

Wastewater monitoring in Saudi Arabia points to antimicrobial resistance risks from mass gatherings¹



Source: ©Shutterstock/Khawaja Umer Farooq 2024.
Note: Al-Mashaaer train station, Makkah, Saudi Arabia.

Mass gatherings can contribute to antimicrobial resistance and threaten public health

Mass gatherings in Saudi Arabia, such as the Hajj and Umrah, attract millions of people from around the world, risking the spread of antibiotic resistance genes (ARGs) and antibiotic-resistant bacteria (ARBs), which can contribute to antimicrobial resistance (AMR) and undermine infectious disease treatment.³

Recurring mass gatherings present predictable, repeating windows when these public health threats could enter the country from elsewhere and spread to local communities. This danger is amplified in western Saudi Arabia, where Hajj and Umrah pilgrimages occur, because only half of the sewage is treated in modern facilities.⁴ The remaining waste, held in septic tanks, can leak and transmit incoming ARBs and ARGs into the local environment.

This KAUST-led study concludes that the Kingdom can monitor local wastewater using both traditional laboratory testing and cutting-edge genetic analysis to identify risks, inform public health strategies, and improve preparedness.

The bottom line

- This KAUST-led² study suggests targeted monitoring of local wastewater to reduce the risks of spreading dangerous genes, bacteria, and AMR during mass gatherings, such as the Hajj and Umrah.
- Wastewater surveillance, using traditional laboratory testing and advanced genetic analysis, can provide the most complete picture of the risks.
- An early-warning system that surveils wastewater for specific threats, triggers automatic testing, and alerts public health officials, wastewater operators, and Hajj officials to the dangers can reduce the risks.
- Additional public health measures, including improvements in antibiotic stewardship, hygiene, and sewage handling could reduce risks, too.



Targeted monitoring with advanced technology can detect risks and inform responses

The study suggests taking a targeted approach to wastewater monitoring during mass gatherings that would combine traditional wastewater testing and bioinformatic analysis, focusing on specific ARGs of concern. Further, it indicates a need for attention to the range of threats, not just the levels of ARBs or ARGs.

Surveillance homes in on threats

Traditional cultivation-based wastewater surveillance can track ARBs at the community level, providing actionable insights for public health protection and environmental safety. This surveillance can identify the introduction and spread of ARBs into the local environment, which may not be detected through clinical surveillance alone. It can also detect the presence of opportunistic pathogens that carry ARGs and can lead to disease outbreaks.

Bioinformatic analysis can complement traditional surveillance. It allows researchers to use advanced technology to analyze the genetic material in sewage samples. This method helps identify different kinds of ARGs, including hidden ones that traditional laboratory tests would miss. It can also uncover new or emerging resistance genes that appear during mass gatherings, helping to warn of emerging public health threats.

Findings can reduce risks

Surveillance findings can inform preparedness and response strategies to address the spread of AMR during mass gatherings. Officials can coordinate efforts across health, environmental, and event management sectors using a “One Health” approach, which could effectively address population health concerns. Monitoring could, for example, play a part in an early-warning system that⁵

- Focuses on a specific list of high-risk AMR markers.
- Triggers automatic checks when a threat is detected during the mass gathering.
- Connects monitoring to action by linking surveillance data to a collaborative response team, including public health officials, wastewater operators, and Hajj officials, to ensure findings lead to an effective response.

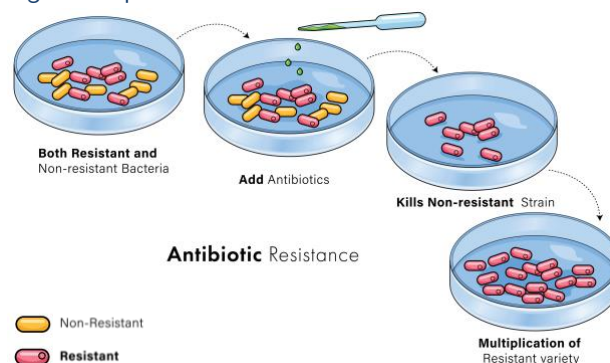
Additional measures can support public health strategies

In addition to monitoring wastewater, officials can consider measures to mitigate the introduction and spread of ARBs and ARGs during mass gatherings, improve public health preparedness, and reduce environmental risk.

Promote antibiotic stewardship and improvements in hygiene

Public health authorities can promote responsible antibiotic use among international pilgrims and local communities, as excessive or inappropriate use facilitates resistance. Figure 1 shows how antibiotic resistance can occur, using a petri dish as an illustration. They can also work to maintain and improve hygiene practices, which can influence the spread of infectious agents and AMR.

Figure 1. A path to antibiotic resistance



Source: ©Shutterstock/Art of Science 2021, adapted.

Upgrade wastewater treatment Infrastructure

Upgrading wastewater treatment infrastructure in western Saudi Arabia would reduce the risk posed by septic tanks and sewage leaking into the local environment.

Travel restrictions presented a research opportunity that revealed new threats

Travel restrictions put in place during the COVID-19 pandemic severely curtailed Hajj and Umrah attendance in 2020 and 2021. The study used this exceptionally low attendance as a baseline and tracked the effect of increased post-restriction pilgrim attendance on the presence of ARBs and ARGs. As shown in Figure 2, pilgrimage traffic increased sharply in 2022 compared with 2020. Pilgrims attending the Hajj came mainly from Asia, Africa, and Europe.

Taken together, the results indicate the importance of considering the range of AMR threats, not just the levels of ARBs or ARGs. Although the quantity of dangerous bacteria and genes did not increase in 2022, at least one new ARG, “bla_{PER},” was detected in local sewage. This gene was more than a harmless DNA fragment; it and others were spreading among pathogenic bacteria in samples from Makkah and Madinah, creating a path for more serious infections in the future and potentially contributing to AMR.

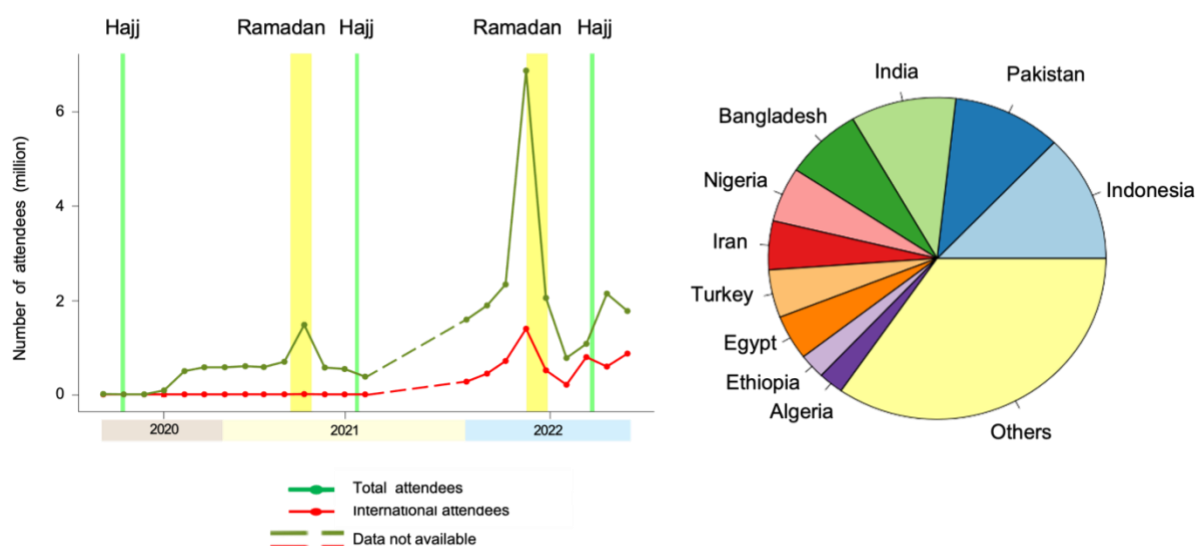


Summing up

When large groups of travelers gather for events such as the Hajj and Umrah in Saudi Arabia, they can bring new public health threats, including ARGs and ARBs that can spread to the local wastewater and contribute to AMR. Using wastewater surveillance with advanced genetic analysis, the KAUST-led researchers spotted emerging threats, finding that the range mattered at least as much as the level. The results highlight the need for targeted monitoring for specific threats, using laboratory testing and bioinformatic analysis to help protect local communities from resistance.

Building on the study, one of the KAUST researchers also offered suggestions for linking the findings to policy and action through a three-part early-warning system. The proposed system would connect surveillance data to a collaborative response team, including public health officials, wastewater operators, and Hajj officials. Additional public health measures, including improvements in antibiotic stewardship, hygiene, and sewage handling, could also contribute to risk reduction. This multifaceted approach — targeted surveillance, early warning, and public health measures — offers broad promise for countries that host mass gatherings with a substantial international presence.

Figure 2. Numbers and country origins of pilgrims during the Hajj and Ramadan



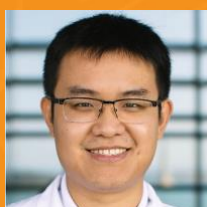
Source: Wang et al. 2025,⁶ based on data from the General Authority for Statistics, Saudi Arabia, at <https://www.stats.gov.sa/>.

Note: On the left, the trendlines depict the total number of attendees and the number of international attendees at mass gatherings in Saudi Arabia from 2020 to 2022, focusing on the Hajj and Umrah during Ramadan; on the right, the chart shows the geographic origins of Hajj pilgrims in 2022, when travel resumed after the COVID-19 pandemic restrictions were lifted.



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1. This Policy Brief summarizes findings from Wang, Changzhi, Yevhen Myshkevych, Tianny Wang, Mohammad Khalil Monjed, and Pei-Ying Hong. 2025. "Wastewater Surveillance Unveils the Impact of Mass Gatherings on Antimicrobial Resistance After the COVID-19 Pandemic in Saudi Arabia." *Nature Water* 3: 693-703. <https://doi.org/10.1038/s44221-025-00446-3>. All rights and any third-party permissions remain with the respective rightsholders. It also includes additional insights on potential applications, including an early-warning system, provided by Dr. Wang.
2. King Abdullah University of Science and Technology (KAUST).
3. Antibiotic resistance is one form of antimicrobial resistance. The World Health Organization (WHO) explains the difference thusly: "Antibiotic resistance occurs when bacteria change in response to the use of these medicines. Bacteria, not humans, become antibiotic resistant. These bacteria may then infect humans and are harder to treat than non-resistant bacteria. Antimicrobial resistance is a broader term, encompassing resistance to drugs to treat infections caused by other microbes as well, such as parasites (e.g. malaria), viruses (e.g. HIV) and fungi (e.g. Candida)." See <https://www.emro.who.int/health-topics/drug-resistance/what-is-the-difference-between-antibiotic-and-antimicrobial-resistance.html>.
4. Pilgrimages occur in Makkah and Madinah, both of which are in western Saudi Arabia.
5. Dr. Wang drew on findings from the underlying study to outline the three-part system.
6. Reused under Creative Commons license (CC), ©Wang et. al. 2025; no changes were made except formatting.