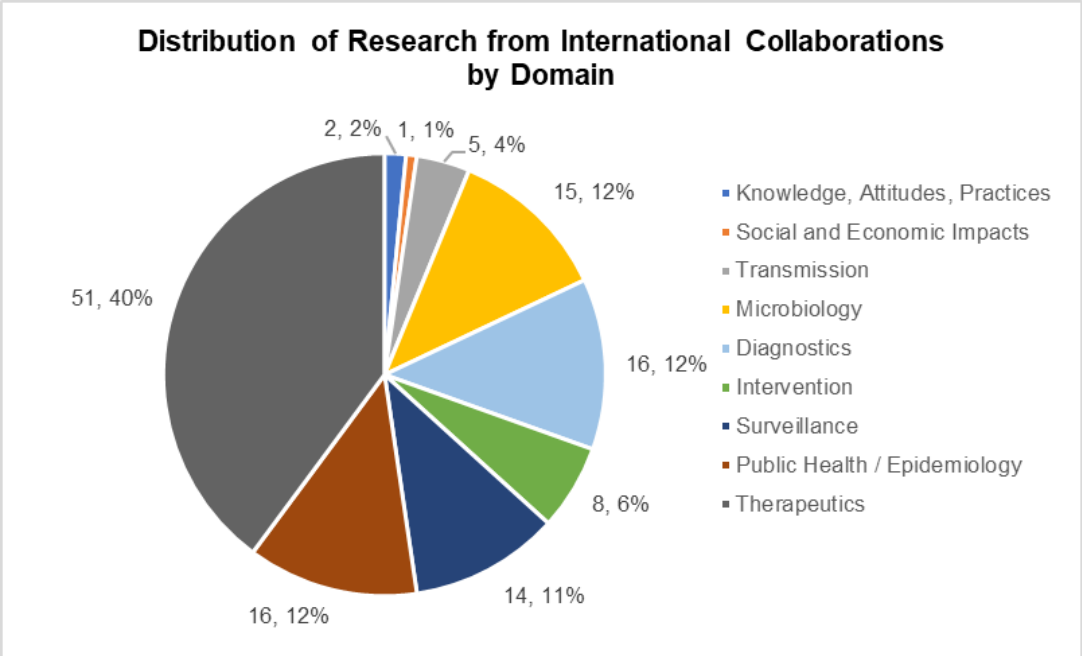
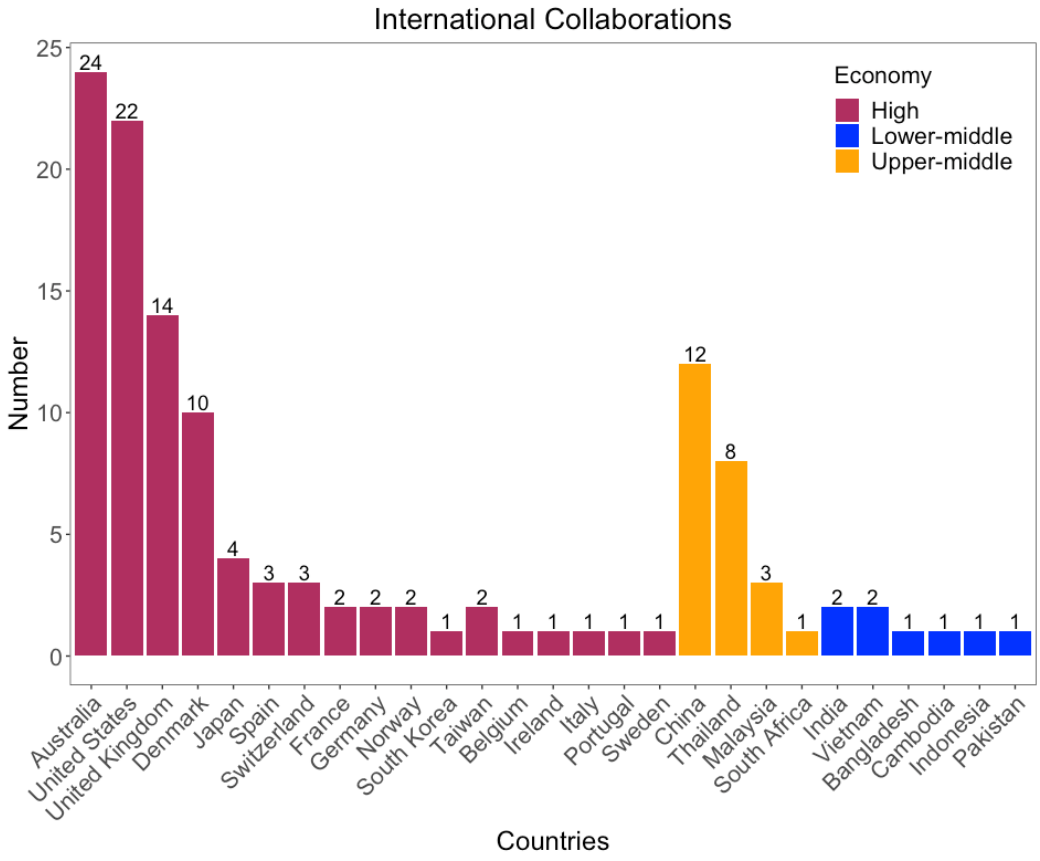


Figure 3. Countries that had AMR research collaborations with Singapore, grouped according to the World Bank country classification by income level[vii].



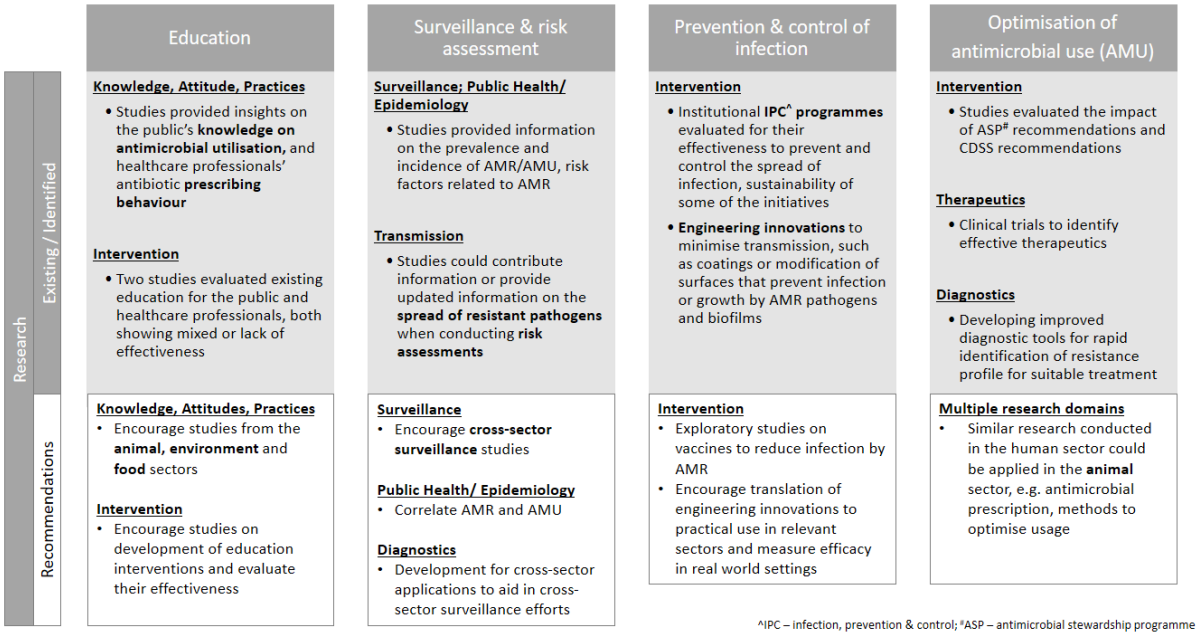
[vii] World Bank Country and Lending Groups.

Annex F. Summary of the types of AMR research that Singapore contributed samples or data to *(Section IV(B))*

Domain	Sector	Types of studies	Reference
Surveillance	Human	Most studies reported the resistance trends of microorganisms to antimicrobials. Some of these studies reported surveillance data from regional studies such as the Study for Monitoring Antimicrobial Resistance Trends (SMART), the COMPACT study, the Survey of Antibiotic Resistance (SOAR), the SENTRY antifungal surveillance programme, the Tigecycline Evaluation and Surveillance Trial (TEST), and the Community-Acquired Respiratory Tract Infection Pathogen Surveillance (CARTIPS) study.	[568, 569, 572, 573, 575-577, 579, 580, 586-588, 590, 591, 596, 597, 601-604, 607, 610, 616, 622]
		A few studies reported the trends in antimicrobial consumption in adults and children.	[617, 624, 625]
		Emergence and distribution of ESBL, AmpC beta-lactamases and carbapenemases were reported.	[570, 598, 608, 609]
		The emergence and spread of carbapenemase genes was reported in one study from the SENTRY Surveillance Programme.	[574]
		Studies on the emergence and spread of influenza A(H1N1) towards antivirals. All studies identified focused after the 2009 pandemic when there was increased use of antivirals.	[571, 582, 595]
	Environment	Drinking water samples from households or point of use were collected to investigate the antibiotic resistome.	[611, 628]
		AMR gene abundance from urban sewage or sewage treatment plants were studied to identify variations and diversity.	[592, 623]
Public Health and Epidemiology	Human	Studies in the human sector were diverse and consisted of investigations into the genetic linkages with resistance phenotypes.	[584, 612]
		Elucidating resistance profile with pathogen characteristics.	[615, 621]
		Correlating resistance profile with the type of antimicrobial treatment received.	[581, 629]
		Population characteristics for the acquisition or colonisation by resistant microorganisms.	[589, 614, 620, 626, 627]
		The pattern and spread of resistant *Helicobacter pylori*, carbapenem-resistance *Acinetobacter baumannii* and MRSA were studied.	[578, 593, 618]
		One study on resistant influenza H1N1 isolated form patients receiving antiviral therapy.	[583]
	Human-animal	*Klebsiella pneumoniae* from human and animal sources were analysed to determine its diversity and population structure, as well as their virulence and AMR.	[600]
Diagnostics	Human	One study that identified gene targets that could be used to predict resistance to 3GC and aminoglycosides in *Klebsiella pneumoniae* and *Escherichia coli*. Another study evaluated the performance of the Xpert MRSA NxG assay in detecting MRSA directly from nasal swabs.	[599, 619]

Therapeutics	Human	Clinical trial to investigate the activity of piperacillin-tazobactam and meropenem in patients with bacteraemia due to ceftriaxone-resistant *E. coli* or *K. pneumoniae*. Pharmacodynamic simulation of carbapenem infusions to determine the dosing regimens required to achieve effective and optimal cumulative fraction of response against resistant bacteria.	[585, 613]
Transmission	Human	Genetic determinants of spread were investigated in *Acinetobacter baumannii*.	[594, 605]
Microbiology	Human	Presence of an *armA* gene (a 16S methyltransferase shown to confer resistance to several aminoglycosides) in carbapenem-resistant *Acinetobacter baumannii* was analysed.	[606]

Annex G. Mapping research relevant to NSAP core strategies and opportunities for future research. *(Section VI(A))*



^IPC – infection, prevention & control; #ASP – antimicrobial stewardship programme

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