Burden of infectious diseases and bacterial antimicrobial resistance in India: a systematic analysis for the global burden of disease study 2019 and 2021(60-95+ age group):

Summary:

Background: Infectious diseases and antimicrobial resistance (AMR) has become pressing concerns in India. We aimed to comprehensively investigate the burden of them. Infectious diseases remain a major public health concern in India, contributing significantly to morbidity and mortality. The rising threat of bacterial antimicrobial resistance (AMR) exacerbates this burden, undermining treatment efficacy and increasing healthcare costs. This study systematically analyzes the burden of infectious diseases and the impact of bacterial AMR in India, leveraging data from the Global Burden of Disease (GBD) Studies 2019 and 2021.

Findings: There were an estimated **2.70 million (95% UI: 2.15–3.24)** infection-related deaths, accounting for 27.2%of the total deaths in India 2019 and 2.6 million(95% uncertainity intervals, UI 2.0-3.1) infection-related deaths, accounting for 17.4% of the total deaths in India 2021. Males(1359735) and females(1335854) were effected in 2019 and males(1305998) and females(1245855) were effected in2021. Bloodstream infections (BSIs) were most lethal infectious syndrome, associating with 558754 deaths(499993, 617514), followed by lower respiratory infections (724219), and peritoneal and intra-abdominal infections (78747) in 2019. These five leading pathogens were tuberculosis, pathogen of diarrhea, S.pneumonia , E.coli ,and K pneumoniae which were associated with 47.4%% (1223407/2583188) of all infection-related deaths. The pathogens of different infectious syndromes exhibited significant heterogeneity. In 2019, more than 1050 thousand deaths were associated with AMR, including 283 thousand deaths attributable to AMR. The top 3 AMR attributable to death were carbapenems-resistance A baumannii (25,316), carbapenems-resistance Streptococcus pneumoniae(21,766) and third-generation carbapenems-resistance klebsiella pneumoniae (19804). For individuals aged **60 to 95** and older, the most affected infectious syndromes include bloodstream infections, lower respiratory infections, tuberculosis, and diarrhoea. These syndromes account for a significant proportion of infectious disease mortality in this age group.

Interpretation: Infectious diseases and bacterial antimicrobial resistance were serious threat to public health in India, related to 2.7 million and2.6 million total deaths in 2019 and 2021 respectively.

Keywords: Burden of infectious diseases; Antimicrobial resistance; Death; DALYs; India

Introduction:

Among the top ten global health threats released by World Health Organization (WHO) in 2019, six were related to infectious diseases (global influenza pandemic; antimicrobial resistance; Ebola and other high-threat pathogens; vaccine hesitancy; dengue; HIV).[1] It was estimated that in 2019, the number of deaths due to infectious diseases was 13.7 million (95% uncertainty intervals, UI 10.9–17.1), while deaths associated with bacteria ranked as the second leading cause of death globally.[2] Whether on a global scale or within India, the issue of bacterial antimicrobial resistance (AMR) has become a pressing concern. It was estimated that AMR cause 1.27 million (95% UI 0.911–1.71) deaths directly, and contribute to 4.95 million (95% UI 3.62–6.57) deaths indirectly worldwide.[3] Globally, lower respiratory infections were responsible for over 1.5 million deaths associated with resistance, making it the most burdensome infectious syndrome. In 2019, India experienced a significant burden from infectious diseases and antimicrobial resistance: An estimated 2.7 million deaths were attributed to infectious diseases in India. Approximately 1.04 million deaths in India were directly attributable to antibiotic-resistant bacterial infections. 2.99 million sepsis-related deaths in India, about 33.4% were linked to bacterial AMR. An estimated 325,000 sepsis deaths in children under five were associated with bacterial infections .

Overview and data sources

In this study, we used a subset of input data describing India from the Global Antimicrobial Resistance Burden (GARB) study to estimate the burden of infectious diseases and bacterial antimicrobial resistance.2,3 The global overall input data from 471.3 million sample size and 9324 number of study-location-years. The data input sources (could be found at: https://ghdx.healthdata.org/ record/ihme-data/global-bacterial-antimicrobial-resistanceburden-estimates-2019) in the GARB study included nine categories: administrative data, demographic surveillance, epi surveillance, estimate, modeled data, report, scientific literature, survey, and vital registration. The data for this study were obtained from a publicly available database and did not require ethical review or informed consent. In this study ,the input data sources for India: https://vizhub.healthdata.org/microbe/?settings=eyIxIjoic3luZHJvbWVzIiwiMiI6ImJhciIsIjMiOiJzZXBzaXMiLCI0IjoyMiwiNSI6MSwiNiI6MywiNyI6MSwiOCI6MTYzLCI5IjoxLCIxMiI6MSwiMTMiOjEsIjE0IjoxLCIxNSI6MiwiMTYiOjIsIjE3IjozLCIxOCI6MjAxOSwiMTkiOmZhbHNlLCIyMCI6ZmFsc2UsIjIyIjoxLCIyNCI6ImVuIiwiMjUiOiJzeW5kcm9tZSIsIjI2IjpbMSwyLDMsNCw1LDYsNyw4LDksMTAsMjJdLCIyNyI6WzQsMzEsNjQsMTAzLDEzNywxNTgsMTY2XSwiMjgiOlsyLDMsNCw1LDYsNyw4LDksMTAsMTEsMTIsMTNdLCIyOSI6WzEsMl0sIjMwIjpbMSw3LDExLDE3LDIzLDIyXSwiMzEiOlsiMS0xIiwiMS0yIl0sIjMyIjoiMS0xIiwiMzMiOlsxLDJdfQ==

Analysis steps :

Our analysis consisted of 5 main steps. In step 1, we estimated the disease burdens (death number/rate, DALYs number/rate) of the total and 12 infectious syndromes in India in 2019 by age and sex. In step 2, we described the disease burden (death number/ rate, DALYs number/rate) caused by 43 pathogens and estimated the proportion of pathogens in differentinfection syndromes. These 43 microorganisms were in 6 major categories: 34 bacteria, 4 viruses, 2 protozoa, fungi, polymicrobial, and other pathogens . In step 3, we calculated the disease burden of total and 12 infection syndromes caused by bacterial AMR in two scenarios (AMR associated deaths, AMR attributable deaths), respectively. Associated deaths were the inclusive estimate of AMR burden, which measures people with a drug-resistant infection that contributed to their death. The infection was implicated in their death, but resistance may or may not have been a factor. Attributable deaths were the conservative estimate of AMR burden, which measures people who would not have died of infection if it was treatable (i.e., if there was no AMR).12 In step 4, we estimated the AMR burden (death number/rate, DALYs number/rate) of 22 bacteria in aforementioned two scenarios. In step 5, we calculated the burden of AMR by 22 bacteria and 19 antibiotics combinations Health Estimates Reporting (GATHER) statement. Role of the funding source .

Estimation:

1. **Data Extraction and Cleaning**
   Relevant epidemiological data for India were extracted from the GBD database, focusing on major infectious diseases such as lower respiratory infections, diarrheal diseases, tuberculosis, and bloodstream infections
2. **Stratification by Demographics**
   The data were stratified by age, sex, and geographical region (state/union territory) to assess disparities in disease burden and AMR impact across population subgroups. This allowed us to identify vulnerable populations such as children under five, the elderly, and residents of urban areas.
3. **Estimation of Disease Burden**
   The burden was estimated using key GBD metrics:
   - **Incidence and Prevalence** of each infectious disease.
   - **Mortality rates** (deaths per 100,000 population).
   - **Disability-Adjusted Life Years (DALYs)**, which include both Years of Life Lost (YLLs) and Years Lived with Disability (YLDs).
   - **Attributable burden due to AMR**, calculated by comparing health outcomes in resistant versus susceptible infections.
4. **Statistical Analysis and Visualization**
   We performed statistical analysis using R software, employing packages such as dplyr and ggplot2 for data wrangling and visualization. To enhance interpretability:
   - **Heatmaps** were created to display the geographical distribution of disease and AMR burden across Indian states.
   - **Bar charts** and **line graphs** illustrated time trends and demographic variations in disease and resistance patterns.
   - **Cluster plots** were used to show relationships among pathogens and resistance levels.

Visual representation of Age-Wise deaths for 2019 and 2021:

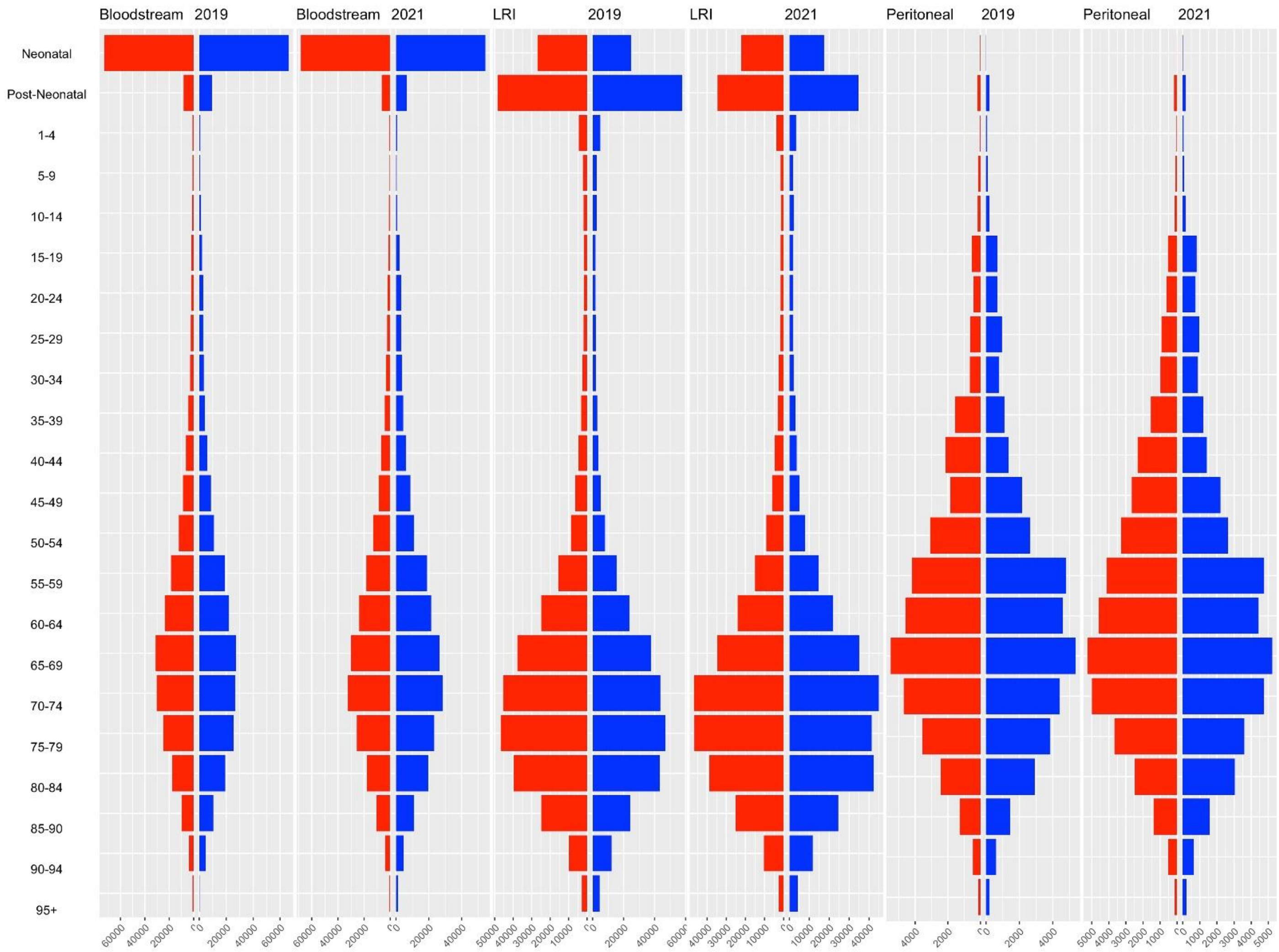


Fig1: Age-wise Population pyramid for the year 2019 and 2021 (Bloodstream, LRI, Peritoneal)

Interpretation:(60 to 95+)

For the 60–95+ age group, mortality due to infectious syndromes remains high across Bloodstream infections, Lower Respiratory Infections (LRI), and Peritoneal infections in both 2019 and 2021. LRI caused the highest deaths, peaking in the 70–84 age range for both males and females, maintaining a major impact with only slight variation over the years. Bloodstream infections show consistently high mortality that increases steadily with age, especially after 85, with a slight rise in female deaths in 2021 (+~3%). Peritoneal infections had the lowest mortality overall but showed a notable increase (+~5%) in the oldest age group (85–94) in 2021, mainly among females. Gender differences were minor but visible, with males and females affected almost equally across infections. These trends highlight age as a critical risk factor and emphasize the need for targeted infection control and prevention strategies, especially for LRI and bloodstream infections, in elderly populations.

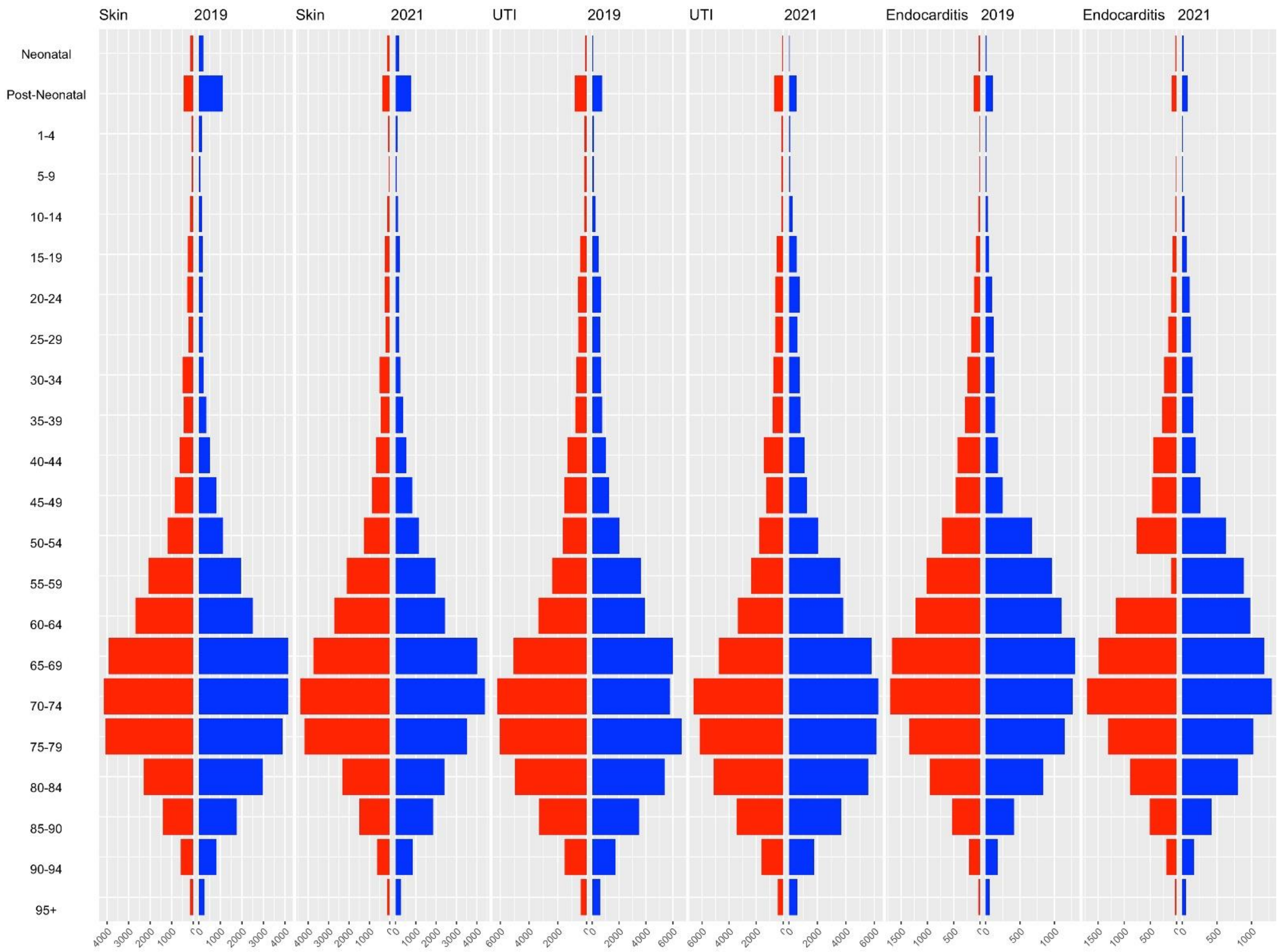


Fig2: Age-wise Population pyramid for the year 2019 and 2021(Skin, UTI, Endocarditis)

<u>Interpretation:(60 to 95+)</u>:

For the 60–95+ age group, mortality due to Skin infections, Urinary Tract Infections (UTI), and Endocarditis shows clear age-related increases between 2019 and 2021. UTIs caused the highest death toll, particularly impacting females aged 65–94, with mortality rising by approximately 7% in 2021, likely linked to pandemic-related factors. Endocarditis mortality was moderate, peaking in the 70–84 age group, with a slight male predominance and stable death rates over the two years. Skin infections showed the lowest mortality, mostly balanced between genders and stable across the years, with deaths peaking at ages 65–79 and declining after 85+. Overall, UTIs represent the greatest risk for older adults, especially women, emphasizing the need for focused healthcare strategies to manage this vulnerability.

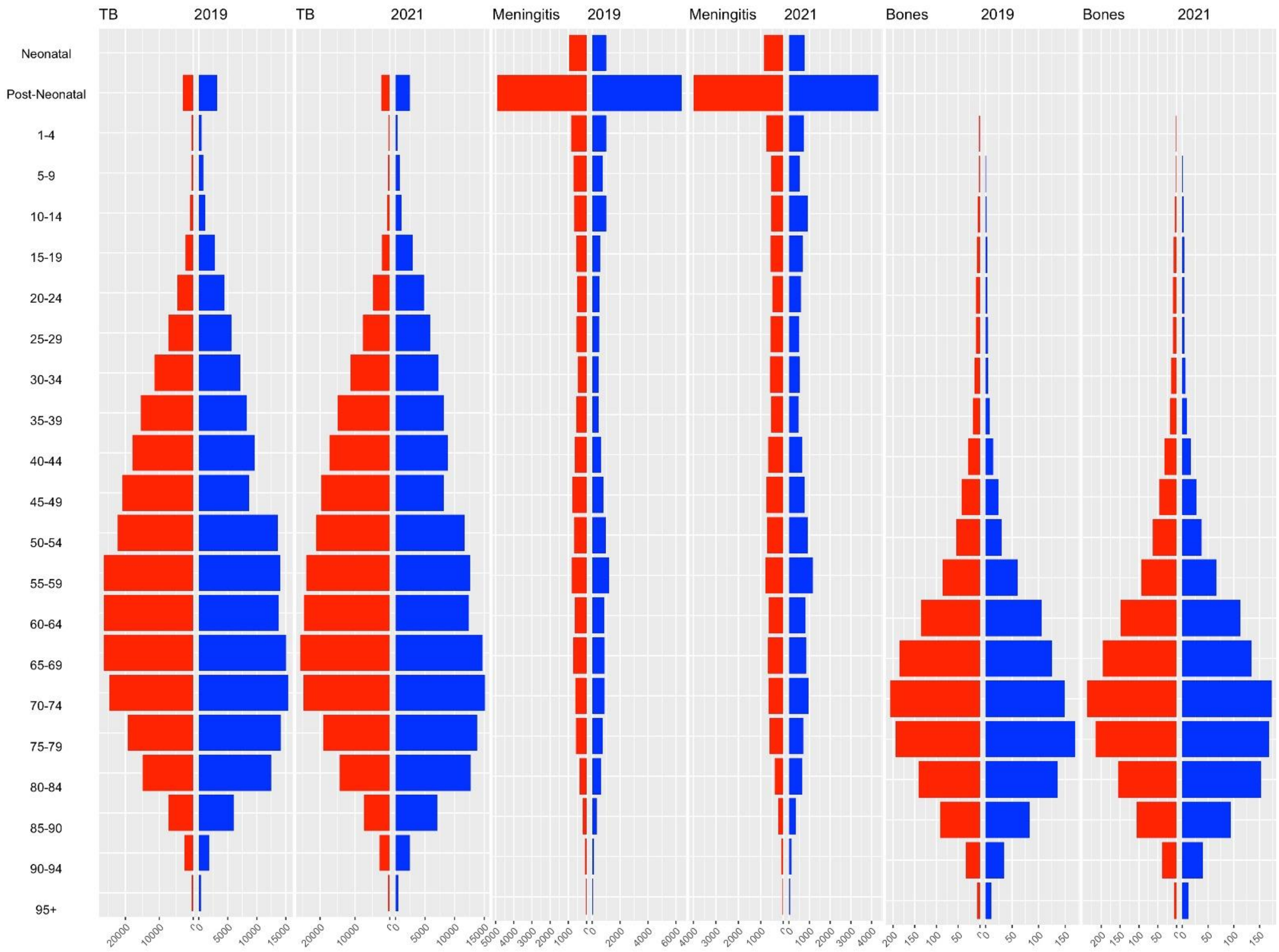


Fig3: Age-wise Population pyramid for the year 2019 and 2021(TB (Tuberculosis), Meningitis, and Bone infections)

<u>Interpretation:(60-95+):</u>

Analysis of mortality by age and gender (60–95+) for Tuberculosis (TB), Meningitis, and Bone infections from 2019 to 2021 reveals distinct patterns. TB remains the most significant cause of death, with high mortality especially in males aged 60–80, showing little change over the two years. Deaths begin to decline after age 85 but persist among those aged 90 and above. Meningitis mortality is low across all older age groups, with slightly higher deaths in males aged 60–74 and almost negligible impact in those over 95, indicating it is not a major cause of death in this population. Bone infections show relatively low mortality but steadily increase from age 60, peaking between 70 and 84, with slightly more deaths in males; mortality drops sharply after age 85. Overall, TB poses the greatest threat to older adults, particularly men between 60 and 80, while meningitis has minimal impact, and bone infections represent a moderate risk. These findings highlight the need to prioritize TB screening and treatment efforts in elderly male populations.

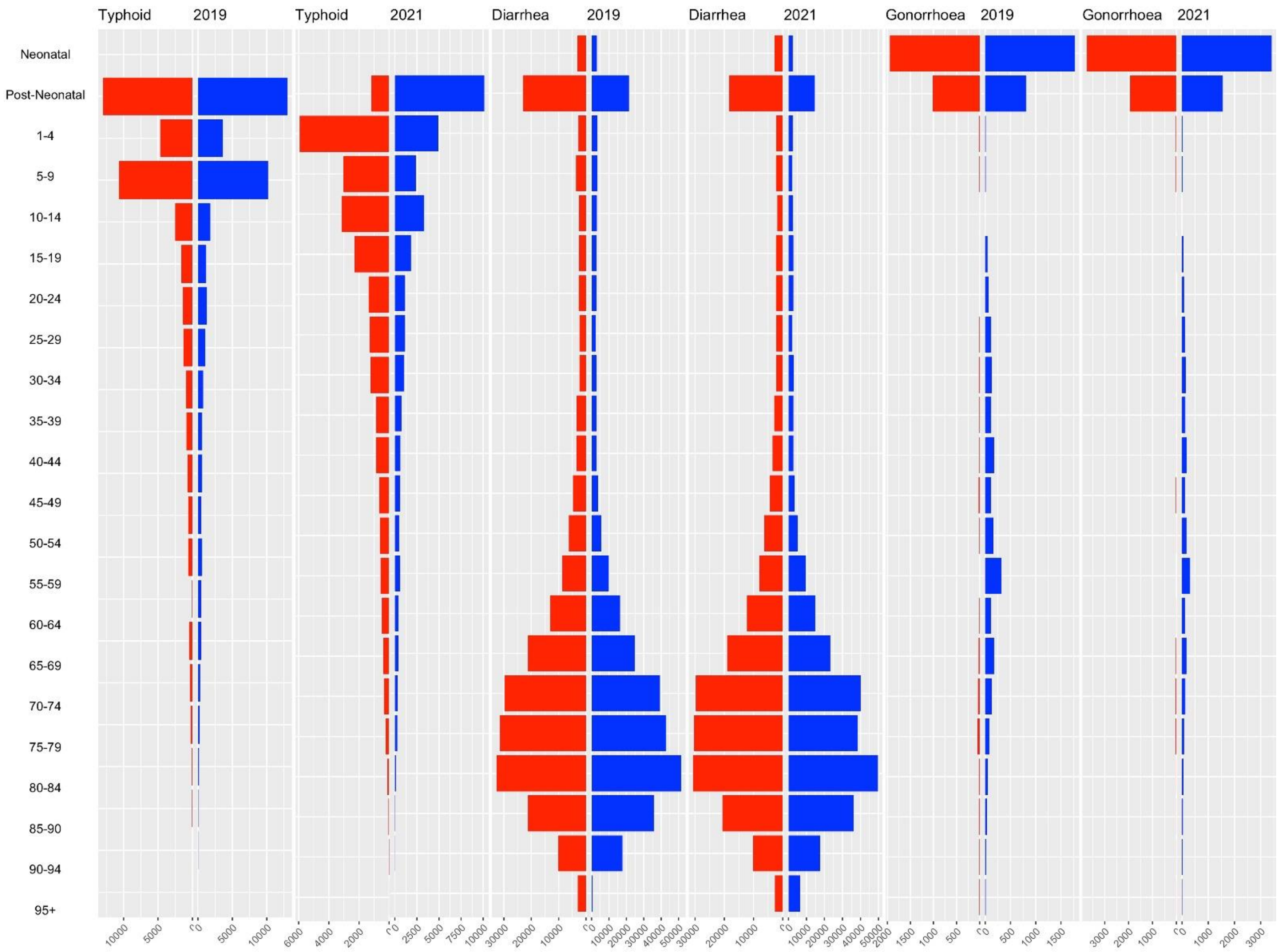


Fig4: Age-wise Population pyramid for the year 2019 and 2021(Typhoid, Diarrhoea, and Gonorrhoea)

Interpretation:(60-95+):

Analysis of mortality for Typhoid, Diarrhoea, and Gonorrhoea in the 60–95+ age group during 2019 and 2021 shows distinct patterns. Typhoid and Gonorrhoea have negligible or no mortality among older adults, with deaths virtually absent across both genders, indicating these infections primarily affect younger populations. In contrast, Diarrhoea causes significant mortality in the elderly, especially males aged 70–84, with deaths slightly increasing or stable from 2019 to 2021. Mortality decreases after age 85 but remains notable, particularly in men. This highlights Diarrhoea as the main concern among these infections in older adults, suggesting that public health interventions should prioritize diarrhoea prevention and treatment for men over 70.

	Deaths 2019	Deaths 2021	Death Rate 2019	Death Rate 2021
	Number (95% UI)	Number (95% UI)	Rate, per 100,000 (95% UI)	Rate, per 100,000 (95% UI)
All infectious syndromes	2695589(2153009,3239047)	2551853(2003450,3101390)	194.1(155.0,233.3)	180.4(141.6,219.3)
male	1359735(1013614,1706304)	1305998(948156,1664405)	191.1(142.4,239.7)	180.3(130.9,229.8)
female	1335854(993616,1678613)	1245855(894111,1598236)	197.3(146.8,248.0)	180.5(129.5,231.5)
Infectious syndrome				
Bloodstream infections	558754 (499993, 617514)	542971 (492910, 593033)	40.2(36.0, 44.5)	38.4 (34.8, 41.9)
Lower respiratory infections and all related infections in the thorax	724219 (659971, 788466)	658708 (583164, 734260)	52.2 (47.5, 56.8)	46.6 (41.2, 51.9)
Peritoneal and intra-abdominal infections	78747 (65469, 92026)	79950 (65415, 94485)	5.7(4.7, 6.6)	5.7 (4.6, 6.7)
Bacterial infections of the skin and subcutaneous systems	53962(47531, 60394)	53913 (46170, 61655)	3.9 (3.4, 4.3)	3.8 (3.3, 4.4)
Urinary tract infections and pyelonephritis	88044(75352, 100737)	88911 (75677, 102144)	6.3(5.4, 7.3)	6.3 (5.4, 7.2)
Endocarditis and other cardiac infections	20428(17055, 23801)	19612 (16297, 22927)	1.5(1.2, 1.7)	1.4(1.2, 1.6)
Tuberculosis	413354(351869, 474838)	399571(325255, 473888)	29.8(25.3, 34.2)	28.3 (23.0, 33.5)
Meningitis and other bacterial central nervous system infections	36100 (30348, 41853)	32121 (27434, 36808)	2.6(2.2, 3.0)	2.3 (1.9, 2.6)
Infections of bones, joints, and related organs	2268 (1676, 2860)	2497 (1879, 3115)	0.2(0.1, 0.2)	0.2 (0.1, 0.2)
Typhoid fever, paratyphoid fever, and invasive non-typhoidal Salmonella	64648(31670, 97625)	55187 (26879, 83495)	4.7 (2.3, 7.0)	3.9 (1.9, 5.9)
Diarrhea	533980 (284916, 783044)	498401 (259182, 737621)	38.5 (20.5, 56.4)	35.2 (18.3, 52.1)
Gonorrhoea and chlamydia	7634(2702-12566)	12747(3480-22015)	0.6(0.2-0.9)	0.9(0.3-1.6)

Table 1: Deaths burden of infectious syndrome in India, 2019&2021.

Interpretation: For individuals aged **60 to 95** and older, the most affected infectious syndromes include bloodstream infections, lower respiratory infections, tuberculosis, and diarrhoea. These syndromes account for a significant proportion of infectious disease mortality in this age group. Therefore, we have analysed these four highlighted syndromes to understand trends in death counts and death rates between 2019 and 2021. **1.Bloodstream Infections:**Between 2019 and 2021, deaths from bloodstream infections decreased slightly from 558,754 to 542,971 (a ~2.8% decline). The death rate per 100,000 also fell from 40.2 to 38.4, indicating a modest improvement. This reduction could reflect better prevention, treatment efforts, or changes in healthcare access and reporting during the pandemic period. **2.Lower Respiratory Infections (and related thoracic infections):**Deaths from lower respiratory infections dropped from 724,219 in 2019 to 658,708 in 2021, a decrease of about 9%. The death rate per 100,000 also declined from 52.2 to 46.6. This reduction may reflect improved respiratory disease management, the impact of public health measures like masking and distancing, or possible misclassification with COVID-19 cases during the pandemic. **3.Tuberculosis:** Tuberculosis (TB) deaths decreased slightly from 413,354 in 2019 to 399,571 in 2021, with the death rate per 100,000 dropping from 29.8 to 28.3. However, the overlapping uncertainty intervals suggest this decline may not be statistically significant. COVID-19-related disruptions in TB services might have impacted case detection and reporting during this period. **4.Diarrhoea:**Diarrhoea-related deaths decreased from 533,980 in 2019 to 498,401 in 2021, with the death rate per 100,000 falling from 38.5 to 35.2. Despite the decline, wide uncertainty intervals suggest caution in interpretation. Improved sanitation, healthcare access, and hygiene practices may have contributed to this reduction.

	DALYs 2019	DALYs 2021	DALY 2019	DALY 2021
	Number (95% UI)	Number (95% UI)	Rate, per 100,000 (95% UI)	Rate, per 100,000 (95% UI)
All infectious syndromes	110101839(85208205,135446756)	100195485(76182631,124675689)	7929(6136,9754)	7083.5(5385.9,8814.1)
male	56662619(40648908,72846073)	52903009(37002054,69029884)	7961.3(5711.3,10235.1)	7304.7(5109.1,9531.4)
female	53439220(39869049,67339972)	47292476(34047021,60811349)	7894.7(5890.0,9948.3)	6851.4(4932.4,8809.9)
Infectious syndrome				
Bloodstream infections	25119335(20720303, 29518367)	23345095(19371018, 27319173)	1808.9 (1492.1, 2125.7)	1650.4(1369.5, 1931.4)
Lower respiratory infections and all related infections in the thorax	27258713(24076419, 30441007)	22350511 (19623881, 25077141)	1963.0 (1733.8, 2192.2)	1580.1 (1387.3, 1772.9)
Peritoneal and intra-abdominal infections	2449734(2068428, 2831040)	2491417 (2067279, 291556)	176.4 (149.0, 203.9)	176.1 (146.1, 206.1)
Bacterial infections of the skin and subcutaneous systems	2068576 (1747957, 2389195)	2082079 (1745052, 2419106)	149.0 (125.9, 172.1)	147.2 (123.4, 171.0)
Urinary tract infections and pyelonephritis	2370448 (1997679, 2743217)	2371635(1994306, 2748964)	170.7(143.9, 197.5)	167.7(141.0, 194.3)
Endocarditis and other cardiac infections	573788 (486413, 661163)	554712 (463404, 646021)	41.3 (35.0, 47.6)	39.2 (32.8, 45.7)
Tuberculosis	15670007(13411874, 17928140)	15099053 (12380146, 17817960)	1128.5 (965.8, 1291.1)	1067.5 (875.2, 1259.7)
Meningitis and other bacterial central nervous system infections	2371249 (1924976, 2817522)	2025201 (1672848, 2377553)	170.8(138.6, 202.9)	143.2 (118.3, 168.1)
Infections of bones, joints, and related organs	447768(269907, 625629)	488024(286497, 689550)	32.2(19.4, 45.1)	34.5 (20.3, 48.7)
Typhoid fever, paratyphoid fever, and invasive non-typhoidal Salmonella	4811694 (2300341, 7323047)	4044984 (1908436, 6181533)	346.5(165.7, 527.4)	286.0 (134.9, 437.0)
Diarrhea	18487982(10705257, 26270707)	16853826 (9493284, 24214369)	1331.4 (770.9, 1891.9)	1191.5 (671.1, 1711.9)
Gonorrhoea and chlamydia	1177967(700789-1655145)	1660717(821238-2500196)	84.8(50.5-119.1)	117.4(58.1-176.8)

Table 2: DALYs burden of infectious syndrome in India, 2019&2021.

Interpretation: For individuals aged 60 to 95 and older, the syndromes with the highest disease burden in terms of Disability-Adjusted Life Years (DALYs) are bloodstream infections, lower respiratory infections, tuberculosis, and diarrhoea. These conditions reflect both premature mortality and years lived with disability, making them critical indicators of health impact in the elderly. Therefore, we analysed these four highlighted syndromes to understand trends between 2019 and 2021. **1.Bloodstream Infections: Bloodstream DALYs** dropped from **25.1 million in 2019** to **23.3 million in 2021**, with the **DALY rate per 100,000** declining from **1808.9 to 1650.4**. This reduction suggests progress in disease burden management—possibly due to better early diagnosis, more effective treatments, improved infection control, or adaptive health system responses during the COVID-19 pandemic. **2.Lower Respiratory Infections: Lower Respiratory Infections (LRI) DALYs** decreased notably from **27.3 million in 2019** to **22.4 million in 2021**, with the **DALY rate** dropping from **1963.0 to 1580.1 per 100,000**.. Additionally, some LRI cases may have been misclassified or merged under COVID-19 in 2021, contributing to the observed reduction.

3.Tuberculosis: Tuberculosis (TB) DALYs showed a modest decline from **15.7 million in 2019** to **15.1 million in 2021**, with the **DALY rate** decreasing from **1128.5 to 1067.5 per 100,000** . The decrease may partly reflect underreporting or disruptions in TB diagnosis and treatment services during the COVID-19 pandemic—especially affecting older populations.

4. Diarrhoea: Diarrheal Diseases DALYs decreased slightly from **18.5 million in 2019** to **16.9 million in 2021**, with the **DALY rate** falling from **1331.4 to 1191.5 per 100,000**. This decline may suggest progress in public health measures such as sanitation, hygiene, and health education.

	Associated with resistance								Attributable to resistance							
	Deaths 2019	Deaths 2021	Death Rate 2019	Death Rate 2021	DALY 2019	DALY 2021	DALY Rate 2019	DALY Rate 2021	Deaths 2019	Deaths 2021	Death Rate 2019	Death Rate 2021	DALY 201	DALY 202	DALY Rate 2019	DALY Rate 2021
	Number (95% UI)	Number (95% UI)	Rate, per 100,000 (95% UI)	Rate, per 100,000 (95% UI)	Number (95% UI)		Rate, per 100,000 (95% UI)	Rate, per 100,000 (95% UI)	Number (95% UI)	Number (95% UI)	Rate, per 100,000 (95% UI)		Number (95% UI)		Rate, per 100,000 (95% UI)	
All Infectious Syndromde	1050811(851596,1277433)	987254(789281,1213107)	75.7(61.3,91.9)	69.9(55.8,85.8)	(32601784,53724402)	(28622647,47830557)	3073.1(2347.8,3868.9)	2667.6(2023.5,3381.5)	283556(219149,356198)	266734(202690,338813)	20.4(15.8,25.7)	18.9(14.3,23.9)	(8266019,14253948)	7255215, 12893692)	800.1(595.3,1026.5)	698.6(512.9,904.5)
Infectious syndrome																
Bloodstream infections	335586 (299308, 371865)	326032 (292118, 359946)	24.2 (21.6, 26.8)	23.0 (20.7, 25.4)	14295376 (11814958, 16775793)	13294249 (10987396, 15601101)	1029.5 (850.8, 1208.1)	939.9 (776.8, 1102.9)	97481 (85516, 85516)	93953 (82464, 105441)	7.0 (6.2, 7.9)	6.6 (5.8, 7.5)	4159890 (3435608, 4884171)	3839326 (3151706, 4526946)	299.6 (247.4, 351.7)	271.4 (222.8, 320.0)
Lower respiratory infections and all related infections in the thorax	394620 (347168, 442072)	355498 (303802, 407194)	28.4(25.0, 31.8)	25.1 (21.5, 28.8)	14984793 (12723224, 17246362)	12121345 (10230264, 14012427)	1079.1 (916.2, 1242.0)	856.9(723.2, 990.6)	105838 (89635, 122041)	95543 (78645, 112440)	7.6 (6.5, 8.8)	6.8 (5.6, 7.9)	3894653 (3201255, 4588051)	3174167 (2584175, 3764158)	280.5 (230.5, 330.4)	224.4 (182.7, 266.1)
Peritoneal and intra-abdominal infections	48232 (40166, 56299)	48481 (39552, 57409)	3.5 (2.9, 4.1)	3.4 (2.8, 4.1)	1528238 (1290325, 1766152)	1539966 (1273588, 1806343)	110.1 (92.9, 127.2)	108.9 (90.0, 127.7)	13197 (10765, 15628)	13143 (10571, 15715)	1.0 (0.8, 1.1)	0.9 (0.7, 1.1)	421316 (347413, 495219)	421004 (342603, 499406)	30.3 (25.0, 35.7)	29.8 (24.2, 35.3)
Bacterial infections of the skin and subcutaneous systems	29811 (25996, 33627)	29178 (24484, 33872)	2.1 (1.9, 2.4)	2.1 (1.7, 2.4)	1207811 (1001387, 1414235)	1204270 (981341, 1427199)	87.0 (72.1, 101.8)	85.1 (69.4, 100.9)	7499 (6420, 8578)	7246 (6032, 8459)	0.5 (0.5, 0.6)	0.5 (0.4, 0.6)	324282(263394, 385170)	321365 (257344, 385386)	23.4 (19.0, 27.7)	22.7 (18.2, 27.2)
Urinary tract infections and pyelonephritis	62833(53512, 72154)	62634(52660, 72607)	4.5 (3.9, 5.2)	4.4 (3.7, 5.1)	1674336 (1404139, 1944533)	1654473 (1376281, 1932664)	120.6(101.1, 140.0)	117.0 (97.3, 136.6)	16936 (14125, 19746)	16670 (13677, 19663)	1.2 (1.0, 1.4)	1.2 (1.0, 1.4)	451530 (372936, 530125)	440818 (359652, 521984)	32.5 (26.9, 38.2)	31.2(25.4, 36.9)
Endocarditis and other cardiac infections	14337 (11961, 16714)	13660 (11154, 16166)	1.0 (0.9, 1.2)	1.0 (0.8, 1.1)	404097 (342496, 465698)	387644 (319554, 455734)	29.1 (24.7, 33.5)	27.4 (22.6, 32.2)	3942(3243, 4642)	3717 (3002, 4432)	0.3 (0.2, 0.3)	0.3 (0.2, 0.3)	111479 (93233, 129725)	105820 (86381, 125258)	8.0 (6.7, 9.3)	7.5 (6.1, 8.9)
Tuberculosis	56614(15053, 125580)	56223 (14793, 125532)	4.1 (1.1, 9.0)	4.0 (1.0, 8.9)	2043470 (552160, 4514167)	2018972 (539740, 4485012)	147.2 (39.8, 325.1)	142.7 (38.2, 317.1)	19598 (0, 47431)	19584 (0, 47203)	1.4 (0, 3.4)	1.4 (0, 3.3)	661325 (0, 1621868)	654956 (0, 1596855)	47.6 (0, 116.8)	46.3 (0, 112.9)
Meningitis and other bacterial central nervous system infections	12350(10163, 14538)	11184(9297, 13072)	0.9 (0.7, 1.0)	0.8 (0.7, 0.9)	759652 (604370, 914934)	656065 (530238, 781892)	54.7 (43.5, 65.9)	46.4 (37.5, 55.3)	3075 (2480, 3671)	2787 (2255, 3318)	0.2 (0.2, 0.3)	0.2 (0.2, 0.2)	188020 (147995, 228045)	162998 (129947, 196049)	13.5 (10.7, 16.4)	11.5 (9.2, 13.9)
Infections of bones, joints, and related organs	1683 (1237, 2128)	1823 (1358, 2288)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	325519 (197709, 453329)	350307 (207843, 492772)	23.4 (14.2, 32.6)	24.8 (14.7, 34.8)	448 (327, 569)	479 (356, 603)	0.0 (0.0, 0.0)	0.03(0.0, 0.0)	96489 (58195, 134783)	102511 (59960, 145061)	6.9 (4.2, 9.7)	7.2 (4.2, 10.3)
Typhoid fever, paratyphoid fever, and invasive non-typhoidal Salmonella	41808 (17811, 65806)	36178 (15294, 57061)	3.0 (1.3, 4.7)	2.6 (1.1, 4.0)	3118939 (1289176, 4948702)	2658356 (1083893, 4232818)	224.6 (92.8, 356.4)	187.9 (76.6, 299.2)	4814(1306, 8322)	4174 (1142, 7205)	0.3 (0.1, 0.6)	0.3 (0.1, 0.5)	356738(90542, 622934)	304471 (76881, 532060)	25.7 (6.5, 44.9)	21.5 (5.4, 37.6)
Diarrhea	52936 (29222, 76651)	46364 (24769, 67959)	3.8 (2.1, 5.5)	3.3 (1.8, 4.8)	2318542 (1381103, 3255981)	1834376 (1091147, 2577606)	167.0 (99.5, 234.5)	129.7 (77.1, 182.2)	10727(5331, 16123)	9440 (4545, 14334)	0.8 (0.4, 1.2)	0.5 (0.4, 0.6)	443452 (255311, 631594)	352277 (206370, 498183)	31.9 (18.4, 45.5)	24.9 (14.6, 35.2)

Table 3: Deaths and DALYs associated with and attributable to bacterial antimicrobial resistance in India,2019 and 2021

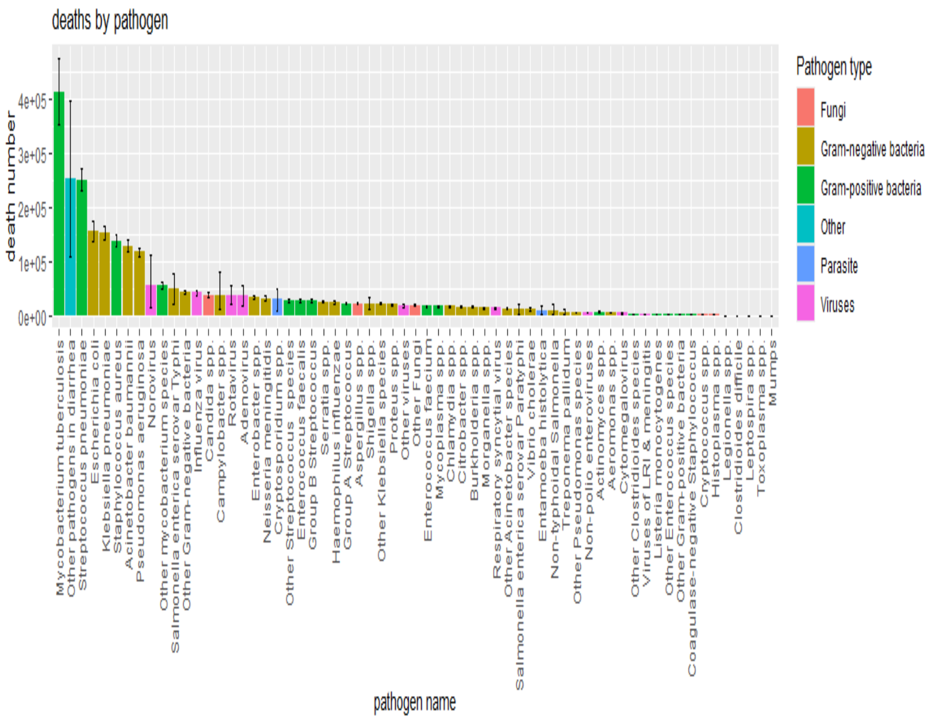
Interpretation: Burden of Infectious Syndromes Associated with and Attributable to Resistance (2019–2021) Among Older Adults (60–95+): Here is a concise **Interpretation** of your findings:

Interpretation

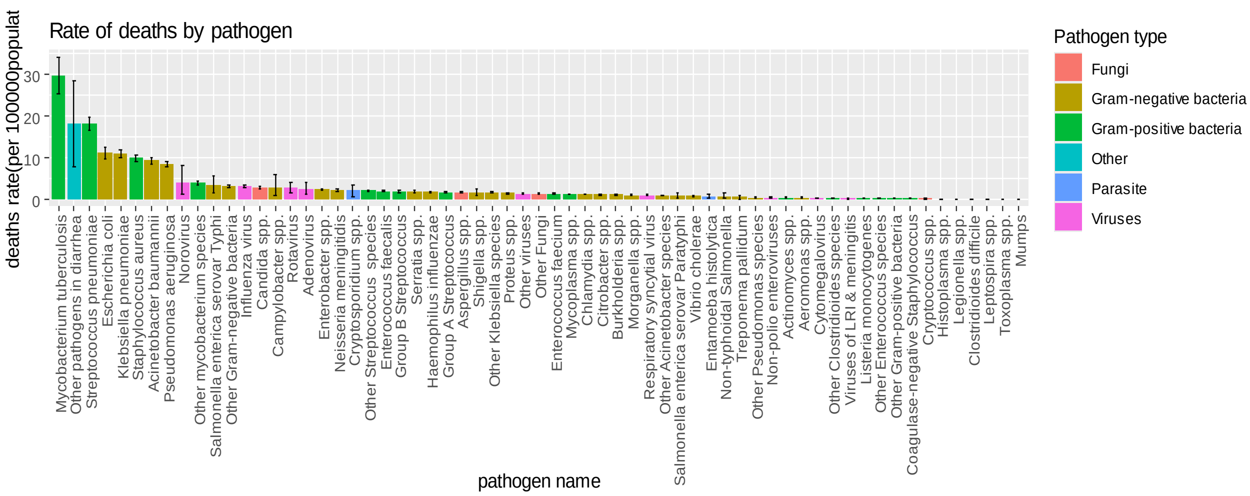
Between 2019 and 2021, infectious syndromes associated with antimicrobial resistance (AMR) showed a modest but encouraging decline in mortality and disease burden among older adults aged 60 and above in India. Notably, bloodstream and lower respiratory infections demonstrated reductions in both deaths and DALYs, with bloodstream infection deaths declining by 3.5% and DALYs by 7%, and lower respiratory infection deaths decreasing by 11.6%. Diarrheal diseases also saw a significant improvement, with a 13% reduction in deaths and a notable drop in DALYs.

While tuberculosis mortality remained relatively stable, small improvements were observed. Infections directly attributable to AMR mirrored these trends, with lower respiratory and diarrheal diseases showing the most marked reductions in both deaths and DALYs. Despite these gains, AMR continues to pose a substantial health threat, especially among the elderly, underscoring the need for continued surveillance, prevention strategies, and antimicrobial stewardship.

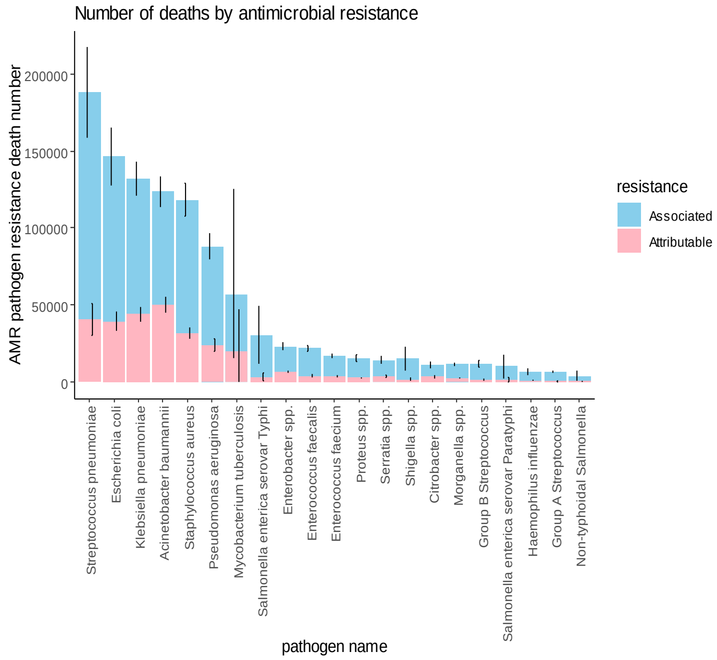
A.



B.



(C)



(D)

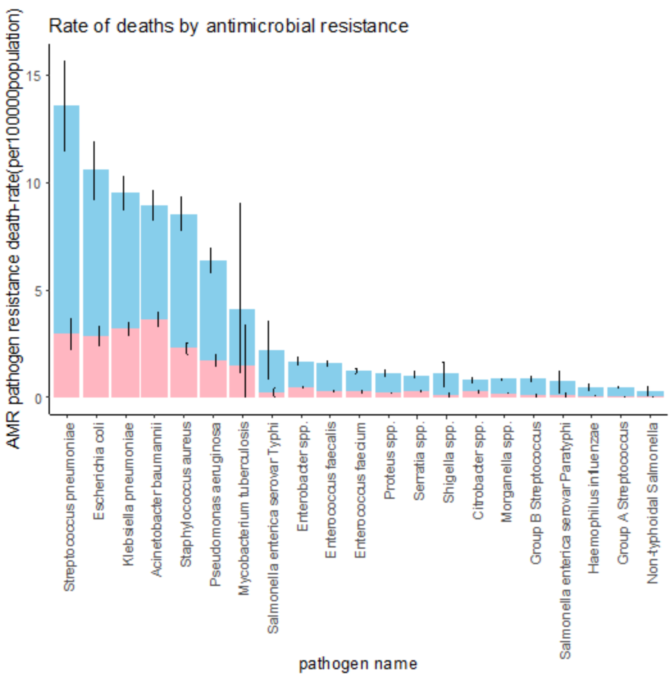


Fig 5: Number of deaths by pathogens and antimicrobial resistance in India,2019. (A)Number of deaths by pathogens; (B)Rate of deaths by pathogens; (C)Number of deaths by antimicrobial resistance; (D)Rate of deaths by antimicrobial resistance. The black vertical line represented 95%confidence interval.

Discussion:

Mycobacterium tuberculosis is the **leading cause of death**, contributing to over **400,000 deaths**, confirming its persistent global health threat—especially in the context of **drug resistance** and impact on older or immunocompromised individuals. **Streptococcus pneumoniae**, **Escherichia coli**, and **Klebsiella pneumoniae** are also among the pathogens, mainly classified as **Gram-positive** and **Gram-negative bacteria.** These pathogens are commonly involved in **pneumonia, bloodstream infections, and UTIs**, with high antimicrobial resistance potential. The majority of high-burden pathogens are either **Gram-negative** or **Gram-positive** bacteria. This underscores that **bacterial infections**, not viral or fungal, account for the largest share of pathogen-attributable deaths, particularly those resistant to antibiotics. **Viruses** and **parasites** appear mostly in the mid-to-lower end of the death count .For example, pathogens like **HIV**, **Mumps**, or **other parasitic protozoa** show far fewer deaths than bacterial agents, possibly due to improved vaccines, treatments, or less prevalence in high-risk populations. **Streptococcus pneumoniae** tops the chart with **over 200,000 deaths** (combined attributable and associated), highlighting it as a critical AMR threat. Other high-burden pathogens include: **Escherichia coli, Klebsiella pneumoniae, A. baumannii, Staphylococcus aureus, Pseudomonas aeruginosa.** These are known for **hospital-acquired infections** and **resistance to multiple antibiotics**, especially in ICUs and immunocompromised patients. Some pathogens like **Streptococcus pneumoniae** and **E. coli** show a **high proportion of attributable deaths**, meaning resistance itself is a direct cause of mortality. Others like **Mycobacterium tuberculosis** show a higher blue (associated) component, implying resistance complicates treatment significantly even if not the direct cause. Toward the right, pathogens like **Haemophilus influenzae**, **Group A Streptococcus**, and **Non-typhoidal Salmonella** have **much lower death numbers**, although still relevant in specific regions or populations. **Drug-resistant bacterial infections** cause a large number of **direct and indirect deaths. Respiratory and bloodstream pathogens**, especially those with **multi-drug resistance**, are the biggest contributors. **AMR is not just an emerging issue—it is already a major global killer**, with **urgent implications** for antibiotic stewardship, infection prevention, and development of new treatments.

Here is the some comparison of Death between the years 2019 and 2021 for older age(85-95+):

85-89(Attributable,2019,Death Number)

	Antibiotic class								
	Aminoglycosides	Carbapenems	Fluoroquinolones	Methicillin	Resistance to one or more antibiotics	Multi-drug resistance in Salmonella enterica	Penicillin	Trimethoprim-Sulfamethoxazole	Third-generation cephalosporins
Pathogen	Category: Access	Category: Watch							
Acinetobacter baumannii	438.8224017	1326.590981	727.084885		2611.025805				
Escherichia coli		1097.842804	676.7325968		3002.223135			338.7650458	485.3452411
Klebsiella pneumoniae	386.1455851	1005.207069	484.2357677		2230.168646				
Streptococcus pneumoniae		1204.805339			2238.052076		347.5636473		
Staphylococcus aureus			367.5744012	1166.70098	1870.546325				
Pseudomonas aeruginosa		673.3355219			1291.513579				
Mycobacterium tuberculosis					629.0834178	595.2177224			

85-89(Attributable,2021, Death Number)

	Antibiotic class							
	Aminoglycosides	Carbapenems	Fluoroquinolones	Methicillin	Resistance to one or more antibiotics	Multi-drug resistance in Salmonella enterica	Trimethoprim-Sulfamethoxazole	Third-generation cephalosporins
Pathogen	Category: Access	Category: Watch						
Acinetobacter baumannii	430.8513	1331.097	727.6604		2613.901			
Escherichia coli		1055.519	695.097		3075.074		384.7989	523.3307
Klebsiella pneumoniae	360.7095	953.2432	517.4631		2204.553			
Streptococcus pneumoniae		1262.306			2225.289			
Staphylococcus aureus			420.7552	1295.611	2056.45			
Pseudomonas aeruginosa		552.0064			1269.064			
Mycobacterium tuberculosis					711.2144	671.9936		
Enterobacter spp.					331.0039			

Antibiotic ResistanceComparison (2019 vs 2021) – Age Group 85–89:

In the 85–89 age group, Escherichia coli deaths related to antibiotic resistance increased by about 2.4% overall, with fluoroquinolones (+2.7%) and Trimethoprim-Sulfamethoxazole (+13.6%) showing notable rises. Streptococcus pneumoniae also saw a slight increase in carbapenem-related deaths (+4.8%). In contrast, Acinetobacter baumannii showed a minimal overall increase of 0.1%, with aminoglycosides and carbapenems roughly stable. Klebsiella pneumoniae deaths decreased slightly by 1.2%, despite a small increase in fluoroquinolone resistance (+6.9%). New pathogen data reported in 2021 for Staphylococcus aureus (2056 deaths), Pseudomonas aeruginosa (1269 deaths), and Mycobacterium tuberculosis highlight emerging resistance challenges. Overall, while some decreases occurred, antibiotic resistance remains a significant burden in this age group.

90-94(Attributable,2019,Death Number)

	Antibiotic class								
	Aminoglycosides	Carbapenems	Fluoroquinolones	Methicillin	Resistance to one or more antibiotics	Multi-drug resistance in Salmonella enterica	Penicillin	Trimethoprim-Sulfamethoxazole	Third-generation cephalosporins
Pathogen	Category: Access	Category: Watch							
Acinetobacter baumannii	183.6502	555.1874	304.2931		1092.735				
Escherichia coli		536.8961	332.8842		1465.399			166.0407	232.1745
Klebsiella pneumoniae	168.7768	439.3566	211.6556		974.7691				
Streptococcus pneumoniae		545.8802			1014.031		157.4762		
Staphylococcus aureus				499.2092	800.3713				
Pseudomonas aeruginosa		289.9648			556.1792				
Mycobacterium tuberculosis					208.2259	197.0164			

90-94(Attributable,2021, Death Number)

	Antibiotic class							
	Aminoglycosides	Carbapenems	Fluoroquinolones	Methicillin	Resistance to one or more antibiotics	Multi-drug resistance in Salmonella enterica	Trimethoprim-Sulfamethoxazole	Third-generation cephalosporins
Pathogen	Category: Access	Category: Watch						
Acinetobacter baumannii	178.6874	552.0471	301.786		1084.069			
Escherichia coli		509.6905	336.4228		1477.674		186.3265	244.4507
Klebsiella pneumoniae	156.0222	412.3184	223.8302		953.5686			
Streptococcus pneumoniae		564.7547			995.5943			
Staphylococcus aureus		235.4601	178.6411	550.0806	873.1121			
Pseudomonas aeruginosa					541.3261			
Mycobacterium tuberculosis					264.1052	249.5408		

Comparison of attributable deaths between 2019 and 2021 for the 90–94 age group due to antibiotic resistance: From 2019 to 2021, antibiotic resistance–attributable deaths in the 90–94 age group showed varied trends by pathogen and drug class. *Acinetobacter baumannii* demonstrated slight declines, with deaths due to aminoglycoside resistance down by 2.7%, carbapenem resistance by 0.6%, and overall resistance-related deaths by 0.8%. *Klebsiella pneumoniae* showed a 6.2% drop in carbapenem-related deaths and a 2.2% decrease overall, though fluoroquinolone resistance–related deaths increased by 5.7%. In contrast, *Escherichia coli* had a 0.8% rise in total resistance-related mortality, driven by increases of 12.2% in trimethoprim-sulfamethoxazole resistance and 5.3% in third-generation cephalosporin resistance, despite a 5.1% decline in carbapenem-related deaths. *Streptococcus pneumoniae* saw a 1.8% overall decline, but carbapenem resistance deaths increased by 3.5%. *Staphylococcus aureus* presented a concerning 10.2% rise in methicillin resistance–attributable deaths and a 9.1% increase in total resistance-related deaths. *Pseudomonas aeruginosa* showed improvement with a 2.7% decline overall. Most notably, *Mycobacterium tuberculosis* showed sharp increases: 26.8% in multi-drug resistance deaths and 26.6% in deaths linked to trimethoprim-sulfamethoxazole resistance.

95+(Attributable,2019,Death Number)

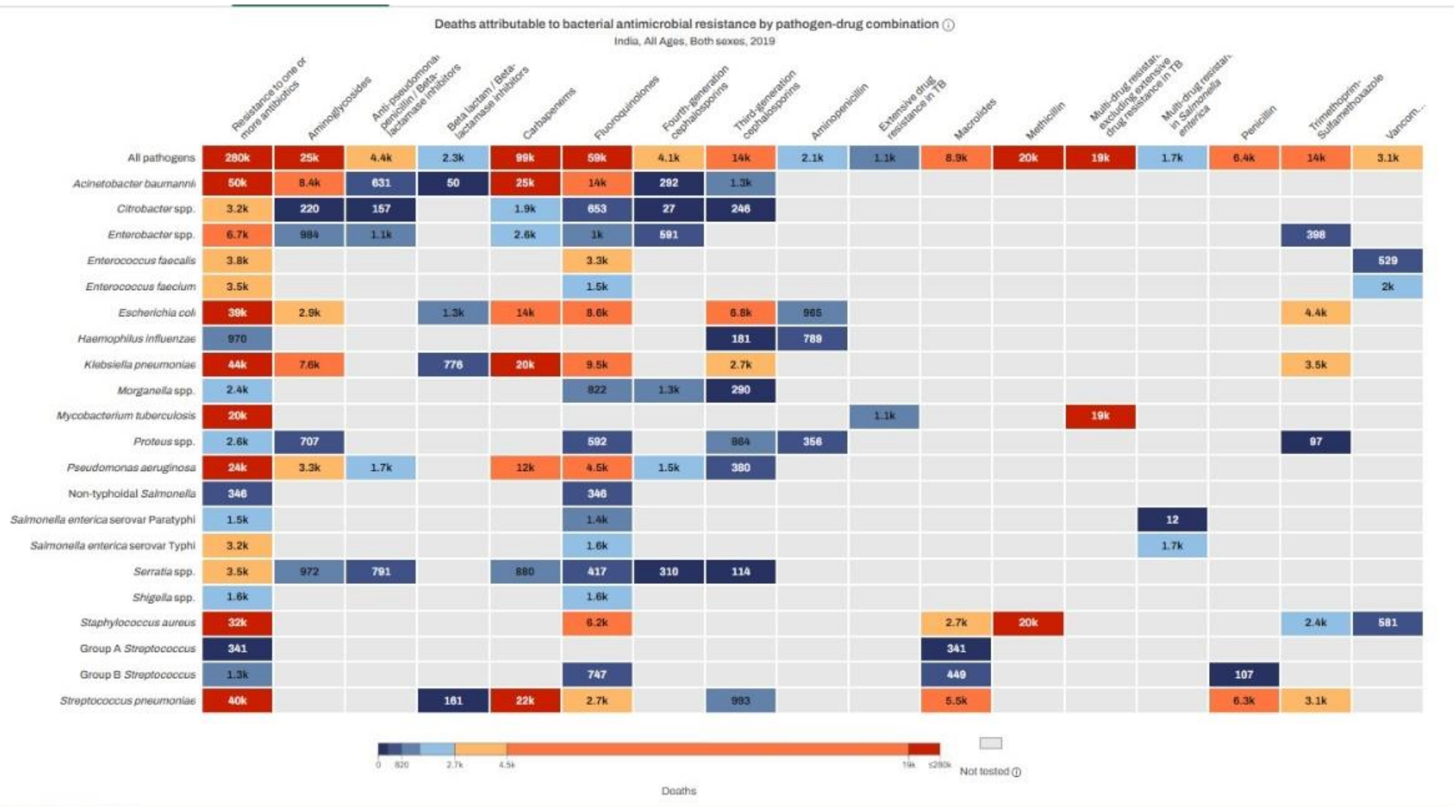
	Antibiotic class								
	Aminoglycosides	Carbapenems	Fluoroquinolones	Macrolides	Methicillin	Resistance to one or more antibiotics	Penicillin	Trimethoprim-Sulfamethoxazole	Third-generation cephalosporins
Pathogen	Category: Access	Category: Watch							
Acinetobacter baumannii	54.57106	164.9721	90.42117			324.7043			
Escherichia coli		190.2610451	118.8043			518.0645		59.00089	80.01891
Klebsiella pneumoniae	52.90546	137.7225	66.34862			305.5573			
Streptococcus pneumoniae		182.5158		45.80695		339.0433	52.65237		
Staphylococcus aureus			48.24975		153.1473	245.5377			
Pseudomonas aeruginosa		89.21728				171.1281			
Mycobacterium tuberculosis									
Enterobacter spp.						42.473			

95+(Attributable,2021,Death Number)

	Antibiotic class							
	Aminoglycosides	Carbapenems	Fluoroquinolones	Resistance to one or more antibiotics	Multi-drug resistance in Salmonella enterica	Penicillin	Trimethoprim-Sulfamethoxazole	Third-generation cephalosporins
Pathogen	Category: Access	Category: Watch						
Acinetobacter baumannii	48.716	150.506	82.27813	295.5539				
Escherichia coli		166.745	110.3486	480.7251			61.14847	76.89156
Klebsiella pneumoniae	45.14799	119.3122	64.77185	275.9356				
Streptococcus pneumoniae		174.0099		306.759		43.49028		
Staphylococcus aureus			50.49583	246.7995				
Pseudomonas aeruginosa		66.6824		153.305				
Mycobacterium tuberculosis				47.94514	45.30114			

<u>Comparison of attributable deaths between 2019 and 2021 in the 95+ age group due to antibiotic resistance</u>: Between 2019 and 2021, there was an overall decline in antibiotic resistance–attributable deaths among the 95+ age group across most major bacterial pathogens and drug classes. Acinetobacter baumannii showed a consistent decrease, with deaths due to aminoglycoside resistance dropping by **10.7%**, carbapenem resistance by **8.8%**, fluoroquinolone resistance by **9%**, and overall resistance to one or more antibiotics decreasing by **9%**. Similarly, Escherichia coli exhibited a notable reduction, with carbapenem-related deaths falling by **12.3%**, and resistance to one or more antibiotics decreasing by **7.2%**, while deaths linked to trimethoprim-sulfamethoxazole showed a slight increase of **3.6%**. Klebsiella pneumoniae followed the downward trend, with aminoglycoside and carbapenem resistance–attributable deaths declining by **14.7%** and **13.4%**, respectively. Streptococcus pneumoniae also showed encouraging declines, with a **9.3%** decrease in carbapenem resistance–attributable deaths and a **9.5%** reduction in overall resistance. However, Staphylococcus aureus was a key exception: deaths due to methicillin resistance surged by **61.2%**, and fluoroquinolone resistance increased by **4.7%**, highlighting an emerging concern. Pseudomonas aeruginosa saw improvements, with carbapenem-related deaths down by **25.3%**. Notably, Mycobacterium tuberculosis appeared in 2021 data for the first time, reporting significant resistance burdens, including 47.95 deaths from multidrug resistance.

A.



B.

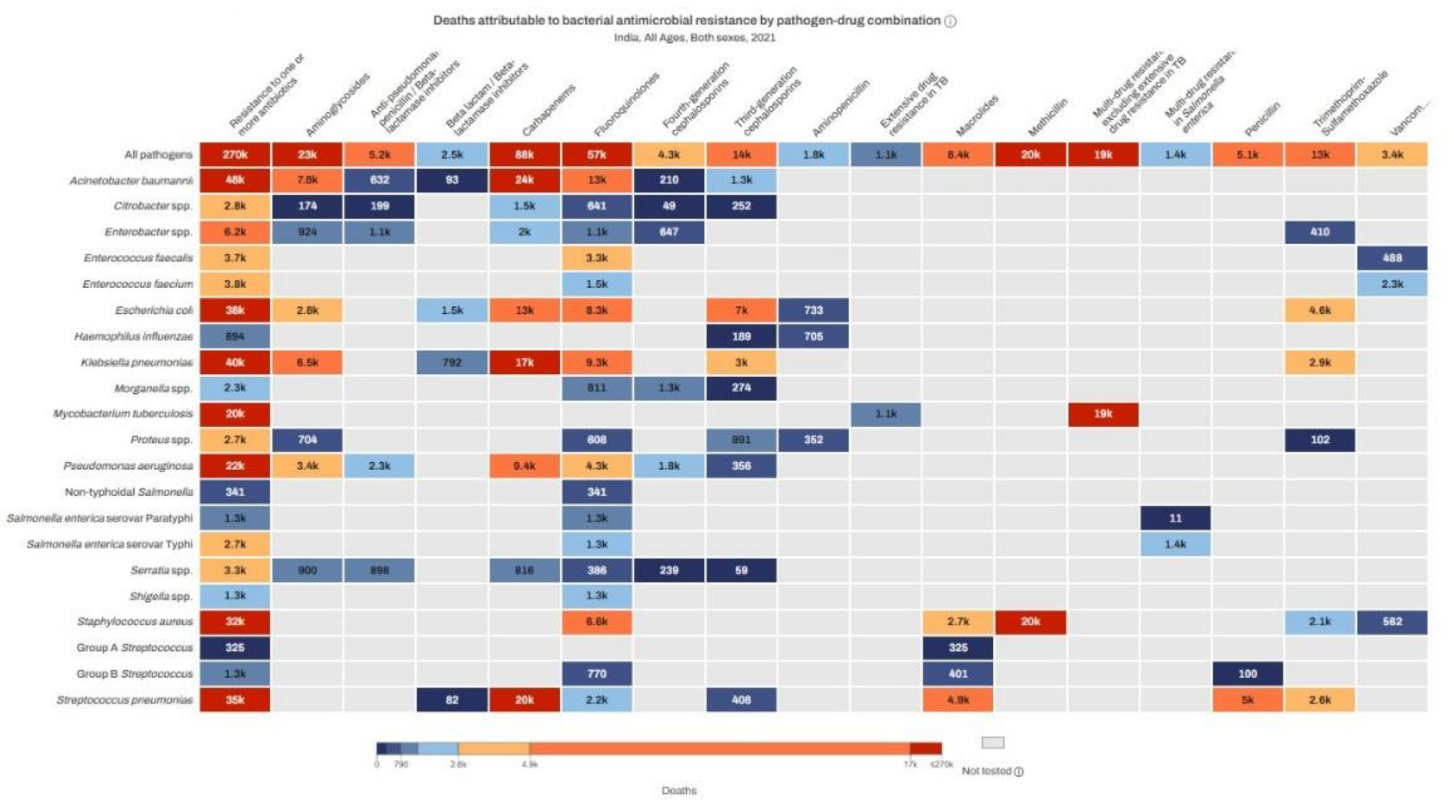


Fig6: Heatmap of_deaths attributed with antimicrobial resistance by pathogen-drug combination.(2019)(A) and 2021(B).

<u>Discussion:</u> Heatmap of_deaths attributed with antimicrobial resistance by pathogen-drug combination for 2019_and 2021:

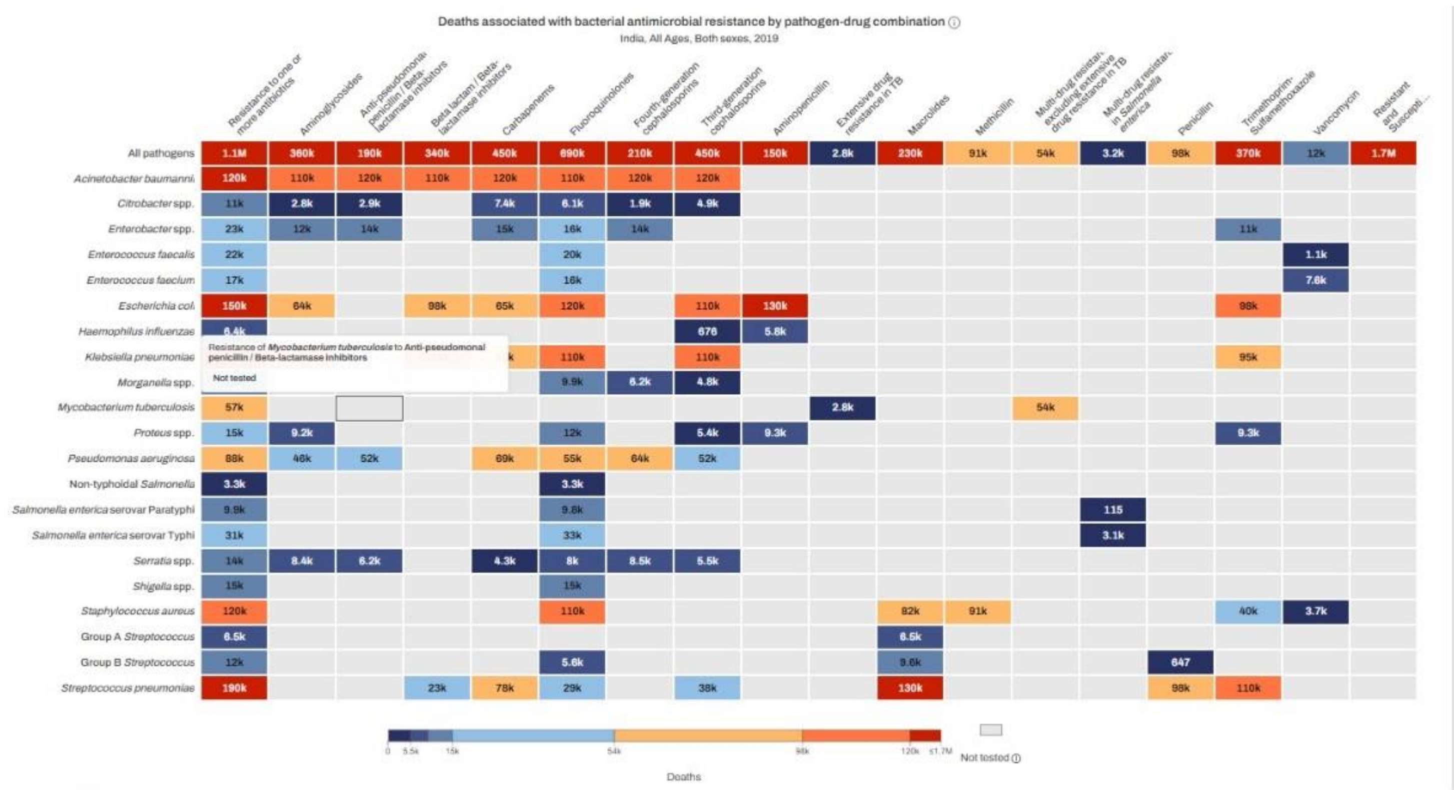
The heatmaps display deaths attributable to bacterial antimicrobial resistance (AMR) in India for the years 2019 and 2021, across all ages and sexes. The total number of deaths due to AMR declined slightly from 280,000 in 2019 to 270,000 in 2021. Among the pathogens, *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Streptococcus pneumoniae* remained consistently among the top contributors to AMR-related deaths in both years, although each showed a modest decline. Notably, *Escherichia coli* was the only major pathogen for which deaths due to AMR increased—from 30,000 in 2019 to 36,000 in 2021—highlighting a growing concern.

In terms of drug classes, resistance to cephalosporins continued to account for the highest number of deaths, though it declined from 99,000 in 2019 to 88,000 in 2021. Resistance to fluoroquinolones remained relatively stable (59,000 to 57,000), while carbapenem resistance saw a slight decrease (25,000 to 24,000). Deaths related to multidrug-resistant tuberculosis (MDR-TB) and methicillin-resistant *Staphylococcus aureus* (MRSA) remained unchanged at 19,000 and 20,000 respectively, suggesting persistent treatment challenges.

Among specific pathogen-drug combinations, *E. coli* resistant to fluoroquinolones and cephalosporins remained especially deadly, with little change in their high fatality numbers. Some minor increases were observed in resistance-related deaths involving less prominent pathogens like Group B *Streptococcus* and *Morganella* spp., though these changes were relatively small. Conversely, deaths linked to resistance in *Streptococcus pneumoniae* and *Klebsiella pneumoniae* against cephalosporins showed meaningful reductions.

Despite the modest overall improvement, the high number of deaths associated with common first-line antibiotics such as cephalosporins and fluoroquinolones indicates ongoing misuse and overuse. The consistently large “not tested” data segments in several pathogen-drug combinations highlight diagnostic gaps that hinder effective treatment. These trends underscore the urgent need for stronger antimicrobial stewardship, better surveillance systems, and expanded diagnostic capacities to combat AMR in India.

(C)



(D)

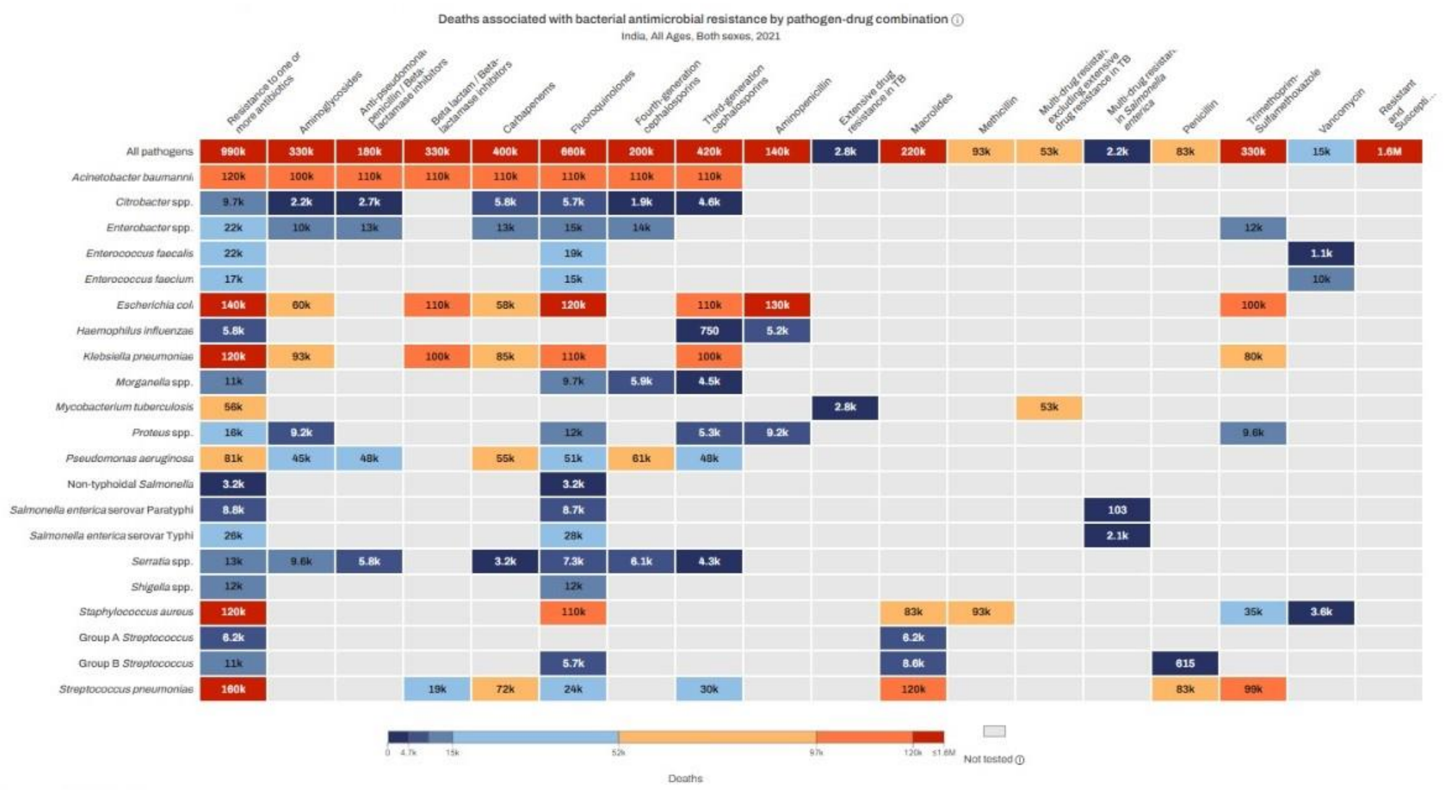


Fig7: Heatmap of_deaths associated with antimicrobial resistance by pathogen-drug combination.(2019)(C) and 2021(D).

Discussion:

The heatmaps for the years 2019 and 2021 present a detailed overview of deaths associated with bacterial antimicrobial resistance (AMR) across various pathogen-drug combinations in India. In both years, the burden of AMR-related deaths remains alarmingly high, with 1.7 million deaths in 2019 and 1.6 million in 2021 linked to resistant infections. The most significant contributors across both years are resistance to fluoroquinolones, beta-lactam/beta-lactamase inhibitors, and third-generation cephalosporins. These drug classes consistently appear in deep red shades, indicating high mortality.

Among pathogens, *Acinetobacter baumannii, Escherichia coli, Klebsiella pneumoniae*, and *Streptococcus pneumoniae* are responsible for the largest number of AMR-associated deaths. For example, in both years, *A. baumannii* shows consistently high resistance-associated mortality (around 120k deaths), particularly with carbapenems and beta-lactams. Similarly, *E. coli* and *K. pneumoniae* show high deaths across multiple drug classes, reflecting their widespread resistance and clinical importance. Notably, *Pseudomonas aeruginosa* and *Mycobacterium tuberculosis* also contribute significantly to the resistance burden, particularly with resistance to fluoroquinolones and rifampicin, respectively.

Comparing the two years, the overall trends remain similar, though there is a slight reduction in total deaths from 1.7 million in 2019 to 1.6 million in 2021. However, certain drug-pathogen combinations such as resistance of *K. pneumoniae* to cephalosporins and *S. aureus* to methicillin and beta-lactams remain persistently high. Additionally, some pathogens like *Group B Streptococcus* and *Shigella spp.* exhibit relatively low but consistent resistance-associated mortality, while a few like *Salmonella enterica serovar Typhi* show an increase in deaths due to resistance to fluoroquinolones and cephalosporins from 2019 to 2021.

In summary, both heatmaps underscore the sustained and broad impact of antimicrobial resistance across a range of pathogens and drug classes in India. The data highlight the urgent need for targeted antimicrobial stewardship, improved surveillance, and development of novel treatment options to address high-mortality resistance patterns, particularly involving beta-lactams, fluoroquinolones, and carbapenems.

References

1. Murray, C. J., et al. (2022).
Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis.
The Lancet, 399(10325), 629–655.
DOI: 10.1016/S0140-6736(21)02724-0
2. GBD 2019 Diseases and Injuries Collaborators. (2020).
Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019.
The Lancet, 396(10258), 1204–1222.
DOI: 10.1016/S0140-6736(20)30925-9
3. Antimicrobial Resistance Collaborators. (2022).
Estimating the burden of AMR in 2021: update from the Global Research on Antimicrobial Resistance (GRAM) project.
Wellcome Open Research / Institute for Health Metrics and Evaluation (IHME)
(Access via GBD-AMR Visualizations and IHME datasets)
4. Institute for Health Metrics and Evaluation (IHME).
Global Burden of Disease Study 2019 & 2021 Results.
Retrieved from: https://www.healthdata.org/gbd
5. World Health Organization (WHO). (2014).
Antimicrobial resistance: global report on surveillance 2014.
Geneva: WHO.
Available at: https://www.who.int/publications/i/item/9789241564748
6. World Health Organization (WHO). (2020).
Global antimicrobial resistance and use surveillance system (GLASS) report: early implementation 2020.
Geneva: WHO.
7. Indian Council of Medical Research (ICMR). (2021).
Annual Report: Antimicrobial Resistance Surveillance and Research Network (AMRSN).
New Delhi: ICMR.
Available at: https://main.icmr.nic.in

Appendix:

```
blood_19 <- read.csv("bloodstream_raw_19.csv")

head(blood_19)

blood_19 <- blood_19[,c(1:3)]

names(blood_19)

library(stringr)

blood_19$agegroup <- str_replace_all(blood_19$agegroup, c("neonatal"="Neonatal","post-neonetal"="Post-Neonatal"))

#blood_19$agegroup

# to get an age wise order

blood_19$agegroup <- factor(blood_19$agegroup, levels=c("95+","90-94","85-90","80-84","75-79","70-74","65-69","60-64","55-59","50-54","45-49","40-44","35-39","30-34","25-29","20-24","15-19","10-14","5-9","1-4","Post-Neonatal","Neonatal"))

library(ggplot2)

g1 <- ggplot(data=blood_19, aes(x=agegroup, y=Male)) +

  geom_bar(stat = "identity",fill="red") + ggtitle("Bloodstream") +

  theme(axis.title.x = element_blank(),

        axis.title.y = element_blank(),

        axis.text.y = element_blank(),

        axis.ticks.y = element_blank(),

        plot.margin = unit(c(1,-1,1,0), "mm")) +

  scale_y_reverse() + coord_flip() +

  theme(axis.text.x = element_text(angle = 45, hjust = 1)) # to rotate the label

g2 <- ggplot(data=blood_19, aes(x=agegroup, y=Female)) +

  geom_bar(stat = "identity",fill="blue") + ggtitle("2019") +

  xlab(NULL)+

  geom_bar(stat = "identity",fill="blue") +

  theme(axis.title.x = element_blank(), axis.title.y = element_blank(),

        axis.text.y = element_blank(), axis.ticks.y = element_blank(),

        plot.margin = unit(c(1,0,1,-1), "mm")) +
```

```
  coord_flip() +

  theme(axis.text.x = element_text(angle = 45, hjust = 1)) # to rotate the label

#g2 <- ggplot(amr.death.all.attr_21) + geom_bar( aes(x=Pathogen, y=Value), stat="identity", fill="skyblue", alpha=0.7) +

#  geom_errorbar( aes(x=Pathogen, ymin=Upper, ymax=Lower), width=0.4, colour="orange", alpha=0.9, linewidth = 1.3) +

#  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1)) +

#  ggtitle("Deaths attributable to AMR in 2021") + scale_y_continuous(labels = scales::comma

blood_21 <- read.csv("bloodstream_raw_21.csv")

head(blood_21)

blood_21 <- blood_21[,c(2:4)]

names(blood_21)

#library(stringr)

#blood_19$agegroup <- str_replace_all(blood_19$agegroup, c("95+"="95+","90-94"="90 to 94","85-90"="85 to 89","80-84"="80 to 84","75-79"="75 to 79","70-74"="70 to 74","65-69"="65 to 69","60-64"="60 to 64","55-59"="55 to 59","50-54"="50 to 54","45-49"="45 to 49","40-44"="40 to 44","35-39"="35 to 39","30-34"="30 to 34","25-29"="25 to 29","20-24"="20 to 24","15-19"="15 to 19","90-94"="10 to 14","90-94"="5 to 9","90-94"="1 to 4","post-neonetal"="Post Neonetal", "neonatal"="Neonatal"))

#blood_19$agegroup

# to get an age wise order

blood_21$age_group <- factor(blood_21$age_group, levels=c("95+","90-94","85-89","80-84","75-79","70-74","65-69","60-64","55-59","50-54","45-49","40-44","35-39","30-34","25-29","20-24","15-19","10-14","5-9","1-4","Post-Neonetal","Neonetal"))

library(readxl)

library(pheatmap)



# Read reshaped data

data <- read_excel("reshaped_heatmap_data.xlsx")

# Set pathogen names as rownames

data_matrix <- as.data.frame(data)

rownames(data_matrix) <- data_matrix$Pathogen

data_matrix$Pathogen <- NULL

# Convert to numeric matrix

data_matrix <- as.matrix(data_matrix)
```

```
# Log10 transform (+1 to avoid log(0))
log_data_matrix <- log10(data_matrix + 1)

# Create display matrix (only show values where original is not 0)
display_matrix <- ifelse(data_matrix == 0, round(data_matrix, 0))  # show original values, blank if 0

# Define color palette
color_palette <- colorRampPalette(c("navy", "skyblue", "yellow", "orange", "red", "darkred"))(100)

# Generate heatmap
pheatmap(log_data_matrix,
         scale = "none",
         display_numbers = display_matrix,  # show real values, blank where 0
         number_format = "%.0f",
         cellwidth = 40,
         cellheight = 20,
         fontsize_row = 10,
         fontsize_col = 10,
         fontsize_number = 8,
         color = color_palette,
         main = "Deaths by Pathogen and Drug Class (0s Hidden)")
```