Faculty of Medical and Health Sciences, University of Poonch Rawalakot
Journal of Pharma and Biomedics
ISSN: 3007-1984(online), 3007-1976 (Print)
https://www.jpbsci.com/index.php/jpbs

Trends in Antimicrobial Resistance of *Salmonella typhi* Among Children in Lahore: A Six-Year Study (2018–2023)

Kiran Nazeer[1], Hafiza Rabia Muneer[1], Saba Riaz[1,2,3]*

[1] Institute of Microbiology and Molecular Genetics, University of the Punjab, Lahore, Pakistan.
[2] CITI Institute of Emerging Health Technologies, Lahore, Pakistan.
[3] Citilab and Research Centre Lahore, Pakistan.

Received: May 18, 2025; *Revised: June 28, 2025;* *Accepted: June 30, 2025*

A B S T R A C T

Background: Typhoid is known as the disease of preschool-aged children (aged 0–5 years) due to its high overall incidence, particularly among people residing in poor settings in low middle-income countries. The study aims to find the rates of drug-resistant Salmonella typhi in children in Lahore in the last six years (2018-2023). **Methods:** The study was conducted in collaboration with MMG and CRC from January 2018 to December 2023. It included patients who were susceptible to typhoid at a younger age, below 13 years, and who visited for diagnosis. The blood samples were processed in a microbiological laboratory according to standard operating procedures. **Results:** A total of 290 blood cultures were positive for S. typhi over six years. Most of them were males and kids aged 6-13. High percentages were found in 2019 and 2023. In addition, the hot season months acted as a typhoid risk factor. Ampicillin was the most resistant drug, whereas carbapenems were the least resistant. There were MDR XDR. **Conclusion:** An alarming pattern of antibiotic drug resistance was observed among children with enteric fever in Lahore. The lowest resistance levels were noted for azithromycin, meropenem, and imipenem. Our findings necessitate implementing tailored antibiotic stewardship and infection control strategies.

Keywords: Salmonella, Antimicrobial resistance, Children.

Corresponding Author: Saba Riaz*
Email: saba.mmg@pu.edu.pk

INTRODUCTION

Despite advancements in hygienic and sanitary conditions and water quality, typhoid cases have not stopped spreading among the people residing in poor settings in low and middle-income countries. Typhoid fever affects more than 9 million cases and causes110 000 deaths yearly (Qadri et al., 2021). WHO reported that typhoid fever affects almost 11 to 21 million individuals and causes about 200,000 deaths globally. Pakistan has been one of the central endemic countries with 22,354 confirmed cases and 15,717 cases of extensively drug-resistant typhoid fever from 2016 to 2020. This calculation measures typhoid fever's disease rate; the ratio calculated is about 15.5/1,000. The current outbreak of XDR ST is affecting more than 19 thousand individuals in Sindh, particularly children below the age of 15 years (Ahmad et al., 2024). Pakistan has an estimated typhoid incidence of 493.5 per 100,000 people per year, with unsafe water supply and poor sanitary conditions leading to large epidemics of this disease. The widespread misuse of antibiotics in Pakistan due to their easy availability led to the emergence of an extensively drug-resistant (XDR) strain of typhoid fever (Qamar et al., 2025). Typhoid is known as the disease of preschool-aged children (aged 0–5 years) due to high overall typhoid incidence, particularly among people residing in poor settings in low and middle-income countries (Qadri et al., 2021). Many of the previous studies

have described typhoid as a childhood disease. In 2017, 63% of typhoid cases and 70% of typhoid deaths in Pakistan occurred in children younger than 15 years (Batool et al., 2023). Tahir et al. calculated the high risk of getting the disease in children aged 5 to 9 years (56% of cases and 59% of deaths) (Tahir et al., 2023). Another study reported that 80% of children were disproportionately afflicted by XDR-ST infection in 2021. This age specification can be justified primarily by low immunity, access to unhygienic food and inefficient sanitation. The highest incidence of typhoid has also been reported in school-going children and young adults due to baseline immune status, unclean food and water and inadequate sewage system (Batool et al., 2023); (Thobani et al., 2022). XDR strains pose an extra burden to effective disease therapeutics and infection management due to the sensitivity of all available treatment options. Pakistan has faced several outbreaks since the first identification of the XDR isolate in November 2016. To address this outbreak of XDR typhoid, a large-scale immunisation campaign using the World Health Organisation (WHO)–recommended typhoid conjugate vaccine (TCV) was implemented in January 2018, targeting the most affected areas of Hyderabad city, i.e. Latifabad and Qasimabad. After the vaccination campaign in Hyderabad 2019, Pakistan became the first country to introduce the WHO-recommended TCV into its routine vaccination regimen through the Expanded Programme of Immunization (Qamar et al.). Typhoid conjugate vaccines (TCV) are highly effective and have been recommended for use in typhoid fever-endemic countries. Vaccine introduction can address the enduring problem of pediatric typhoid fever and the evolving multi-drug resistance (MDR) situation in affected regions (Kim et al., 2022). However, the burden of typhoid fever has not been reduced to an acceptable rate (Marchello et al., 2020).

Previous studies have examined the typhoid cases in Sindh, but have not captured the substantial number of observational studies on typhoid fever in children in Punjab in recent years. Furthermore, some past reviews were restricted by location, population, or age. To support country-level decisions on typhoid control, including TCV introduction, and to provide contemporary estimates of morbidity and mortality in Punjab, we performed a retrospective analysis of the prevalence of typhoid fever in children in Punjab. XDR typhoid fever is not limited to Sindh Province and is spreading throughout Pakistan. We have observed a surge in typhoid fever cases in our facility (Ahmad et al.). We are conducting this study to evaluate the antibiotic sensitivity patterns in *S. typhi* isolated from children with clinical suspicion of enteric fever. This evaluation will help us formulate management guidelines for patients with drug-resistant strains and emphasise the need for vaccination against S. typhi.

MATERIALS AND METHODS

Study design and data collection

This study was conducted in the Institute of Microbiology and Molecular Genetics, University of the Punjab, Lahore, in collaboration with Citilab and the Research Centre, Lahore. Ethical approval was taken for the study from the CRC ethical committee (Reference # 26th-09-CLRC / 26-09). Samples from young patients below 13 were studied according to the Inclusion criteria. Blood samples of suspected typhoid patients were received from more than 100 collection centres and processed according to the microbiological laboratory's standard operating procedures (SOPs). Blood from each patient was inoculated into tryptic soya broth bottles and incubated in the automated Bactec/ALERT blood culture system (Biomerieux). The culture bottles with negative signs of pathogen growth were re-incubated to confirm the negative results. Positive broth cultures were grown on bacteriological media. Isolated colonies were identified based on colony morphology and biochemical tests using API 20E (Biomerieux, France). All demographic information (including age and gender) and the sample collection time were obtained for further analysis.

Antimicrobial susceptibility testing

The Bauer disc diffusion method tested a panel of antibiotics on Muller-Hinton agar to determine the empirical antibiotics for treatment. Antimicrobial susceptibility test involves the following discs: ampicillin (AM), amoxicillin/clavulanate (AMC), chloramphenicol (C), trimethoprim-sulfamethoxazole (SXT), ciprofloxacin (CIP), levofloxacin (LEV), nalidixic acid (NA), ceftriaxone (CRO), cefuroxime (CXM), cephradine (CE), cefixime (CFM), cefoperaxone/sulbactum (sulzone) (CES), Piperacillin/tazobactam (tazocin) (TPZ), amikacin (AK), gentamycin (CN), moxifloxacin (MXF), aztreonam (ATM), tetracycline (TE), azithromycin (AZM), imipenem (IPM) and meropenem (MEM). After 24 hours of incubation at 37 °C, each antibiotic's inhibition zones were measured to interpret the results as sensitive, intermediate, and resistant. The same panel was used by the National Antimicrobial Resistance Monitoring System (NARMS) (Karp et al., 2017).

MDR and XDR Screening

All of the strains resistant to first-line drugs such as (AMP,

C and SXT) were considered MDR *S. Typhi*. MDR strains that were not sensitive to fluoroquinolones (CIP) and third-generation cephalosporins (CRO) were termed XDR *S. typhi* (Marchello et al., 2020).

Data analysis

The data were presented graphically using SPSS version 22 to compare the trends in different groups. Descriptive statistics were used to calculate the frequencies and percentages of the qualitative variables.

RESULTS

This study evaluates the rates of typhoid fever in children and antibiotic sensitivity patterns over the past six years in Lahore, Punjab. A total of 290 cases were included in the study. The mean age of the patients was 6.2 ± 3.3 years, with males being predominantly affected (174 cases, or 60.6%) compared to females (114 cases, or 39.3%). The most affected age group was children aged 6-10 years (118 cases, or 40.7%), followed by toddlers aged 1-5 years (108 cases, or 37.2%), children aged 11-15 years (59 cases, or 20.3%), and newborns under 1 year old (4 cases, or 1.4%). The distribution of cases by age and gender exhibited similar patterns, with higher percentages in male children. Year-wise distribution revealed that typhoid fever was endemic in the pre-COVID period of 2019, with 107 cases (36.9%). The disease rates dropped during COVID-19, with only 23 cases (7.9%) recorded in 2020. However, a surge in typhoid cases was observed over the following years: 44 cases (15.2%) in 2021, 43 cases (14.8%) in 2022, and 59 cases (20.3%) in 2023.

Table 1: Antimicrobial resistance patterns.

Classes	Antibiotics	Resistant	Sensitive	Intermediate
Penicillins	Ampicillin (AMP)	238 (82.1%)	50 (17.24%)	2 (0.7%)
	Augmentin (AMC)	178 (71.5%)	70 (28.11%)	1 (0.45)
Phenicols	Chloramphenicol (C)	174 (66.9%)	86 (33.08%)	0 (0.0%)
Folate pathway inhibitors	Trime-sulphamethoxazole (SXT)	209 (76.8%)	62 (22.79%)	1 (0.4%)
Floroquinolones	Ciprofloxacin (CIP)	161 (55.5%)	101 (34.8%)	28 (9.7%)
	Levofloxacin (LEV)	111 (52.6%)	78 (36.9%)	22 (10.4%)
	Nalidixic acid (NA)	228 (92.3%)	18 (7.29%)	1 (0.4%)
	MXF (MXF)	37 (82%)	2 (4%)	6 (13%)
Cephalosporins (Beta-lactam)	Ceftriozone (CRO)	160 (55.2%)	127 (43.79%)	3 (1.0%)
	Cefepime (FEP)	123 (58.3%)	86 (40.76%)	2 (0.9%)
	Cefoperazone (CEP)	150 (55.6%)	118 (43.70%)	2 (0.7%)
	Cefexime (CFX) CFM	106 (59.9%)	71 (40.11%)	0 (0.0)
Combination	Aztreonam (ATM)	164 (56.6%)	123 (42.41%)	3 (1.0%)
	cefoperazone-sulbactam (CES)	104 (36.9%)	159 (56.4%)	19 (6.7%)
	Tazocin (TPZ)	70 (24.4%)	196 (68.3%)	21 (7.3%)
Macrolides	Azithromycin (AZM)	143 (71.5%)	54 (27%)	3 (1.5%)
Tetracycline	Tetracycline (TE)	55 (19.45))	227 (79.93%)	2 (0.7%)
Carbapenems	Imipenem (IPM)	3 (1%)	285 (98.96%)	0 (0.0%)
	Meropenem (MEM)	4 (1.4%)	281 (98.60%)	0 (0.0%)

It was noted that the hot and wet climate before winter in Pakistan can be a risk factor for increased illness. In 2018 and 2019, most cases emerged after the hot season in August, September, and October, with incidence rates of 28.57% and 20.56%, respectively. In 2020, typhoid fever cases were recorded at the end of the year with incidences of 17.39%, 30.43%, and 39.13%. Conversely, at the beginning of 2021, cases were observed in 22.73%. Overall, typhoid cases were highest in August, September, October, and November. First-line drugs exhibited high resistance rates among all tested antibiotics, with AMP 238 at 82.1%, SXT 209 at 76.8%, and C 174 at 66.9%. Among fluoroquinolones, the resistance rates were CIP 161 at 55.5% and LEV 111 at 52.6%. Third-generation cephalosporins also demonstrated significant non-susceptibility, with CRO 160 at 55.2%, CEP 150 at 55.6%, FEP 123 at 58.3%, and CFM 106 at 59.9%. Regarding combination drugs, resistance was noted as follows: ATM 164 at 56.6%, AMC 178 at 71.5%, TPZ 70 at 24.4%, and CES 104 at 36.9%. In contrast, carbapenems showed the

least resistance, with IPM at 3% (1.0%) and MEM at 4% (1.4%).

Out of 247 isolates from children, more than half of the strains were not susceptible to first-line drugs, totalling 155 (62.8%). Among these, 69 strains (27.9%) were classified as multidrug-resistant (MDR), and 86 strains (34.8%) were resistant to both fluoroquinolones and cephalosporins. Among the extensively drug-resistant (XDR) strains, 63 (25.5%) were also resistant to azithromycin. The remaining strains exhibited different resistance patterns, with 92 (37.2%) classified as non-MDR. Among these non-MDR strains, 24 (9.7%) showed resistance to ceftriaxone (CRO), 45 (18.2%) were resistant to azithromycin (AZM), and 21 (8.5%) were resistant to both antibiotics (Figure 2).

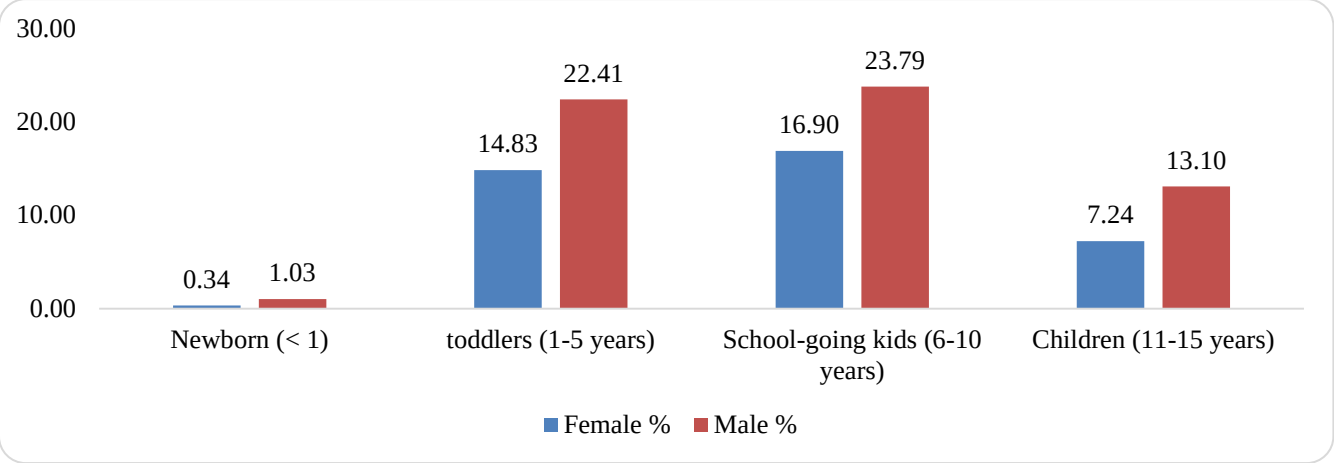

Figure 1: Age and gender-wise distribution of typhoid cases in Children in Six years data.

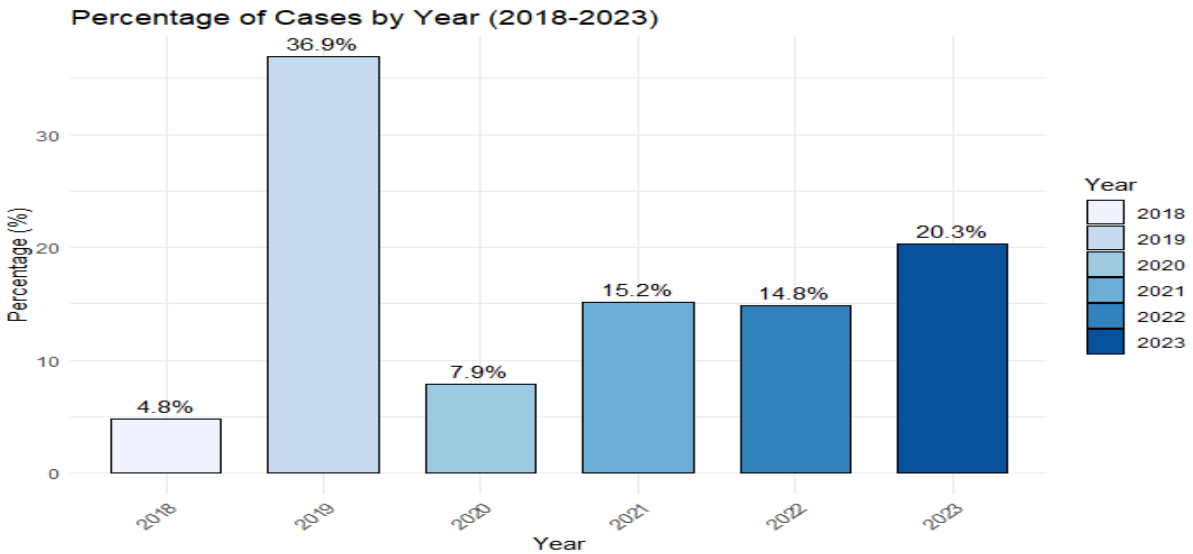

Figure 2: Year-wise distribution of typhoid cases in Children in six years of data.

DISCUSSION

This study evaluates the rise in drug-resistant *S. typhi* infection in children in Lahore, Pakistan. In the study, we found that the school-going kids (5-13 years), 147 (56.7%), were a high-risk typhoid group in Pakistan. Our findings resemble those of previous studies that revealed the high disease risk in children. Tahir et al., calculated the high risk of getting the disease by children aged 5 to 9 years (56%of cases and 59% of deaths) in Pakistan (Tahir et al., 2023). Similarly, another study reported that 80% of school-going children were disproportionately afflicted by XDR-ST infection in 2021 (Ahmad et al., 2024).In 2017, 63% of typhoid cases and 70% of typhoid deaths in Pakistan occurred in children younger than 15 years (Batool, et al.,

2023). This age specification can be justified primarily by low immunity in childhood, access to unclean food and water and inefficient sewage system (Batool et al., 2023); (Thobani et al., 2022, Ahmad et al., 2024).Zakir et al. also described the prominent pattern of infection in males, which might be culture-confirmed typhoid. There is no biological logic of this predisposition. However, it may be attributed to more exposure to the outside environment, dining outside and eating vendor foods carefree nature, and risk-oriented attitude as compared to females (Zakir, et al., 2021; Ahmad, Rasool et al.). It has been observed that most of the infections occur in hot and wet seasons. It may be due to high temperatures during the summer that enhanced the multiplication of *S. typhi* in contaminated foods.

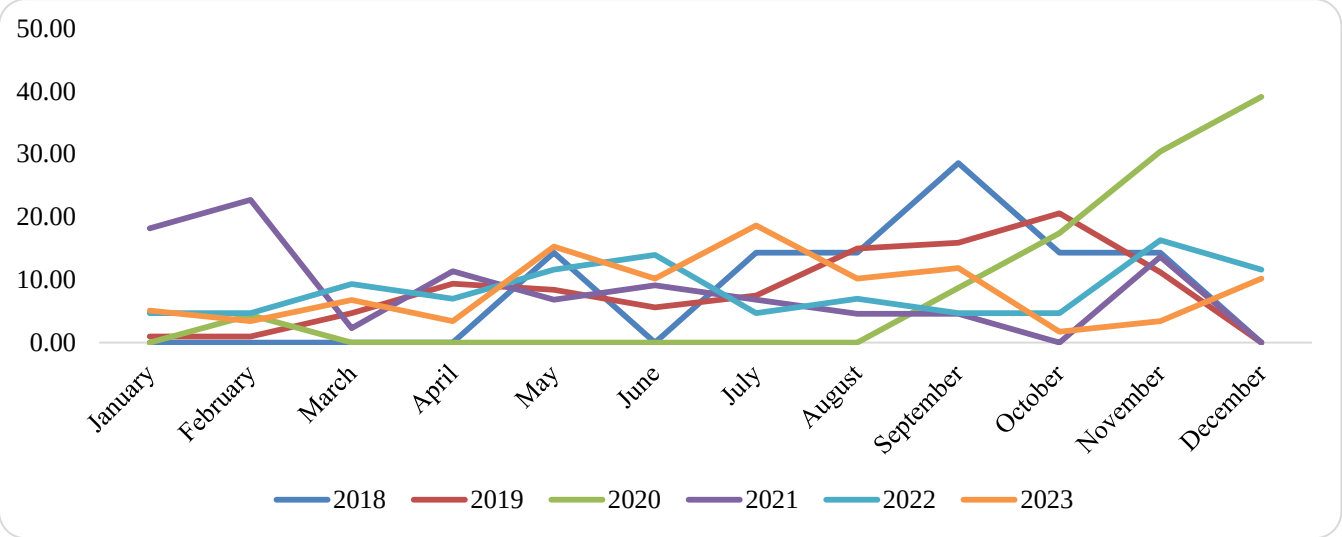

Figure 3: Frequency of typhoid fever during twelve months of each year.

During hot seasons, consumption of unsafe refreshments (such as locally made flavored popsicles and flavored drinks) increases by children and the risk of typhoid is a high {Srinivasan, 2022 #28}. Pakistan has remained one of the endemic countries in the world. In 2016, the first outbreak of XDR typhoid was noticed in Hyderabad, Sindh. Later on, this highly resistant strain spread in Pakistan with many typhoid cases (Baig et al., 2023). In this study, disease rates were high in 2019, before COVID-19. Then, a clear and sharp decline was observed in the rates of disease during the COVID-19 era. This indicates the underdiagnosed cases of typhoid due to panic and complicated conditions of a pandemic. At the beginning of 2020, typhoid was co-epidemic with COVID-19 in Pakistan. It has been reported that around 20,000 typhoid cases within 10 days during June 2020 have been diagnosed along with COVID-19 (Chongtrakool et al., 2023).Another study reported similar symptoms of infections, decreased surveillance, and the primary goal of controlling COVID-19 made it difficult to find the actual rates of typhoid {Tharwani, 2022 #32}. Tharwani et al., reported a surge in the number of typhoid patients from January 2017 to June 2021, 14,360 cases, compared to 864 new cases just within June 2021 to August 14, 2021 alone (Tharwani et al., 2022). Whereas, in Lahore, a 12-fold increase in isolation rate was observed at Jinnah Hospital over the 12 months July 2018 to June 2019 (number of cases = 370) relative to the previous 12 months ($n < 30$) (Rasheed et al., 2020). We found 63 MDR and 79 XDR strains according to the CLSI 2021 guidelines. These XDR isolates have been identified as a haplotype of *S. typhi* H58, initially described as a fluoroquinolone-resistant *S. typhi* subtype, which subsequently acquired a novel IncY plasmid encoding a $bla_{\text{CTX-M-15}}$ extended-spectrum β-lactamase gene and *qnrS* fluoroquinolone resistance gene (Posen et al., 2023). A recent study found the rates of XDR in Lahore were very similar to ours. Jabeen et al., found 150 (40%) were identified as extensively drug resistant (XDR), 126 (32%) as multidrug resistant (MDR), and only three (2%) as azithromycin resistant (AZM resistant) {Jabeen, 2023 #40}. A large number of azithromycin-resistant isolates was a bigger matter of concern. A previous study identified the AZM-resistant strains in Lahore, along with 10/57 MDR and 39/57 XDR cases. This situation is leading to the last resort of drugs, carbapenems and tigecycline (Butt et al., 2022).

Carbapenems are expensive, and their mainstream use is unfavourable given the resource-stricken environments where typhoid is most prevalent. Moreover, both tigecycline and carbapenems are administered parenterally, and the concurrently rising resistance of typhoid against azithromycin highlights an additional need to develop orally administered antibiotics. Since 90% of typhoid patients are treated as outpatients, a limited number of oral antibiotic options would necessitate treating such cases as inpatients, thereby improving the chances of overburdening hospitals where nosocomial infections associated with drug-resistant pathogens are common (Akram et al., 2024). Another study identified that 56.8%) were XDR. Regarding the combination of ceftriaxone and azithromycin, 32 (33.7%) *S*. Typhi isolates were sensitive to both antibiotics. Fifty-four (56.8%) were resistant, and 9 (9.5%) were resistant to both. Among the isolates resistant to ceftriaxone, 50 (84.7%) demonstrated sensitivity to azithromycin (Baig et al., 2023). Particularly, research has highlighted the overuse of azithromycin to treat COVID-19, and this practice might impair one of the few remaining solutions against the XDR *S. typhi*.

Facing COVID-19 and XDR simultaneously can result in a catastrophe in Pakistan because it is entirely occupied with the pandemic, and it has been reported that around 20,000 typhoid cases within a period of 10 days during June 2020 have been diagnosed along with COVID-19. Such an unfortunate situation can cause havoc, and it would heavily affect the already compromised public health sector that is losing due to the inability to serve and care for all the patients at the same time with limited financing and healthcare resources (Butt, 2022). This is the first longitudinal study of six years on typhoid infections in children. Study data was collected from a single diagnostic centre in Lahore, which is the study's limitation. Also, the genotyping of these strains and large sample sizes can provide detailed information. Our findings will help paediatricians select empirical antibiotics and typhoid management. This study emphasises the urgent need for antibiotic stewardship and strategies to control infection rates in Punjab, Pakistan.

CONCLUSION

School-going Children are at high risk of getting an infection with S. typhi. Typhoid fever has been endemic in the cities of Punjab. During COVID-19, typhoid remained co-epidemic but unnoticed. S. typhi strains have converted to a highly resistant form, XDR. After COVID-19, the strains developed resistance against azithromycin. Carbapenems and tigecycline are antibiotics of last resort to cope with infection rates.

REFERENCES

Ahmad, M., Rasool, M.H., Rasheed, F., Aslam, B. & Khurshid, M. (n.d.) Genetic analysis of antimicrobial resistance in *Salmonella Typhi*: An extensive surveillance study with national and global relevance.

Ahmad, M., Saeed, M., Rasheed, F., Rasool, M.H., Jamil, I., Saba, N., Wazeer, A., Qasim, Z. & Khurshid, M. (2024) Typhoid fever: Pakistan's unique challenges and pragmatic solutions. *Journal of Islamabad Medical & Dental College*, 13, pp.151–161.

Akram, M., Ul Ain, Q., Tariq, A., Javed, S., Nayab, K. & Fatima, S. (2024) Comparison of efficacy of azithromycin with ciprofloxacin in the treatment of uncomplicated enteric fever in children. *Journal of Rawalpindi Medical College*, 28.

Baig, U., Mehdi, S.M. & Iftikhar, N. (2023) A pattern of antibiotic drug resistance of *Salmonella Typhi* and *Salmonella Paratyphi* among children with enteric fever in a tertiary care hospital in Lahore, Pakistan. *Croatian Medical Journal*, 64, p.256.

Batool, R., Qureshi, S., Haq, Z., Yousafzai, M.T., Salam, R.A., Ali, R., Sadaf, T., Ali, M. & Qamar, F.N. (2023) Coverage survey of typhoid conjugate vaccine among children aged 6 months to 15 years in an urban slum settlement of Lyari Town Karachi, Pakistan. *PLOS ONE*, 18, e0289582.

Butt, M.H., Saleem, A., Javed, S.O., Ullah, I., Rehman, M.U., Islam, N., Tahir, M.A., Malik, T., Hafeez, S. & Misbah, S. (2022) Rising XDR-typhoid fever cases in Pakistan: Are we heading back to the pre-antibiotic era? *Frontiers in Public Health*, 9, 794868.

Chongtrakool, P., Wangleotsakulchai, P., Tabboon, T., Thuncharoon, H., Pummangura, C., Samretwit, D., Yungyuen, T., Khowwigkai, P., Suttisaewan, T. & Srifeungfung, S. (2023) Isolation and antibiotic susceptibility profile of *Salmonella* spp. from patients in a tertiary care hospital in Thailand. *Journal of the Medical Association of Thailand*, 106.

Karp, B.E., Tate, H., Plumblee, J.R., Dessai, U., Whichard, J.M., Thacker, E.L., Hale, K.R., Wilson, W., Friedman, C.R. & Griffin, P.M. (2017) National antimicrobial resistance monitoring system: Two decades of advancing public health through

integrated surveillance of antimicrobial resistance. *Foodborne Pathogens and Disease*, 14, pp.545–557.

Kim, C.L., Cruz Espinoza, L.M., Vannice, K.S., Tadesse, B.T., Owusu-Dabo, E., Rakotozandrindrainy, R., Jani, I.V., Teferi, M., Bassiahi Soura, A. & Lunguya, O. (2022) The burden of typhoid fever in sub-Saharan Africa: A perspective. *Research and Reports in Tropical Medicine*, pp.1–9.

Marchello, C.S., Carr, S.D. & Crump, J.A. (2020) A systematic review on antimicrobial resistance among *Salmonella Typhi* worldwide. *American Journal of Tropical Medicine and Hygiene*, 103, pp.2518.

Posen, H.J., Wong, W., Farrar, D.S., Campigotto, A., Chan, T., Barker, K.R., Hagmann, S.H., Ryan, E.T., Larocque, R.C. & Earl, A.M. (2023) Travel-associated extensively drug-resistant typhoid fever: A case series to inform management in non-endemic regions. *Journal of Travel Medicine*, 30, taac086.

Qadri, F., Khanam, F., Liu, X., Theiss-Nyland, K., Biswas, P.K., Bhuiyan, A.I., Ahmmed, F., Colin-Jones, R., Smith, N. & Tonks, S. (2021) Protection by vaccination of children against typhoid fever with a Vi-tetanus toxoid conjugate vaccine in urban Bangladesh: A cluster-randomised trial. *The Lancet*, 398, pp.675–684.

Qamar, F.N., Qureshi, S., Qamar, Z.H., Yousafzai, M.T., Qazi, I., Irfan, S., Iqbal, N.T., Amalik, Z., Hotwani, A. & Ali, Q. (n.d.) Longevity of immune response following a single dose of typhoid conjugate vaccine (Typbar-TCV) against *Salmonella Typhi* among children in Hyderabad, Pakistan.

Qamar, F.N., Yousafzai, M.T., Qazi, I., Qureshi, S., Bar-Zeev, N., Sultana, S., Jawwad, M., Hotwani, A., Irfan, S. & Memon, M.A. (2025) Trends of enteric fever and emergence of extensively drug-resistant typhoid in Pakistan: Population-based laboratory data from 2017–2019. *Open Forum Infectious Diseases*. Oxford University Press US, ofaf106.

Rasheed, F., Saeed, M., Alikhan, N.-F., Baker, D., Khurshid, M., Ainsworth, E.V., Turner, A.K., Imran, A.A., Rasool, M.H. & Saqalein, M. (2020) Emergence of resistance to fluoroquinolones and third-generation cephalosporins in *Salmonella Typhi* in Lahore, Pakistan. *Microorganisms*, 8, 1336.

Tahir, M.J., Zaman, M., Saffi, J., Asghar, M.S., Tariq, W., Ahmed, F., Islam, R., Farooqui, U.S., Ullah, I. & Saqlain, M. (2023) Knowledge, attitudes, and practices of the general population of Pakistan regarding typhoid conjugate vaccine: Findings of a cross-sectional study. *Frontiers in Public Health*, 11, 1151936.

Tharwani, Z.H., Kumar, P., Salman, Y., Islam, Z., Ahmad, S. & Essar, M.Y. (2022) Typhoid in Pakistan: Challenges, efforts, and recommendations. *Infection and Drug Resistance*, pp.2523–2527.

Thobani, R.S., Yousafzai, M.T., Sultana, S., Kazi, A.M., Jan, M., Rafey, A., Khan, A., Irfan, S., Ujjan, I.U. & Brown, N. (2022) Field evaluation of typhoid conjugate vaccine in a catch-up campaign among children aged 9 months to 15 years in Sindh, Pakistan. *Vaccine*, 40, pp.5391–5398.