Antimicrobial resistance and the great divide: inequity in priorities and agendas between the Global North and the Global South threatens global mitigation of antimicrobial resistance

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To limit the catastrophic effects of the increasing bacterial resistance to antimicrobials on health, food, environmental, and geopolitical security, and ensure that no country or region is left behind, a coordinated global approach is required. In this Viewpoint, we argue that the diverging resource availabilities, needs, and priorities of the Global North and the Global South in terms of the actions required to mitigate the antimicrobial resistance pandemic are a direct threat to success. We argue that evidence suggests a need to prioritise and support infection prevention interventions (ie, clean water and safe sanitation, increased vaccine coverage, and enhanced infection prevention measures for food production in the Global South contrary to the focus on research and development of new antibiotics in the Global North) and to recalibrate global funding resources to address this need. We call on global leaders to redress the current response, which threatens mitigation of the antimicrobial resistance pandemic.

Introduction

Antimicrobial resistance (AMR) is recognised as a "wicked problem" that is resistant to resolution, lacking a stopping rule, and for which solutions are not right or wrong, but better or worse.[1,2] AMR threatens One Health and global security. Each individual intervention to mitigate AMR is important, but the measure of better or worse depends on the divide between the Global North and the Global South in resource availability, priorities, and needs. In this Viewpoint, we use the terms Global North and Global South as defined by Bram Wispelwey and colleagues to "connote the division of states along lines of power, colonial history, and associated wealth".[3] Our premise is that the needs and priorities of the Global North and South are so fundamentally different, that the existing inequality threatens to undermine overall mitigation of AMR.

In the Global North, politics, governance, and economic growth have enabled public health interventions and subsequently improved the health of these populations.[4] Access to clean water, improved sanitation, and hygiene; strong health systems with funding for high-coverage vaccination programmes; and generally high nutrition standards have reduced the burden of disease and antibiotic use.[5] Accordingly, mitigation priorities in high-income countries focus on research and development of new, probably costly, antibiotics for difficult-to-treat, resistant bacterial infections associated with health care. Contrastingly, the focus for low-income, lower-middle-income, and most upper-middle-income countries is on reducing infection burden for the majority of the population (so as to reduce the need for antibiotic use), rather than on costly new antibiotics that can be accessed only by a minority of people attending private or tertiary level academic teaching hospitals.[6]

Drivers of AMR in the Global North and the Global South

The concept that the more antibiotics are used, the greater the degree of resistance, is often taken as fact. At an individual antibiotic–bacterium level, this idea is largely true. In 2005, Goossens and colleagues reported a direct correlation between penicillin use in individual European countries and *Streptococcus pneumoniae* resistance rate to penicillin in those countries.[7] This direct association was not shown in a 2018 study, which included many low-income and middle-income countries (LMICs) in the analysis of resistance to and use of fluoroquinolones or third-generation cephalosporins for *Escherichia coli* (*E coli*).[8] In this study, which investigated the effect of different groupings of universally applicable interventions (ie, governance, health expenditure, gross domestic product per capita, education, infrastructure, and climate), the largest reduction in AMR came from infrastructure interventions. These interventions comprised adequate sanitation, access to improved water sources and electricity, and urbanisation.

The importance of access to water, sanitation, and hygiene (WASH) to mitigate AMR is supported by a country-level metagenomic study of sewage.[9] The total number of AMR genes per sample was greatest from countries in Africa, South America, and Asia. The World Bank Human Development Index in a country was inversely proportional to the number of AMR genes in the country's sewage. Three of the top five Human Development Index variables most accurately predicting total AMR gene abundance relate to access to sanitation services. Correlation between the country-level antibiotic usage and total AMR gene abundance was not observed, suggesting a greater relative importance of non-antibiotic-use factors in driving the presence of AMR genes in sewage. A study investigating One

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Health risks for human and animal colonisation with extended-spectrum β-lactamase-producing *E coli* and *Klebsiella pneumoniae* in Southern Malawi households showed the importance of environmental contamination as a driver of resistance.[10] These three examples show how the drivers of AMR can differ in many aspects between the Global North and the Global South.

The role of environmental contamination as a driver of AMR should not be surprising. Only half of the worldwide population (predominantly the Global North) uses safely managed sanitation services, and a quarter are without safe drinking water.[11] In 2022, 377 million (90%) of 419 million people living in rural areas still practised open defecation, the majority being in the Global South.[12] Furthermore, only half of health-care facilities worldwide have functional hand hygiene facilities at points of care,[13] which are major sites of transmission of AMR bacteria. UNICEF reports that one in four health-care facilities globally has no running water, increasing the likelihood of AMR transmission within the hospital environment.[14]

Trial evidence of the effects of WASH interventions on diarrhoeal episodes varies to date.[15] The small scale of trial interventions and varying epidemiology of causative pathogens are likely to be the reasons for these variations. Greater insight is anticipated in forthcoming publications from *The Lancet* WASH Commission.[16]

Preventing infections by increasing vaccine coverage in LMICs provides another major opportunity to mitigate AMR. Pneumococcal conjugate vaccine is estimated to reduce antibiotic treatment episodes for childhood acute respiratory tract infection by 19·7% (95% CI 3·4–43·4), and rotavirus vaccine is estimated to reduce episodes for diarrhoea by 11·4% (4·0–18·6).[17] Universal coverage of these vaccines could prevent a further 40 million episodes of antibiotic-treated illnesses.[17] Across 11 countries, the incidence of antibiotic prescribing during the first 3 months of life among infants whose mothers were assigned to receive respiratory syncytial virus vaccine was 133·7 prescription courses per 100 person-years at risk compared with 148·7 prescription courses per 100 person-years at risk in infants whose mothers who were assigned to receive placebo.[18] For lower respiratory tract infections, the number of antibiotic prescription courses was 70·4 per 100 person-years in infants whose mothers received the vaccine and 81·4 prescription courses per 100 person-years in infants whose mothers received placebo, resulting in a vaccine efficacy against antibiotic prescription course for lower respiratory tract infections of 16·4% (95% CI 1·3–29·3).[18] In adults, moving from voluntary to mandatory influenza vaccination in Ontario, Canada, reduced antibiotic prescriptions from 17·9 per 1000 people to 6·4 per 1000 people (relative risk 0·36, 95% CI 0·26–0·49) during the influenza season, indicating that vaccination in adults is also an important strategy to reduce antibiotic prescriptions.[19]

Pneumococcal conjugate vaccine is efficacious in directly reducing AMR in *Pneumococcus*[20] and the typhoid conjugate vaccine is efficacious in directly reducing AMR in *Salmonella enterica* serotype Typhi,[21] primarily by replacement of AMR-carrying vaccine serotypes with less resistant serotypes. Typhoid conjugate vaccine had a vaccine effectiveness of 97% (95% CI 95–98) in reducing extensively drug-resistant typhoid infections,[21] and a modelling study across 73 countries predicted that 21·2 million cases and 342 000 deaths from multidrug-resistant typhoid fever would be averted over 10 years following the introduction of typhoid conjugate vaccine with a catch-up campaign.[22] Hence, these crucial vaccinations can not only reduce the major driver of AMR (ie, antibiotic use) but also have a direct effect on antibiotic-resistant strains causing infection.

Animal vaccination and other infection prevention measures can also reduce antimicrobial use in food production.[23] The European Commission has formulated infection prevention measures for food security, including feeding practices, livestock housing, hygiene, and treatment management.[24] The Commission earmarked €6·3 billion to support voluntary actions under eco-schemes and rural development, such as improved feeding practices, livestock housing, hygiene, and treatment management, aiming to reach 23% of EU livestock units. Furthermore, there is consumer pressure in favour of antibiotic-free meat. Considerable pressure is being exerted on the Global South to reduce antimicrobial use in food production, but it is a difficult agenda to implement in LMICs, where approaches to remove antibiotics from the food animal supply chain are not yet well understood or financially incentivised. Additionally, projections have suggested that the Global South will be the greatest loser of agricultural productivity due to climate change,[25] and illegal mining in these areas also forces food production into greater intensification. These pressures, and weak regulatory systems, will make it difficult to provide the conditions that are necessary for reducing antibiotic use in food production.

The unequal flow of funding

The danger of the Global South falling short of opportunities to fundamentally mitigate AMR is further exacerbated by the focus of global funding towards research and development of new antibiotics. Apart from the UK Government's £265 million Fleming Fund programme, supporting laboratory infrastructure in some low-income countries, most funding in AMR (ie, US$11·95 billion worth of investment in research and development since Jan 1, 2017) goes to basic research and therapeutics, with little funding for vaccines let alone other infection prevention efforts, such as boosting WASH.[26] Funding for research and development in diagnostics is similarly poor,[26] despite reports of the use of rapid diagnostics reducing antibiotic prescribing in LMICs. For example, a randomised controlled trial in

Viet Nam showed that use of point-of-care CRP reduced antibiotic prescribing in primary care clinics. The number of patients who used antibiotics within 14 days in the CRP group was 581 (64%) of 902 compared with 738 (78%) of 947 patients in the control group (odds ratio 0·49, 95% CI 0·4–0·61; p<0·0001).[27] Further inequality is evident, as the Global North procures more than 60% of the global pharmaceutical market,[28] whereas antibiotic production occurs predominantly in countries such as China and India, with the risk of contamination of nearby water sources due to antibiotic residue discharge.[29]

The profit margin for new antimicrobials is slim, which is a factor in the decline in big pharmaceutical companies active in antimicrobial research and development. Those companies that continue to work in this area have taken their cue for research and development from WHO's 2017 bacterial priority pathogen list.[30] The composition of this list was fundamentally directed at research and development needs for AMR-resistant bacterial pathogens for which the antimicrobial pipeline was largely impaired. Gram-negative bacteria causing health-care-associated infections were listed as the critical priority. The number of people in low-income and lower-middle-income countries with access to hospitals that would have access to antimicrobials for critical priority resistant pathogens is small. In South Africa for example, an upper-middle-income country where the situation is expected to be better than in low-income and lower-middle-income countries, these last-resort antibiotics, such as colistin and tigecycline, are available only in private or tertiary academic hospitals in major cities. Ceftazidime–avibactam and cefiderocol are costly and might be unaffordable in LMICs. By virtue of the current bacterial priority pathogen list being constructed on the basis of gaps in the research and development market rather than on the basis of public health needs, the current list favours the production of antimicrobials for the Global North, and its validity, and the huge investment in research and development of antimicrobials that the list drives, is another example of North–South inequity.

On a programmatic scale, the Global South needs access to narrow-spectrum Access antibiotics, as defined in *The WHO AWaRe (Access, Watch, and Reserve) Antibiotic Book*.[31] Penicillin is the backbone of treatment of syphilis and rheumatic fever, which are prime examples of infections that have gone untreated due to an ongoing global stockout since 2015.[32] The WHO Essential Medicines List identifies narrow spectrum penicillins (predominantly aminopenicillins with or without clavulanate) as treatment of choice for most common community infections.[31] Access antibiotics are the priority antimicrobials needed by the Global South, not cefiderocol, which is a last-resort Reserve antibiotic. Last-resort Reserve antibiotics will do nothing to substantially mitigate antibiotic resistance nor benefit country-level population health. Securing consistent access to Access antibiotics is key for the Global South.

Fulfilling the commitment to leave no one country behind

The UN General Assembly AMR High-Level Meeting in 2024 is an important opportunity to raise the profile of the existing inequality in current mitigation efforts across the Global North and the Global South, and the global consequence of such divide. Importantly, the meeting occurs at a specific moment in time, but the declaration and planned actions should be considered within a longer framework of time. Arguably, one of the failings of the 2016 UN General Assembly AMR High-Level Meeting was suboptimal follow-through, with only one of four major global governance initiatives having been realised.[33]

Several urgent actions are needed (panel). Firstly, an independent panel on evidence for action, recommended to the Secretary General of the UN in April, 2019,[33] should be constituted expediently. Without this panel, equitable long-term mitigation interventions cannot be easily ensured. The Intergovernmental Panel on Climate Change provides an excellent model.

For more on the **Intergovernmental Panel on Climate Change** see https://www.ipcc.ch

The second crucial action is intensified inclusion and long-term commitment of leaders from the Global

***Panel:* High-level interventions required to begin recalibration of the global mitigation response to AMR**

- The UN Secretary General should accelerate the constitution and funding of an Independent Panel on Antimicrobial Resistance (AMR).
- The G7, G20, and G77 should review the threat to global AMR mitigation from the current state of inequity in AMR funding and interventions across the North–South divide.
- G77 leaders should prioritise AMR as a health, food, environmental, and geopolitical security threat by:
  - leveraging existing and new funding opportunities (eg, World Bank and regional banking systems) to increase funding for intensified water, sanitation, and hygiene, vaccination coverage, and food production biosafety and biosecurity interventions;
  - applying pressure for equitable flow of global funding mechanisms to redress the inequity in funding prioritisation;
  - incorporating AMR interventions into each of the 14 AMR-specific or AMR-sensitive country-level Sustainable Development Goal (SDG) targets, with heightened monitoring and evaluation;
  - and developing a unified negotiating position for the UN General Assembly AMR High-Level Meeting 2024, drawing on expertise in AMR and One Health across the Global South.
- The UN should reconsider the co-benefits of linking equitable AMR mitigation interventions to the attainment of country-level SDGs across all 14 of the 17 SDGs that are either AMR-specific or AMR-sensitive.
- The UN should lead negotiations on knowledge transfer and capacity development for existing and novel antimicrobials (including active pharmaceutical ingredients), vaccines, and diagnostics to control infectious diseases and increase access to mitigation tools for AMR in the Global South.

South, without which sustainability of the required programmes of intervention will be challenged. Decreasing health budgets since the Abuja Declaration in 2001 run contrary to the pledges and commitments made by African leaders.[34] Current AMR policy agenda is predominantly set by the G7 and G20. The G7's priority focus is on research pipeline investment and pull incentive mechanisms (ie, money given to pharmaceutical companies to incentivise drug supply),[35] whereas the G20 are focused on health emergency prevention, preparedness, and response in the wake of COVID-19, with a focus on One Health and AMR. However, the spotlight seems more on the next pandemic than on attending to the slow and dangerous pandemic that is AMR. The representative body of the Global South (ie, the G77) has been largely silent on AMR since September, 2017. With China, they issued a declaration emphasising three priority areas for AMR action: to enhance international cooperation for LMICs to take action; to ensure affordable and equitable access to existing and new antimicrobials, vaccines, diagnostics, and tools; and to increase innovation in research and development delinking costs from sales volume.[36] The past 6 years has seen little to no communication and no action on AMR from the G77. Although the responsibility is shared, large political bodies, such as the African Union, the Association of Southeast Asian Nations, and blocks such as the Independent Alliance of Latin America and the Caribbean, should use their influence to lobby and work with the G77 to increase engagement in AMR at the highest level.

Much attention relating to global governance is focused on opportunities to write AMR into the WHO Convention, Agreement or Other International Instrument on Pandemic Prevention, Preparedness, and Response (WHO-CA+). The current WHO-CA+ draft defines a pandemic as "the global spread of a pathogen or variant that infects human populations with limited or no immunity through sustained and high transmissibility from person to person, overwhelming health systems with severe morbidity and high mortality and causing social and economic disruptions, all of which require effective national and global collaboration and coordination for its control".[37] The definition lends itself predominantly to a SARS-CoV-2-like respiratory pathogen that causes explosive epidemics leading to a pandemic. Whether AMR's slower transmissibility rate will qualify it as a pandemic under this definition is unclear. The AMR Global Leaders Group have championed how inclusion of AMR into the pandemic instrument could have co-benefits for AMR and pandemic preparedness and response.[38] However, embedding AMR into the WHO-CA+ seems unlikely to redress the divide in AMR mitigation efforts between the Global North and the Global South.

Instead, we argue for the development of an AMR mitigation instrument in its own right, one that recognises and works to redress inequity. Before the UN General Assembly AMR High-Level Meeting in 2016, a sustained effort was made for AMR to be recognised within the Sustainable Development Goals (SDGs). 14 of the 17 SDGs relate to AMR either in a direct or indirect manner. Unfortunately, these efforts largely failed, resulting in only one indicator (ie, SDG 3.d.2), which relates to health-care-associated infections in bloodstream.[39] Developing a standalone AMR pandemic instrument, which focuses AMR interventions within the wider framework of the SDGs (and the SDG successor, coming in 2030) would be an opportunity to deliver an equitable global AMR mitigation strategy that benefits both the Global North and the Global South.

If our premise is correct that the Global South has been disadvantaged by a North-centric vision of AMR mitigation and that current evidence suggests that infection prevention rather than research and development of new antibiotics is the key to mitigating AMR in the Global South, then we need what Collins and Porras framed as "big hairy audacious goals".[40] These goals are defined as clear and compelling long-term goals guided by a company's (in this case the world's) values and purpose. An infection prevention goal (including maximal WASH and vaccine coverage) would go some way to rectifying inequity and delivering significant co-benefits to transform the lives of people living in the Global South.

We acknowledge principal limitations to our premise in so much as not all LMICs, and particularly upper-middle-income countries, are the same, and for some countries, the worrying increase in the use of Watch antibiotics in human health is an important indicator for a focus on tighter antibiotic stewardship. Other systemic factors (eg, climate change, poverty, malnutrition, urbanisation with overcrowding, non-resilient health systems, and vector-borne infections)[41–43] also contribute to driving the differential burden of infection in the Global South, which is often addressed with the largely inappropriate use of antibiotics.

We also acknowledge increased efforts to facilitate technology transfer, investment in local vaccine production,[44] and harmonised regulation in terms of registration of antibiotics and their procurement by Global South countries,[45] but we believe that more should be done to mitigate the impending disaster resulting from AMR-related bacterial infection challenges.

We recognise that increased investment for our suggested interventions presents a financial challenge. New funding streams from the Global Fund and the Pandemic Fund, and options for World Bank and Development Bank country-level loans to maximise primary prevention programmes, offer opportunities. Increasing WASH and vaccination access has broader health economic arguments to support them in terms of human wellbeing and livelihoods.[46]

Funding for an independent scientific panel falls to the UN and, if too financially challenging, could potentially be incorporated into a wider panel covering pandemic preparedness or One Health to share costs. Upscaling coverage of vaccination programmes comes with implementation challenges both in relation to human resources for operations and impediments such as war and reach. However, systems set up by Gavi, the Vaccine Alliance make upscaling a realistic measure.

As countries jostle to influence the contents of the UN General Assembly AMR High-Level Meeting 2024 declaration, we urge meaningful reflection on the current divide between Global North and the Global South and a recalibration of priority interventions, which hold the key to progress and a long-term future for the AMR mitigation effort.

Contributors

MMe and MMp conceived of the work and wrote the first draft. All co-authors provided edits to subsequent drafts, reviewed the final manuscript, and agreed to the submission for publication.

Declaration of interests

EC has provided two lectures on antimicrobial stewardship at public engagement events and health-care worker educational events, which were funded by Pfizer, and she has received honoraria for her time and contribution. ACG has received consulting fees from Aché, Eurofarma, Uniã Quimica, and The Wellcome Trust and honoraria from bioMerieux, Eurofarma, MSD, Pfizer, and Sandos. MSD and Pfizer have supported her attendance at meetings or travel, or both. She participates on data safety monitoring boards or advisory boards of Aché, Eurofarma, MSD, Pfizer, Sandoz, United Medical, and União Quimica. She is a member of the Scientific Advisory Committee for GARDP, a member of the Health 1 Area Coordination Board, Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), and is a researcher of the Brazilian National Council for Scientific and Technological Development. All other authors declare no competing interests.

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References

1 Rittel HWJ, Webber MM. Dilemmas in a general theory of planning. *Policy Sci* 1973; **4:** 155–69.

2 Council on Foreign Relations. A conversation with Dame Sally Davies. Sept 23, 2016. https://www.cfr.org/event/conversation-dame-sally-davies (accessed Dec 12, 2023).

3 Wispelwey B, Osuagwu C, Mills D, et al. Towards a bidirectional decoloniality in academic global health: insights from settler colonialism and racial capitalism. *Lancet Glob Health* 2023; **11:** e1469–74.

4 Kruk ME, Gage AD, Arsenault C, et al. High-quality health systems in the Sustainable Development Goals era: time for a revolution. *Lancet Glob Health* 2018; **6:** e1196–252.

5 Fuhrmeister ER, Harvey AP, Nadimpalli ML, et al. Evaluating the relationship between community water and sanitation access and the global burden of antibiotic resistance: an ecological study. *Lancet Microbe* 2023; **4:** e591–600.

6 Bhutta ZA, Salam RA, Das JK, et al. Tackling the existing burden of infectious diseases in the developing world: existing gaps and the way forward. *Infect Dis Poverty* 2014; **3:** 28.

7 Goossens H, Ferech M, Vander Stichele R, Elseviers M. Outpatient antibiotic use in Europe and association with resistance: a cross-national database study. *Lancet* 2005; **365:** 579–87.

8 Collignon P, Beggs JJ, Walsh TR, Gandra S, Laxminarayan R. Anthropological and socioeconomic factors contributing to global antimicrobial resistance: a univariate and multivariable analysis. *Lancet Planet Health* 2018; **2:** e398–405.

9 Hendriksen RS, Munk P, Njage P, et al. Global monitoring of antimicrobial resistance based on metagenomics analyses of urban sewage. *Nat Commun* 2019; **10:** 1124.

10 Cocker D, Chidziwisano K, Mphasa M, et al. Investigating One Health risks for human colonisation with extended spectrum β-lactamase-producing *Escherichia coli* and *Klebsiella pneumoniae* in Malawian households: a longitudinal cohort study. *Lancet Microbe* 2023; **4:** e534–43.

11 UNICEF. Triple threat: how disease, climate risks, and unsafe water, sanitation and hygiene create a deadly combination for children. New York, NY: United Nations Children's Fund, 2023.

12 UNICEF, WHO. Progress on household drinking water, sanitation and hygiene 2000–2022: special focus on gender. New York, NY: United Nations Children's Fund and World Health Organization, 2023.

13 WHO. Half of health care facilities globally lack basic hygiene services—WHO, UNICEF. Aug 30, 2022. https://www.who.int/news/item/30-08-2022-half-of-health-care-facilities-globally-lack-basic-hygiene-services---who--unicef (accessed July 29, 2023).

14 UNICEF, WHO. Progress on WASH in health care facilities 2000–2021: special focus on WASH and infection prevention and control. United Nations Children's Fund and World Health Organization, 2023.

15 Cumming O, Arnold BF, Ban R, et al. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. *BMC Med* 2019; **17:** 173.

16 Amebelu A, Ban R, Bhagwan J, et al. *The Lancet* Commission on water, sanitation and hygiene, and health. *Lancet* 2021; **398:** 1469–70.

17 Lewnard JA, Lo NC, Arinaminpathy N, Frost I, Laxminarayan R. Childhood vaccines and antibiotic use in low- and middle-income countries. *Nature* 2020; **581:** 94–99.

18 Lewnard JA, Fries LF, Cho I, Chen J, Laxminarayan R. Prevention of antimicrobial prescribing among infants following maternal vaccination against respiratory syncytial virus. *Proc Natl Acad Sci USA* 2022; **119:** e2112410119.

19 Kwong JC, Maaten S, Upshur RE, Patrick DM, Marra F. The effect of universal influenza immunization on antibiotic prescriptions: an ecological study. *Clin Infect Dis* 2009; **49:** 750–56.

20 Andrejko K, Ratnasiri B, Hausdorff WP, Laxminarayan R, Lewnard JA. Antimicrobial resistance in paediatric *Streptococcus pneumoniae* isolates amid global implementation of pneumococcal conjugate vaccines: a systematic review and meta-regression analysis. *Lancet Microbe* 2021; **2:** e450–60.

21 Yousafzai MT, Karim S, Qureshi S, et al. Effectiveness of typhoid conjugate vaccine against culture-confirmed *Salmonella enterica* serotype Typhi in an extensively drug-resistant outbreak setting of Hyderabad, Pakistan: a cohort study. *Lancet Glob Health* 2021; **9:** e1154–62.

22 Birger R, Antillón M, Bilcke J, et al. Estimating the effect of vaccination on antimicrobial-resistant typhoid fever in 73 countries supported by Gavi: a mathematical modelling study. *Lancet Infect Dis* 2022; **22:** 679–91.

23 Micoli F, Bagnoli F, Rappuoli R, et al. The role of vaccines in combatting antimicrobial resistance. *Nat Rev Microbiol* 2021; **19:** 287–302.

24 European Commission. Combatting antimicrobial resistance on farms thanks to CAP support. April 26, 2023. https://agriculture.ec.europa.eu/news/combatting-antimicrobial-resistance-farms-thanks-cap-support-2023-04-26_en (accessed July 29, 2023).

25 Cline WR. Global warming and agriculture. March, 2008. https://www.imf.org/external/pubs/ft/fandd/2008/03/pdf/cline (accessed Dec 12, 2023).

26 Global AMR R&D Hub. Investment in AMR R&D. https://dzifhelmholtzdashboard.azurewebsites.net/reports/investments/overview (accessed Nov 8, 2023).

27 Do NT, Ta NT, Tran NT, et al. Point-of-care C-reactive protein testing to reduce inappropriate use of antibiotics for non-severe acute respiratory infections in Vietnamese primary health care: a randomised controlled trial. *Lancet Glob Health* 2016; **4:** e633–41.

28 Navadhi. Global pharmaceuticals industry analysis and trends 2023. https://www.navadhi.com/publications/global-pharmaceuticals-industry-analysis-and-trends-2023 (accessed July 20, 2023).

29 Boston Consulting Group, Wellcome Trust. Understanding the antibiotic manufacturing ecosystem. https://cms.wellcome.org/sites/default/files/2022-04/understanding-the-antibiotic-manufacturing-ecosystem-2022.pdf (accessed on Dec 12, 2023).

30 WHO. Prioritization of pathogens to guide discovery, research and development of new antibiotics for drug-resistant bacterial infections, including tuberculosis. Sept 4, 2017. https://www.who.int/publications/i/item/WHO-EMP-IAU-2017.12 (accessed July 10, 2023).

31 WHO. The WHO AWaRe (Access, Watch, Reserve) antibiotic book. Dec 9, 2022. https://www.who.int/publications/i/item/9789240062382 (accessed May 10, 2023).

32 Shafiq N, Pandey AK, Malhotra S, et al. Shortage of essential antimicrobials: a major challenge to global health security. *BMJ Glob Health* 2021; **6:** e006961.

33 WHO. No time to wait: securing a future from drug-resistant infections. April 29, 2019. https://www.who.int/publications/i/item/no-time-to-wait-securing-the-future-from-drug-resistant-infections (accessed Dec 20, 2023).

34 Organisation of African Unity. Abuja declaration on HIV/AIDS, tuberculosis, and other related infectious diseases. https://www.veritaszim.net/sites/veritas_d/files/abuja%20declaration.pdf (accessed Aug 2, 2023).

35 Pinsent Masons. New antibiotics to be added to NICE's 'Netflix-style' subscription service. April 20, 2022. https://www.pinsentmasons.com/out-law/news/new-antibiotics-added-nices-netflix-style-subscription-service#:~:text=The%20%27Netflix%2Dstyle%27%20national,delivery%20of%20product%20when%20needed (accessed Dec 12, 2023).

36 G77. Ministerial declaration. http://www.g77.org/doc/Declaration2017.htm (accessed Aug 3, 2023).

37 WHO. Bureau's text of the WHO convention, agreement or other international instrument on pandemic prevention, preparedness and response (WHO CA+). June 2, 2023. https://apps.who.int/gb/inb/pdf_files/inb5/A_INB5_6-en.pdf (accessed Aug 2, 2023).

38 Global Leaders Group on Antimicrobial Resistance. Why AMR must be a substantive element of the international instrument on pandemic prevention, preparedness and response. April 7, 2022. https://www.amrleaders.org/resources/m/item/why-amr-must-be-a-substantive-element-of-the-international-instrument-on-pandemic-prevention-preparedness-and-response (accessed on Nov 11, 2023).

39 WHO. SDG target 3.d.2: bloodstream infections due to selected antimicrobial-resistant organisms. https://www.who.int/data/gho/data/themes/topics/indicator-groups/indicator-group-details/GHO/sdg-target-3.d.2---bloodstream-infections-due-to-selected-antimicrobial-resistant-organisms (accessed Dec 12, 2023).

40 Collins J, Porras J. Built to last: successful habits of visionary companies. New York, NY: Random House, 2005.

41 Hess J, Boodram LG, Paz S, Stewart Ibarra AM, Wasserheit JN, Lowe R. Strengthening the global response to climate change and infectious disease threats. *BMJ* 2020; **371:** m3081.

42 Reyes R, Ahn R, Thurber K, Burke TF. Urbanization and infectious diseases: general principles, historical perspectives, and contemporary challenges. *Chall Infect Dis* 2012; published online May 19. https://doi.org/10.1007/978-1-4614-4496-1_4.

43 Bhutta ZA, Sommerfeld J, Lassi ZS, Salam RA, Das JK. Global burden, distribution, and interventions for infectious diseases of poverty. *Infect Dis Poverty* 2014; **3:** 21.

44 Gavi, the Vaccine Alliance. The African vaccine manufacturing accelerator. What is it and why is it important? Dec 7, 2023. https://www.gavi.org/vaccineswork/african-vaccine-manufacturing-accelerator-what-and-why-important (accessed Dec 16, 2023).

45 Berman D, Chandy SJ, Cansdell O, Moodley K, Veeraraghavan B, Essack SY. Global access to existing and future antimicrobials and diagnostics: antimicrobial subscription and pooled procurement. *Lancet Glob Health* 2022; **10:** e293–97.

46 Rodrigues CMC, Plotkin SA. Impact of vaccines; health, economic and social perspectives. *Front Microbiol* 2020; **11:** 1526.