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Foodborne Salmonellosis: Global Trends, Antibiotic Resistance, and Public Health Implications with a Focus on Baluchistan, Pakistan

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Abstract: *Salmonellosis, a significant zoonotic and foodborne disease, continues to pose severe public health challenges globally. Caused primarily by Salmonella enterica, this infection results in gastrointestinal illnesses and typhoid fever, with growing concern due to emerging antibiotic-resistant strains. Despite global progress in hygiene, food safety, and vaccination strategies, countries like Pakistan remain highly affected, particularly in underdeveloped regions such as Baluchistan. Factors including poor sanitation, limited surveillance, inadequate diagnostic facilities, and irrational antibiotic use in both humans and animals contribute to the persistence and spread of resistant Salmonella strains. The high prevalence of Salmonella infections in Pakistan, including extensively drug-resistant (XDR) strains, demands urgent public health attention. This review consolidates global trends, mechanisms of resistance, zoonotic transmission routes, and public health implications, while highlighting critical gaps in data and infrastructure in Baluchistan. Strengthening one-health surveillance, public education, food vendor training, and vaccine coverage are essential strategies for combating salmonellosis in endemic regions.*

Keyword: *Foodborne,* Salmonella enterica*, One Health Perspective, Zoonotic, Food science, Baluchistan*

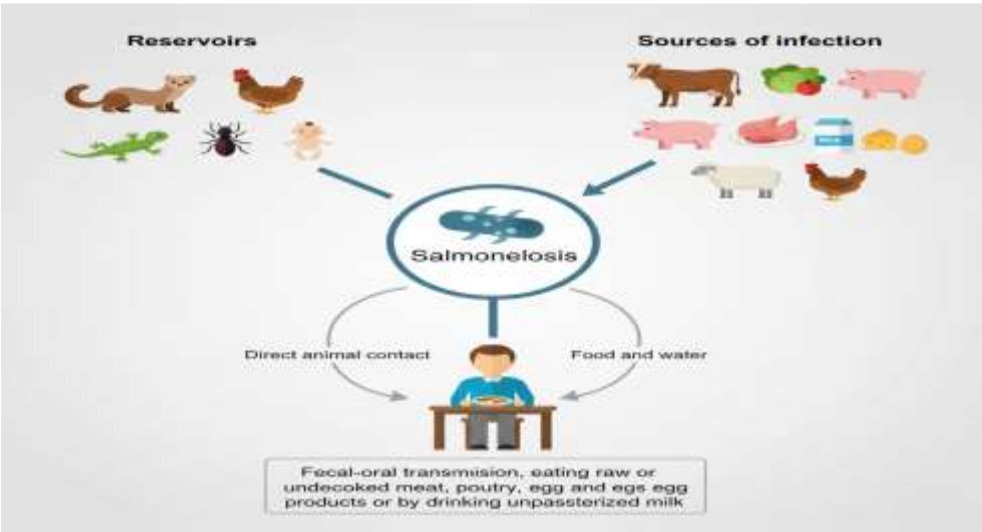
1. Introduction

Foodborne diseases are among the leading global health concerns. Among bacterial zoonoses, salmonellosis is particularly important because of its high burden on both public health and economic point of view (Pal *et al*., 2024). The World Health Organization (WHO) identifies Salmonella as one of the four leading causes of diarrhea worldwide. According to the Centers for Disease Control and Prevention (CDC), Salmonella infects approximately 1.35 million people each year in the United States, resulting in about 420 deaths annually. (Lamichhane *et al*., 2024). The economic burden of Salmonella ranks third among 14 foodborne pathogens, with an annual cost of about $3.3 billion (Galán-Relaño *et al*., 2023). *The bacterial pathogen Salmonella enterica is responsible for a number of illnesses, ranging from mild gastroenteritis to more serious systemic infections like typhoid fever. A major cause of foodborne illnesses worldwide, S. enterica infections are thought to cause between 200 million and over 1 billion infections annually, including approximately 93 million cases of gastroenteritis and 155,000 deaths. These infections are mostly linked to tainted food and water sources. (Lozano-Aguirre et al., 2025).* Salmonella Enteritidis (SE), which accounts for 13–19% of isolates and 26-34%

of reported outbreaks each year, has long been one of the top three serovars in the US that cause human (Wright *et al*., 2016). Contaminated eggs in commercial layer flocks are usually the consequence of illnesses contracted from environmental Salmonella that persists over time, especially those linked to the serovar Enteritidis.(Andino and Hanning, 2015). Despite the significant investments made by both industry and governments, foodborne pathogens continue to pose a serious threat to public health (Newell *et al*., 2010). *Salmonella enterica* is a major contributor to zoonotic infections, infecting poultry's digestive tracts and contaminating meat and egg products during slaughter. As a result, it poses a serious risk to human health by spreading to humans through the food chain. (Xie *et al*., 2024). Comprising over 2500 serovars, *Salmonella enterica* causes typhoid fever and gastroenteritis, with Non-Typhoidal Salmonella (NTS) responsible for the latter (Teklemariam *et al*., 2023). Antimicrobial resistance poses a significant global threat in both animal and human medicine, primarily due to treatment failure and the risk of transmitting resistant pathogens, including their use as growth promoters in animal production and excessive clinical application. Antimicrobial resistance in human illnesses has been connected to the use of antibiotics in agriculture, and eating certain foods is thought to be a possible way for people to contract bacteria and genes that are resistant to antibiotics. (Patel *et al*., 2024). According to surveillance statistics, the percentage of Salmonella isolates that are resistant to at least one antibiotic is rising. It went from 16% in 1979–1980 to 24% in 1984–1985 and 29% in 1989–1990. Additionally, several serotypes have shown an increasing tendency of multiple resistance to antibiotics, including ampicillin, streptomycin, sulfonamides, ampicillin, and chloramphenicol or kanamycin (Steveyan *et al*., 2004). The bacterium that causes typhoid fever is *Salmonella enterica* serovar Typhi, or S. Typhi. The cause of paratyphoid fever is *Salmonella enterica* serovar Paratyphi, or S. Paratyphi. Type C is the rarest of the three S. Paratyphi kinds, which are A, B, and C. Typhoid fever is thought to kill 150,000 people and cause 11 to 21 million cases worldwide each year. Paratyphoid fever causes roughly 6 million cases and over 50,000 deaths each year (Gouda, 2024). In developing countries like Pakistan, typhoid is endemic, with a prospective surveillance study across five Asian countries reporting an annual incidence of 412.9 per 100,000 person-years, the second highest studied nation. In Pakistan’s pediatric population, the incidence is 170/100,000 annually, driven by persistent poverty, poor hygiene, and inadequate sanitation (Siddiqui *et al*., 2015).

According to WHO data, a broadly drug-resistant (XDR) typhoid fever endemic in Pakistan, from November 2016 to December 2018, affected over 5200 individuals. which began in 2016, saw a substantial amount of S. typhi isolates from confirmed cases of enteric fever in Quetta, Baluchistan. Exhibiting multi-drug resistance (MDR) and XDR profiles, rising concern about the potential spread of these strains due to frequent domestic travel (Nasir *et al*., 2020). Effective Management strategies to curb antibiotic resistance include raising awareness, regulating non-antibiotic use in food animal production systems, improving diagnostic procedures, and enhancing microbiological infrastructure and personnel (Siddique *et al*., 2021). These interventions are critical for reducing antimicrobial resistance and strengthening the healthcare system, particularly in underserved regions like Baluchistan.

1.2. Global burden and epidemiology of salmonellosis



Salmonellosis is a principal cause of foodborne illness globally. In 2000, enteric fever was estimated to cause 22 million cases and 200,000 deaths primarily in developing countries. The incidence and mortality rate of enteric fever vary from region to region, with mortality reaching up to 7% despite antibiotic therapy (Eng *et al*., 2015)**.** Africa, Asia, Central and South America, the Middle East, and Eastern and Southern Europe are all endemic for the disease, which has low incidence rates of more than 10 cases per 100,000. Many Asian nations, including China, India, Vietnam, Pakistan, and Indonesia, have high rates of enteric fever. where the annual incidence rates exceed 100 cases per 100,000 inhabitants (Hamdulay *et al*., 2024). Age-standardized incidence rates (ASR) of invasive non-typhoidal Salmonella (iNTS) and typhoid and paratyphoid fever exhibited differing patterns between 1990 and 2021. The worldwide ASR for paratyphoid and typhoid fever in 2021 was 127.77.(95% CI: 99.50-163.19), down from 461.34 (95% CI: 370.05-574.72) in 1990, with an Estimated Annual Percent Change (EAPC) of-4.15 (95% CI: -4.45 to -3.85), indicating a significant decline. conversely, ASR for iNTS in 2021 was 7.21 (95% CI: 5.83-8.64), up from 5.986 (95% CI: 4.937-7.034) in 1990, with an EAPC of 0.45 (95% -0.32 to 1.22), reflecting an upward trend (Shi and You, 2025).

In 2021, the global age-standardized disability-adjusted life years DALYs for typhoid and paratyphoid fever were 115.26 (95% CI: 59.32-198.47), compared to 301.362 (95% CI: 158.155-519.105) in 1990, with an EAPC of -2.99 (95% CI: −3.23 to −2.74), showing a decreasing burden. In contrast, DALYs for iNTS in 2021 were 69.14 (95% CI: 39.70–111.21) compared to 61.696 (95% CI: 35.538−98.757) in 1990, with an EAPC of 0.52 (95% CI: −0.23 to 1.27), indicating an increase in burden (Shi and You, 2025). Similarly, the universal age-standardized mortality rate for typhoid and paratyphoid fever in 2021 was (95% CI: 0.78–2.54), down from 3.916 (2.036-6.739) in 1990, with an EAPC of -2.70 (-2.85 to -2.55), for iNTS the mortality rate in 2021 was 0.88 (95% CI: 0.52-1.41), compared to 0.865 (95% CI: 0.500-1.357) in 1990, with an EAPC of 0.40 (95% CI: −0.02 to 0.83), reflecting a slight upward trend (Shi and You, 2025).

Table 1: Global trends in the age-standardized incidence rate (ASR) and DALYs for typhoid paratyphoid fever and invasive non-typhoidal salmonellosis (iNTS) from 1990 to 2021.

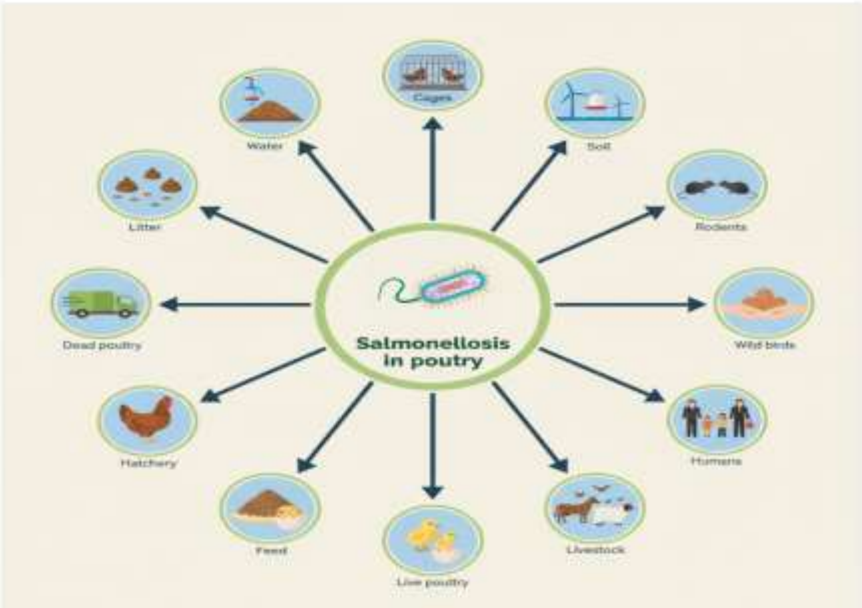
Metric	Pathogenic group	1990 Estimate	2021 Estimate	EAPC	Trend
ASR (100,0000	Typhoid/paratyphoid	461.34	127.77	-4.15	Significant Decrease

	Invasive NTS	5.99	7.21	+0.45	Slight Increase
DALYs (100,000)	Typhoid/paratyphoid	301.36	115.26	-299	Significant decrease
	Invasive NTS	61.70	69.14	+0.52	Slight Increase

A recent comprehensive trend analysis highlights the divergent epidemiological paths of typhoidal salmonellosis and iNTS over the past three decades, as summarized in Table 1. While control measures have successfully reduced the global burden of enteric fever, iNTS presents an emerging concern (Shi *et al*., 2025).

1.3. Zoonotic transmission and food chain contamination

Although transovarial transmission has been documented in poultry, the fecal-oral route is the main way that Salmonellae spread in humans. Consuming food or water with another person or animal, including raw fruits and vegetables, is the most frequent way for humans and animals to contract the disease. (Oludairo *et al*., 2023). *Salmonella enterica* subspecies *enterica* serovar Typhimurium is responsible for large-scale mortality in free-living birds, though some wild



birds are asymptomatic carriers, posing risks to wildlife and humans (Perez *et al*., 2025). S. Typhimurium can create biofilms on a variety of surfaces that come into contact with food, and these biofilms can persist for extended periods of time, with the added challenge of being difficult to remove (Naughton *et al*., 2024). Typhoidal serovars, including S. Typhi, S. Sendai, and S. Paratyphi typhi, are human-specific and not carried by animals (Pal *et al*., 2024). In the US, the prevalence of S. Enteritidis in chicken products increased from 0.45% to 1.5% between 2002, highlighting poultry as a significant risk factor for human infection. 10% of human cases of salmonellosis are linked to eating beef, while 34%, 25%, and 16% of cases are caused by chicken, pigs, and beef, respectively (Lamichhane *et al*., 2024).

Figure.2. Salmonellosis in Poultry

1.4. Antibiotic Resistance in Salmonella: Global Trends and Mechanisms

Salmonella enterica is one of the important causes of foodborne disease globally. In 2019, non-typhoidal Salmonella (NTS), Salmonella Typhi, and Salmonella Paratyphi caused 215,000, 182,000, and 23,300 deaths, respectively, according to the Global Burden of Disease (GBD) Study. The emergence of antimicrobial-resistant *S. enterica* has increased the disease burden, particularly resistance to critically important antimicrobials like fluoroquinolones and third- and fourth fourth-generation cephalosporins (Wang *et al*., 2025). Since the 1960s, resistance to antibiotics such as chloramphenicol, ampicillin, and trimethoprim-sulfamethoxazole has risen in countries like the UK, the US, and Saudi Arabia. Multidrug-resistant (MDR) strains complicate treatment and pose significant public health concerns (Nazir *et al*., 2025). Ceftriaxone, a broad-spectrum cephalosporin, is commonly used to treat invasive *Salmonella* infections, but ceftriaxone-resistant strains have emerged in humans and livestock globally (Fontana *et al*., 2025). The Salmonella Panama PN2 strain is resistant to clinically relevant antibiotics such as ceftriaxone, cefotaxime, cefepime, ceftiofur, and aztreonam, but it is still susceptible to carbapenems, aminoglycosides, and colistin. It is also less susceptible to ciprofloxacin and enrofloxacin (Fontana *et al*., 2025). ATP-binding cassette (ABC), small multi-drug resistance (SMR), drug inactivation through enzyme modifications such as acetylation, phosphorylation, and adenylation, and efflux pumps are some of the mechanisms that drive antimicrobial resistance in Salmonella, multi-drug and toxic compound extrusion (MATE), major facilitator superfamily (MFS), and resistance nodulation cell division (RND) families (Punchihewage-Don *et al*., 2024). Chromosomal resistance arises from a mutation in a gene that encodes a drug target or transport system (Ugboko and De, 2014).

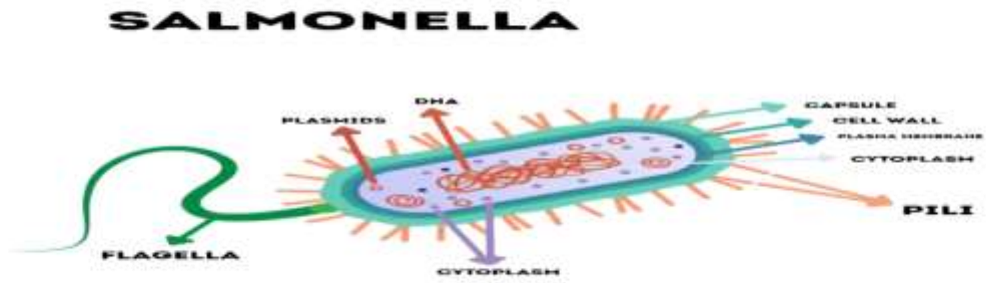


Figure.3. Salmonella

1.5. Public health impacts of resistant Salmonella strains

Antimicrobial resistance in *Salmonella* can lead to treatment failures, increasing morbidity and mortality (Yan *et al*., 2004). The rise in gastroenteritis and sepsis caused by resistant strains, particularly Typhimurium and its monophasic variants, *S. infants* and *S. Kentucky*, is a global concern (Parisi *et al*., 2018). The WHO considered antibiotic-resistant foodborne pathogens like Salmonella a major public health challenge, exacerbated by antibiotic misuse food food-producing animals. Without intervention, antibiotic resistance could cause 10 million deaths and 100 trillion in economic loss by 2050 (Noto, 2022). Resistant *S.* Typhimurium DT104 infections are associated with higher hospitalization rates than pan-susceptible strains, particularly in the USA, where over 15% of isolates link to septicemia (Hur *et al*., 2012). However, a 1998 UK study found that MR *S. typhimurium* DT 104 was not more invasive than other common serotypes (Threlfall, 2002). Relapse, severe consequences (typhoid encephalopathy, gastrointestinal hemorrhage, intestinal perforation), or death occur in about 10% of patients, frequently as a result of ongoing infections by antibiotic-resistant strains (Afolami and Onifade, 2018).

1.6. Situation in Pakistan: prevalence, Resistance, and challenges

South Asia exhibits high *Salmonella* prevalence, with Bangladesh reporting the highest at 34.23% (95% CI: 23.73-46.56) and Pakistan 26.15% (95% CI: 15.04-41.47) (Talukder *et al*., 2023). Enteric fever caused by *Salmonella enterica* serovar typhi is endemic in Pakistan and ranks as the fourth leading cause of death globally, causing 128,000 to 161,000 deaths annually (Ullah *et al*., 2025). In Pakistan, the incidence rate for children between the ages of 2 and 5 is 573.2 per 100,000 annually. (Ullah *et al*., 2025). The Poultry sector, Pakistan's second-largest industry, significantly contributes to salmonella infections due to contaminated poultry products (Younus *et al*., 2021). A study looked at Salmonella's pattern of antibiotic resistance. Blood culture isolates containing the enteric serotypes Typhi and Paratyphi were obtained from labs spread throughout Pakistan. Another study reveals that S.Enterica serotypes Typhi and Paratyphi in blood culture isolates across Pakistan reported resistance rates to S. Typhi to Ampicillin (74%), Ciprofloxacin (68%), Chloramphenicol (66%), third-generation Cephalosporins (59%), and Azithromycin 1.6%. S. Paratyphi resistance rates were 36% (Ciprofloxacin), 20% (Ampicillin), 6% (Azithromycin), 3.3% (Chloramphenicol), and 2.7% Cephalosporin). Overall, 35% isolates were XDR 11% were MDR (Naseer *et al*., 2025). Azithromycin and Meropenem showed 100% sensitivity to S.Typhi (Javed *et al*., 2024). The overuse of antibiotics in farm animals is causing foodborne bacteria to acquire resistance genes (Saeed *et al*., 2019). Antibiotic residues and resistant bacteria in animals' manure further drive resistance spread (A. Qamar *et al*., 2020). Inadequate hygiene, poor sanitation, and unregulated antimicrobial use are major drivers in low-and middle-income countries (Kumar *et al*., 2025). Risk factors, such as inadequate water supplies, overcrowding, poor sanitation, and substandard living conditions, exacerbated typhoid incidence in Pakistan, limited vaccine coverage due to restricted access and lack of awareness, compounded the situation (Tharwani *et al*., 2022). Surveillance challenges include a lack of quality diagnostic laboratories in rural and underprivileged areas and the issues of unskilled staff and inappropriate equipment (Ahmad *et al*., 2024).

Table 2: Reported antimicrobial resistance rates in *Salmonella enterica* serovars Typhi and Paratyphi from human isolates in Pakistan.

Antimicrobial Class	Antibiotic Agent	*S.* Typhi Resistance Rate (%)	*S.* Paratyphi Resistance Rate (%)
Aminopenicillins	Ampicillin	74%	20%
Fluoroquinolones	Ciprofloxacin	68%	36%
Phenicol	Chloramphenicol	66%	3.3%
3rd Gen. Cephalosporins	Ceftriaxone/Cefotaxime	59%	3.3%
Macrolides	Azithromycin	1.6%	2.7%
Carbapenems	Meropenem	0% (Sensitive)	-

(Naseer et al. 2025; Javeed et al. 2024)

1.7. Focus on Baluchistan: Risk Factors, Data Gaps, and Socioeconomic Issues

Typhoid fever is a significant public health issue in Quetta, Baluchistan, causing substantial morbidity and mortality, particularly among children from low socioeconomic backgrounds (Butt *et al*., 2024; K. Hussain *et al*., 2017). Prevalence is high in rural areas due to poor hygiene and economic conditions, with increased transmission during the rainy season due to contaminated water sources (Tariq *et al*., 2025). Limited epidemiological data in Balochistan and Khyber Pakhtunkhwa hinder effective control, necessitating a robust surveillance system linked with clinical data to identify risk factors and develop targeted policies (F. N. Qamar *et al*., 2025). The lack of published research from Quetta, where the typhoid cases are high due to weak health facilities and delayed reporting is concerning, especially as young adults increasingly present osteoarticular complication linked to typhoid (Khan *et al*., 2025) Ready-to-eat street food in Quetta is highly contaminated, with pathogenic of *Salmonella* serotypes, underscoring The need for training street food vendors on food safety (Raza *et al*., 2021).

Table 3: Risk Factors and Socioeconomic Drivers for Typhoid in Pakistan and Baluchistan

Category	**Specific Risk Factor / Driver**	**Impact and Context**
Infrastructure and Environment	Inadequate Water Supply	Contaminated water is used for drinking and irrigation; easy contaminated during the rainy season.
	Poor Sanitation	Lack of basic hygiene; human fecal contamination of food and environment.
	Overcrowding	Facilitates rapid person-to-person transmission, especially in urban slums.
Healthcare System	Unregulated Antimicrobial Use	Misuse in clinical settings and in food animals as growth promoters.
	Weak Diagnostic Capacity	Unavailability of labs in rural areas, unskilled staff, improper

		equipment, leading to misdiagnosis.
	Low Vaccine Coverage	Limited access to immunization; lack of knowledge and awareness about TCV.
Socioeconomics	Poverty and Low Economic Status	40% population is below the poverty line; substandard living circumstances.
	Financial Instability	The entire healthcare system has limited funding ($151 million), restricting control efforts.
Specific to Baluchistan	Limited Research and Data	"Major limitation... limited availability of epidemiological data."
	Weak Health Facilities	"Weak health facilities and untimely reporting systems" in Quetta.
	Food Safety Issues	RTE street food "highly contaminated" with pathogenic *Salmonella* serotypes.

The high incidence of typhoid in Pakistan and Baluchistan is not driven by a single factor, but by a complex web of interconnected infrastructural, healthcare, and socioeconomic challenges, which are synthesized in Table 3.

1.8. Prevention and Control Strategies: Global and Local Approaches

Biosecurity measures are crucial for minimizing environmental *Salmonella* contamination in animal houses, through prevention is challenging due to persistent fecal-oral transmission and asymptomatic shedding by healthy animals (Mkangara, 2023). Whole-genomic sequencing (WGS) is increasingly used for routine surveillance and outbreak detection in countries like the UK and the USA (Arya *et al.*, 2017). Typhoid fever cases have decreased in Western Europe and North America as a result of municipal water treatment, dairy pasteurization, and precautions against human fecal contamination of food. Similar decreases have been observed in areas of Asia and Latin America as a result of improved sanitation and economic prosperity (Buzilă *et al.*, 2025). European regulations emphasize sanitization, handwashing, proper refrigeration, cooking, and separation of raw and cooked foods to ensure food safety (Zizza et al., 2024; Kirti *et al.*, 2024). In Pakistan, the lack of reliable food safety data highlights the need for improved protocols (Das *et al.*, 2018). Although it is a crucial step, the typhoid conjugate vaccine (TCV) has not yet been fully included in Pakistan's regular immunization regimen (Abdullah *et al.*, 2025). Two vaccines, Ty21a (oral) and Vi (parenteral), are available for children aged 2 years and older (A. Hussain *et al.*, 2019). Contaminated water, weak socioeconomic conditions, and condition and limited healthcare funding ($151 million) exacerbate the spread of typhoid in Pakistan (Irfan *et al.*, 2024).

1.9. Future Research Directions and One Health Perspective

Currently, diagnostic methods for typhoid, such as bacterial culture and the Widal test, date back to the 19th century (Andrews and Ryan, 2015). The Salmonella typhi Ty21a oral vaccine is widely used but requires multiple doses for long-term protection (Zhang *et al.*, 2008). existing vaccines target *S. Typhi and S. Paratyphi A*, despite their clinically indistinguishable disease, necessitating effective protection against both serovars (MacLennan *et al.*, 2014). A trivalent glycoconjugate vaccine targeting *S. Typhimurium, S. Enteritidis,* and *S. typhi* is under development (Excler *et al.*, 2025). Animal models have advanced understanding of human Salmonellosis disease and evaluate new vaccines (Tsolis *et al.*, 2011; Higginson *et al.*, 2016).

The One Health approach, recognizing the interconnectedness of human, animal, and environmental health, is highly effective for addressing zoonotic diseases (Aqeel *et al*., 2024). *Salmonella* resistance pattern is similar to human and ruminant isolates, though the contribution of cattle, sheep, and goats resistance is relatively low (García-Díez *et al*., 2024). The One Health perspective underscores the link between NTS distribution, Antimicrobial Resistance, and animal-derived food (Chen *et al*., 2024). Preventing vertical transmission of *S. Enteritidis* requires a multidisciplinary approach addressing human, animal, economic, and environmental health (Liu *et al*., 2023).

1.10. Conclusion

The prevalence of *Salmonella* is notably high in Pakistan, especially in Balochistan, where typhoid fever contributes to a significant number of illnesses and deaths. Most of the available data focus on the provincial capital, Quetta, while rural areas remain underreported despite having a high incidence-particularly during the rainy season. This increased burden is largely due to the shortage of clean water; in many rural communities, people are forced to consume water contaminated with rainwater that may carry *Salmonella,* leading to typhoid outbreaks, and limited access to healthcare services. These factors highlight the urgent need to improve water quality, expand vaccination coverage, and strengthen healthcare infrastructure throughout Baluchistan.

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