THE STATE OF THE WORLD’S ANTIBIOTICS 2015

AUTHORS
HELLEN GELBAND
MOLLY MILLER-PETRIE
SURAJ PANT
SUMANTH GANDRA
JORDAN LEVINSON
DEVRA BARTER
ANDREA WHITE
RAMANAN LAXMINARAYAN
CONTRIBUTORS

NK Ganguly for the GARP-India Working Group
Samuel Kariuki, Linus Ndegwa, and Eveline Wesangula for the GARP-Kenya Working Group
Betuel Sigaúque and Esperança Sevène for the GARP-Mozambique Working Group
Buddha Basnyat, Paras Pokharel, Sameer Mani Dixit, and Santoshi Giri for the GARP-Nepal Working Group
Adriano Duse, Olga Perovic, and Kim Faure for the GARP-South Africa Working Group
Said Aboud, Robinson Mdega, and Khadija Msami for the GARP-Tanzania Working Group
Denis K. Byarugaba, Donna A. Kusemererwa, and James Lakony for the GARP-Uganda Working Group
Nguyen Van Kinh, Heiman Wertheim, and Do Thuy Nga for the GARP-Vietnam Working Group

CDDEP BOARD OF DIRECTORS

Adel Mahmoud, Chairman; Professor, Woodrow Wilson School and Department of Molecular Biology, Princeton University
Sir George Alleyne, Chancellor, University of the West Indies
George Bickerstaff, Managing Director, M.M. Dillon & Co.
Mark Cohen, Professor of Law and Management, Vanderbilt University
Maureen Cropper, Professor, Department of Economics, University of Maryland
Edward Hand, Senior Strategy Advisor, Resources for the Future
Sir Richard Peto, Professor, Medical Statistics and Epidemiology, University of Oxford
Ramanan Laxminarayan, Director, Senior Fellow, CDDEP
<table>
<thead>
<tr>
<th>ACRONYMS</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGAR</td>
<td>Australian Group on Antimicrobial Resistance</td>
</tr>
<tr>
<td>CARA</td>
<td>Canadian Antimicrobial Resistance Alliance</td>
</tr>
<tr>
<td>CDC</td>
<td>Centers for Disease Control and Prevention (United States)</td>
</tr>
<tr>
<td>CDDEP</td>
<td>Center for Disease Dynamics, Economics &amp; Policy</td>
</tr>
<tr>
<td>CRE</td>
<td>Carbapenem-resistant Enterobacteriaceae</td>
</tr>
<tr>
<td>EARS-Net</td>
<td>European Antimicrobial Resistance Surveillance Network</td>
</tr>
<tr>
<td>ESBL</td>
<td>Extended-spectrum beta-lactamase</td>
</tr>
<tr>
<td>ESR</td>
<td>The Institute of Environmental Science and Research (New Zealand)</td>
</tr>
<tr>
<td>GARP</td>
<td>Global Antibiotic Resistance Partnership (CDDEP)</td>
</tr>
<tr>
<td>LMICs</td>
<td>Low- and middle-income countries</td>
</tr>
<tr>
<td>NARST</td>
<td>National Antimicrobial Resistance Surveillance Center, Thailand</td>
</tr>
<tr>
<td>NME</td>
<td>New molecular entity</td>
</tr>
<tr>
<td>MRSA</td>
<td>Methicillin-resistant <em>Staphylococcus aureus</em></td>
</tr>
<tr>
<td>SASCM</td>
<td>South African Society for Clinical Microbiology</td>
</tr>
<tr>
<td>TSN</td>
<td>The Surveillance Network (United States)</td>
</tr>
<tr>
<td>VINARES</td>
<td>Vietnam Resistance Project</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
</tr>
</tbody>
</table>
Since their introduction into medicine in the 1940s, antibiotics have been central to modern healthcare. Their role has expanded from treating serious infections to preventing infections in surgical patients, protecting cancer patients and people with compromised immune systems, and promoting growth and preventing disease in livestock and other food animals.

Now, however, once-treatable infections are becoming difficult to cure, raising costs to healthcare facilities, and patient mortality is rising, with costs to both individuals and society. Decreasing antibiotic effectiveness has risen from being a minor problem to a broad threat, regardless of a country’s income or the sophistication of its healthcare system. Many pathogens are resistant to more than one antibiotic, and new, last-resort antibiotics are expensive and often out of reach for those who need them.

Antibiotic resistance is a direct result of antibiotic use. The greater the volume of antibiotics used, the greater the chances that antibiotic-resistant populations of bacteria will prevail in the contest for survival of the fittest at the bacterial level.

Two trends are contributing to a global scale-up in antibiotic consumption. First, rising incomes are increasing access to antibiotics. That is saving lives but also increasing use—both appropriate and inappropriate—which in turn is driving resistance. Second, the increased demand for animal protein and resulting intensification of food animal production is leading to greater use of antibiotics in agriculture, again driving resistance.

This State of the World’s Antibiotics report records the status of this important global resource and provides critical policy analysis on three issues:

- global patterns and trends in antibiotic resistance and antibiotic use in human beings and animals;
- the existing antibiotic supply and the research and development pipeline; and
- interventions that have been shown to help rationalize antibiotic use and are practicable in all countries.

We present a comprehensive country-level policy response, consisting of six strategies, based on the experience of the Global Antibiotic Resistance Partnership (GARP), which has fostered the development of locally driven antibiotic policy in eight countries. The strategies should be particularly relevant for the many countries that have not yet formally addressed antibiotic resistance.

**Patterns and Trends in Antibiotic Resistance (Chapter 1)**

Evidence from around the world indicates an overall decline in the total stock of antibiotic effectiveness: resistance to all first-line and last-resort antibiotics is rising. The patterns of which bacteria are resistant to specific antibiotics differ regionally and by country, mirroring patterns of infectious disease and antibiotic use.

The U.S. Centers for Disease Control and Prevention (CDC) estimates that antibiotic resistance is responsible for more than 2 million infections and 23,000 deaths each year in the United States, at a direct cost of $20 billion and additional productivity losses of $35 billion (CDC 2013).

In Europe, an estimated 25,000 deaths are attributable to antibiotic-resistant infections, costing €1.5 billion annually in direct and indirect costs (EMA and ECDC 2009). Although reliable estimates of economic losses in the developing world are not available, it is estimated that 58,000 neonatal sepsis deaths are attributable to drug-resistant infections in India alone (Laxminarayan et al. 2013). Studies from Tanzania and Mozambique indicate that resistant infections result in increased mortality in neonates and children under five (Kayange et al. 2010; Roca et al. 2008).

**Resistant bacteria in humans**

Methicillin-resistant *Staphylococcus aureus* (MRSA) has declined in incidence in Europe, the United States and Canada over the past eight years, to 18 percent, 44 percent, and 16 percent, respectively (EARS-Net 2014; CDDEP 2015b; Public Health Agency of Canada 2015). It also has begun to decline in South Africa (to 28 percent), where antibiotic stewardship is taking hold (Kariuki and Dougan 2014; CDDEP 2015b) (Figure ES-1). In sub-Saharan Africa, India, Latin America, and Australia, it is still rising (AGAR 2013; CDDEP 2015b), recorded at 47 percent in India in 2014, and 90 percent in Latin American hospitals in 2013 (PAHO, forthcoming).

**Escherichia coli** (*E. coli*) and related bacteria have become resistant to newer third-generation cephalosporins, indicating that they are difficult-to-treat extended-spectrum beta-lactamase (ESBL) producers. In 2013, in 17 of 22 European countries, 85 to 100 percent of *E. coli* isolates were ESBL positive (EARS-Net 2014). In 2009 and 2010, 28 percent of all Enterobacteriaceae (the *E. coli* family) from urinary tract infections in 11 countries in Asia were ESBL producers, and resistance to third- and fourth-generation cephalosporins ranged from 26 to 50 percent (Lu et al. 2012). In Latin America in 2014 resistance in *Klebsiella pneumoniae* ranged from 19 percent in Peru to 87 percent in Bolivia (PAHO, forthcoming). In sub-Saharan Africa, median prevalence of
resistance to third-generation cephalosporins ranged up to 47 percent (Leopold et al. 2014).

Carbapenem-resistant Enterobacteriaceae (CRE) are resistant even to last-resort carbapenems. In Europe, five countries reported increases in 2013, starting from low levels of less than 10 percent (EARS-Net 2014). In U.S. hospitals, 11 percent of *K. pneumoniae* and 2 percent of *E. coli* were resistant to carbapenems in 2012 (CDC 2013). In Latin America in 2013, resistance of *K. pneumoniae* to carbapenems ranged from full susceptibility in the Dominican Republic to 28 percent resistant in Guatemala (PAHO, forthcoming). In India, 13 percent of *E. coli* were resistant to carbapenems in 2013. For *K. pneumoniae*, 57 percent were resistant in 2014 (CDDEP 2015b).

*Clostridium difficile* infections are related to antibiotic use: the bacteria are not affected by most antibiotics and therefore proliferate in the human intestine after most other bacteria are killed by antibiotics. *C. difficile* causes an estimated 14,000 deaths per year in the United States (CDC 2013).

Evidence from around the world indicates an overall decline in the total stock of antibiotic effectiveness: resistance to all first-line and last-resort antibiotics is rising.

**ResistanceMap**, an interactive, data-rich visualization tool, brings together the most current antibiotic resistance surveillance statistics from the United States, Europe, and many low- and middle-income countries (LMICs) (www.resistancemap.org).

**Resistant bacteria in food animals and the environment**

Poultry, cattle, and swine raised with antibiotics harbor significant populations of antibiotic-resistant bacteria, which are transmitted to humans through direct contact with the animals and through their meat, eggs, and milk (Marshall and Levy 2011). Some proportion of the antibiotics used in agriculture and aquaculture ends up in the broader

![](image)

**FIGURE ES-1:** Percentage of *Staphylococcus aureus* isolates that are methicillin resistant (MRSA) in selected countries, 1999–2014

*Source: CDDEP 2015*

Depending on the country, resistance to one or more of the following drugs may have been used to test for MRSA: Oxacillin, cefoxitin, flucloxacillin, cloxacillin, dicloxacillin, and methicillin. Intermediate-resistant isolates are included as resistant.

---

1 CDDEP 2015 sources include: AGAR (Australia), CARA (Canada), EARS-Net (Europe), ESR (New Zealand), NARST (Thailand), SASCM (South Africa), SRL Diagnostics (India), TSN (USA), and VINARES (Vietnam).
Demand for antibiotics continues to rise, particularly to treat children with potentially fatal sepsis and pneumonia.

Agricultural consumption (Chapter 3)

Increasing prosperity and population growth drive an increasing demand for animal protein. To satisfy this need, many farmers are transitioning to intensive agriculture and often use antibiotics to optimize production. Antibiotics are used not only to treat individual animals with bacterial infections and prevent infections in herds or flocks, but also to promote growth—a controversial and high-use application. Worldwide, in 2010, at least 63,200 tons of antibiotics were consumed in livestock—likely to be more than all human consumption (Van Boeckel et al. 2015). By 2030, this figure is projected to rise by two-thirds, to 105,600 tons, to meet the demands of a projected 8.5 billion human population (United Nations 2015). Two-thirds of the projected increase is accounted for by increases in the number of animals raised for food production and the remaining one-third by the shift from small-scale to industrial-scale production (Van Boeckel et al. 2015) (Figure ES-3).

Antibiotic growth promotion is the focus of most legal and regulatory efforts to reduce animal antibiotic use because it provides no health benefit to the animals but accelerates antibiotic resistance. Recent analyses suggest that growth promoters have a smaller effect on animal growth than assumed, particularly in production systems that are otherwise optimized (Laxminarayan et al. 2015). The countries with the greatest expected increases in food demand and animal antibiotic use currently have the least efficient farming systems. Emphasis should be on improving productivity without antibiotic growth promoters, as is increasingly the case in high-income countries.

NEW ANTIBIOTICS AND OTHER INTERVENTIONS (CHAPTER 4)

Antibiotics are among the most familiar of medicines and are used liberally by people all over the world. The societal consequence of loss of effectiveness is of little concern to the individual user or prescriber, since resistance affects the next patient. These characteristics combine to foster gross antibiotic overuse and accelerate antibiotic resistance. Importantly, for at least some antibiotics, resistance levels decrease with declining use, conserving and even recovering some antibiotic effectiveness. In some high-income countries, where antibiotic stewardship has taken hold and public health is good, antibiotic resistance levels have stabilized or declined: when antibiotic use declines, the prevalence of antibiotic-resistant bacteria tends to fall. Vaccines against a range of diseases and improved water and sanitation have moderated antibiotic demand in higher-income countries, and per capita use has begun to level off in many of these countries.
The global capacity to treat common infections depends on maintaining an adequate supply of antibiotic effectiveness. Over the past 10 years, the discussion has been dominated by an “empty pipeline” argument, with proposed solutions involving financial incentives for drug developers. Independent analysis suggests that the pipeline has been consistently productive for the past three decades (Outterson et al. 2013) (Figure ES-4). New incentives to spur drug development, by themselves, would do nothing to realign existing incentives for the overuse of antibiotics, nor would they incentivize the development of antibiotics targeted to the most urgent needs. Moreover, new drugs are not widely available in LMICs, where they are unaffordable for patients and healthcare systems (Kariuki et al. 2015).

Feasible, practicable interventions, however, could contribute to maintaining antibiotic effectiveness. Changing the norms regarding how antibiotics are perceived and used requires behavioral change. Alternative and complementary approaches to infection control and treatment, such as improved diagnostic tools, new vaccines, and bacteriophages, will also help maintain the effectiveness of current and emerging antibiotics. Global antibiotic stewardship in the broadest sense should make it possible not only to conserve the current effectiveness of existing antibiotics, but even to reclaim some of effectiveness that has been lost.

**EXTENDING ANTIBIOTIC EFFECTIVENESS (CHAPTER 5)**

Antibiotic resistance is a global problem, but antibiotic use has its greatest effects locally. It is in every country’s self-interest—for the health of its own population—to prolong antibiotic effectiveness. This means reducing use where possible and making sure that antibiotics are accessible when needed. Rather than focusing on new drug development, we should leverage existing capabilities and technologies to maximize antibiotic effectiveness. Some feasible interventions include:

- **Changing how antibiotics are perceived and used**
  - Behavioral change is crucial. We need to change how antibiotics are perceived and used, moving beyond the “empty pipeline” argument.
  - Alternative and complementary approaches, such as improved diagnostic tools, new vaccines, and bacteriophages, can also help maintain antibiotic effectiveness.

- **Increasing antibiotic stewardship**
  - Global antibiotic stewardship is necessary to conserve and even reclaim antibiotic effectiveness.

- **Addressing antibiotic access in LMICs**
  - In LMICs, antibiotics are often unaffordable, which limits their effectiveness. Feasible interventions could contribute to maintaining antibiotic effectiveness.

**Increasing prosperity and population growth drive an increasing demand for animal protein. To satisfy this need, many farmers are transitioning to intensive agriculture and often use antibiotics to optimize production.**

**FIGURE ES-3: Antibiotic consumption in livestock, top ten countries 2010–2030 (projected for 2030)**

*Source: Van Boeckel et al. 2015*

**FIGURE ES-4: Systemic new molecular entity (NME) antibiotics still marketed in the US by period of introduction, 1980–2015*\**

*Source: Outterson et al. 2013*

*As of August 21, 2015; additional market discontinuations since 2009 are not calculated. Bedaquiline, approved for multidrug-resistant tuberculosis in 2012, is included.
than regulating individual actions, however, policymakers should address the mindset about antibiotics. Instead of being the default treatment for a host of mild ailments—particularly coughs, colds, and uncomplicated diarrhea—antibiotics must be considered life-saving medicines to be used when needed.

The transformation will be not easy, but social norms can and do change—witness the change in attitudes toward cigarette smoking. A set of coordinated antibiotic resistance strategies can start the norm-changing process.

GARP has worked with eight countries to establish the capacity and methods for developing antibiotic resistance policies. Six strategies will contribute to slowing resistance and maintaining the effectiveness of current drugs (Figure ES-5):

1. **Reduce** the need for antibiotics through improved water, sanitation, and immunization.
   Improving coverage for existing vaccines and adding new ones, improving access to clean water and sewerage systems, and ensuring a safe and healthful food supply all reduce the need for antibiotics, thereby reducing antibiotic resistance rates.

2. **Improve** hospital infection control and antibiotic stewardship.
   Better hygiene, particularly hand washing with soap or using alcohol disinfectant between patients, and antibiotic stewardship programs reduce infection rates. Surveillance of resistance and hospital-acquired infections gives administrators information for management and policy decisions.

3. **Change** incentives that encourage antibiotic overuse and misuse to incentives that encourage antibiotic stewardship.
   Eliminating economic incentives that encourage the overuse of antibiotics all along the supply chain—in hospitals, in communities, and in agriculture—can conserve antibiotic effectiveness.

4. **Reduce** and eventually phase out subtherapeutic antibiotic use in agriculture.
   Eliminating antibiotic use for growth promotion and minimizing use for disease prophylaxis need not jeopardize animal or human health.

5. **Educate** health professionals, policymakers, and the public on sustainable antibiotic use.
   Education and guidelines for healthcare professionals, engagement with policymakers, and national awareness campaigns for the public will begin changing the norms in antibiotic use and promote conservation.

6. **Ensure** political commitment to meet the threat of antibiotic resistance.
   Presenting the case to policymakers and gaining their political and financial support are critical to success.

**GLOBAL AND NATIONAL COMMITMENTS**

In May 2015, the World Health Assembly endorsed the Global Action Plan on Antimicrobial Resistance, which calls on all countries to adopt national strategies within two years (WHO 2015). With support from WHO and the international community, this resolution could catalyze change—or, like similar resolutions over the past decade, it may be ignored.

In the United States, the National Action Plan for Combating Antibiotic-Resistant Bacteria (White House 2015) stresses the need to slow the spread of antibiotic resistance through stewardship at all levels. The European Union has taken a similar stance (European Commission 2011). Southeast Asian WHO countries committed to addressing the issue in the Jaipur Declaration (WHO 2011). The process is also
under way in South Africa, started by the work of GARP and continued through a broad coalition of government and private sector leaders.

The evidence in this report, documenting the seriousness of the problem and offering a successful approach to country-level action, supports both the urgency and the feasibility of making progress in conserving antibiotic effectiveness. The Center for Disease Dynamics, Economics & Policy (CDDEP) will continue collecting reliable data from around the world on antibiotic use and resistance, making the information available to all through ResistanceMap (www.resistancemap.org), and monitoring progress on global antibiotic stewardship.

REFERENCES


ABOUT THE CENTER FOR DISEASE DYNAMICS, ECONOMICS & POLICY

The Center for Disease Dynamics, Economics & Policy (CDDEP) was founded with the objective of using research to support better decision-making in health policy. CDDEP researchers employ a range of expertise—including economics, epidemiology, disease modeling, risk analysis, and statistics—to conduct actionable, policy-oriented research on malaria, antibiotic resistance, disease control priorities, environmental health, alcohol and tobacco, and other global health priorities.

CDDEP projects are global in scope, spanning Africa, Asia, and North America and include scientific studies and policy engagement. The CDDEP team is experienced in addressing country-specific and regional issues, as well as the local and global aspects of global challenges, such as antibiotic resistance and pandemic influenza. CDDEP research is notable for innovative approaches to design and analysis, which are shared widely through publications, presentations and web-based programs.

CDDEP has offices in Washington, D.C. and New Delhi and relies on a distinguished team of scientists, public health experts, and economists around the world.