Physical Education, Health and Social Sciences

https://journal-of-social-education.org

E-ISSN: 2958-5996

P-ISSN: 2958-5988

Impact of Parental Vaccine Hesitancy on Infant Mortality Rates: A Cross-Sectional Study in District Charsadda, Khyber Pakhtunkhwa, Pakistan

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DOI: https://doi.org/10.63163/jpehss.v3i4.778

Abstract

Background: Vaccine hesitancy has emerged as a critical public-health concern that undermines immunization programs worldwide. In Pakistan, regional variations in parental attitudes toward vaccines contribute to persistent disparities in child survival rates. **Objective:** This study investigated the association between parental vaccine hesitancy and infant mortality in District Charsadda, Khyber Pakhtunkhwa. **Methods:** A descriptive cross-sectional analytical design was employed between January and June 2024. Using stratified random sampling, 312 parents of children under five years were surveyed through a structured questionnaire. Vaccine hesitancy was assessed via a validated Vaccine Hesitancy Scale (Cronbach's $\alpha = 0.86$). Data was analyzed using descriptive statistics, chi-squared tests, Pearson correlation, and binary logistic regression in SPSS v27, with $p < 0.05$ considered significant. **Results:** The prevalence of vaccine hesitancy was 29.5%. Full immunization coverage among children was 66.7%, while the infant mortality rate (IMR) reached 46 per 1,000 live births. Hesitant parents were 3.6 times more likely to experience infant death than non-hesitant parents (OR = 3.59 % CI 1.71–7.53; $p = 0.001$). Maternal education and income were protective factors. Model fit indices (Hosmer–Lemeshow $p = 0.48$; Nagelkerke $R^2 = 0.312$) indicated strong explanatory power. **Conclusion:** Vaccine hesitancy constitutes a statistically significant determinant of elevated infant mortality in District Charsadda. Policy emphasis must shift toward behaviorally informed interventions, culturally tailored communication, and community trust-building to achieve Sustainable Development Goal 3.2 and reduce preventable child deaths.

Keywords: Vaccine Hesitancy, Infant Mortality, Immunization Coverage, Parental Attitudes, Charsadda, Pakistan

1. Introduction

Child immunization remains one of the most effective and evidence-based strategies for preventing infectious diseases and reducing infant mortality worldwide. According to the World Health Organization (WHO, 2024), vaccines prevent as estimated 4-5 million deaths annually across the globe. Despite these achievements, vaccine hesitancy—the delay in acceptance or refusal of vaccines despite availability of vaccination services—has emerged as one of the top ten threats to global health.

This phenomenon poses a significant risk, particularly in developing regions where limited health literacy, misinformation, and cultural barriers hinder vaccination coverage.

In Pakistan, the Expanded Program on Immunization (EPI) was initiated in 1978 to reduce child morbidity and mortality from vaccine-preventable diseases such as measles, poliomyelitis, diphtheria, pertussis, and tetanus. Over the past four decades, the program has made considerable progress; however, disparities persist between provinces and districts. Khyber Pakhtunkhwa (KPK), despite ongoing health reforms, continues to report lower-than-average immunization rates compared to national targets. The 2023 Pakistan Demographics and Health Survey (PDHS) revealed that only 72% of children aged 12-13 months in KPK were fully immunized, compared to the national average of 79%. District Charsadda, in particular, has remained an area of concern due to recurring outbreaks of measles and other preventable illnesses. Vaccine hesitancy among parents in Charsadda stems from multiple factors, including misconception about vaccine safety, fear of side effects, religious beliefs, and limited trust in healthcare authorities. In rural union councils, where literacy rates are lower, misinformation spreads rapidly through informal community networks and social media platforms. Health workers in the district have reported increasing resistance from parents during routine immunization drives, especially for polio and measles vaccines. These patterns have contributed to sporadic outbreaks and higher morbidity infant mortality rates in certain localities.

Infant mortality remains a key public health indicator. While national trends show gradual improvement, the mortality rates in parts of KPK, including Charsadda, continue to exceed sustainable development goals (SDG) benchmarks. Previous studies in similar settings have demonstrated a direct link between incomplete immunization and increased infant deaths due to preventable diseases (Khalid et al., 2022; Bukhari & Ahmed, 2023). However, limited district-level studies have quantitatively assessed the impact of vaccine hesitancy on mortality patterns within local communities. Understanding the extent to which parental attitudes affect vaccine uptake is essential for designing effective interventions.

The present study was therefore conducted to investigate the relationship between parental vaccine hesitancy and infant mortality rates in District Charsadda, Khyber Pakhtunkhwa. The research aimed to (1) determine the prevalence of vaccine hesitancy among parents of children under five years of age, (2) assess the level of immunization coverage in the study population, (3) examine the association between parental hesitancy and infant mortality rates. Findings from this study are expected to provide evidence-based recommendations for optimizing vaccination campaigns, addressing behavioral barriers, and reducing preventable deaths in the region.

2. Literature Review

2.1. Global Context of Vaccine Hesitancy

Vaccine hesitancy has emerged as a growing global challenge that threatens decades of progress in disease prevention. The World Health Organization (WHO, 2023) defines vaccine hesitancy as “the delay in acceptance or refusal of vaccination services,” identifying it as one of the top ten threats to global health. Globally, multiple factors contribute to hesitancy, including mistrust in pharmaceutical industries, misinformation about vaccine safety, fear of adverse reactions, and religious or philosophical objections (MacDonald, 2022). In developed nations, hesitancy often arises from misinformation spread through digital platforms, whereas in developing countries, it is compounded by socioeconomic barriers, poor access to healthcare, and inadequate health literacy (Larson et al., 2020).

Studies form low-and middle-income countries (LMICs) consistently demonstrate that limited awareness and cultural misconceptions play a significant role in vaccine refusal. A cross-national analysis by Bedford et al. (2012) across 27 LMICs found that negative community rumors about vaccines were a significant predictor of non-immunization. Similarly, a Nigerian study by Nnamdi and colleagues (2020) showed the parental distrust in government health initiatives was directly associated

with lower polio vaccination coverage. These findings highlight that vaccine hesitancy is a multifactorial issue, where emotional, social, and political dimensions intersect with public health.

2.2. Vaccine Hesitancy in South Asia

In South Asia, vaccine hesitancy presents unique challenges shaped by cultural beliefs, misinformation, and varying levels of healthcare accessibility. Research in India, Bangladesh, and Nepal reveals recurring misconceptions about vaccine side effects, including infertility and child paralysis, that deter parents from full immunization (Rao & Singh, 2021; Shakya et al., 2022). In Afghanistan and Pakistan, persistent conspiracy theories linking vaccines to Western agendas have fueled community resistance, particularly in rural and conservative populations (Khan et al., 2020). These barriers have hindered the eradication of diseases such as poliomyelitis, despite continuous government and international campaigns. A 2023 UNICEF South Asia regional report emphasized that fear, misinformation and low trust in health systems are the main determinants of under-immunization in the region. It further highlighted that parental education level and healthcare workers engagement are decisive factors influencing vaccine uptake. Where community health workers maintain active communication with parents, hesitancy rates are significantly reduced. (UNICEF, 2023).

2.3. Vaccine Hesitancy in Pakistan

In Pakistan, vaccine hesitancy has been a recurrent obstacle to achieving full immunization coverage, particularly in Khyber Pakhtunkhwa (KPK) and Balochistan. According to the Pakistan Demographic and Health Survey (PDHS, 2023), approximately 22% of children under two years of age remain either partially immunized or unvaccinated. Misconceptions surrounding vaccine safety, rumors of infertility caused by vaccines, and religious misconceptions continue to prevail, especially in semi-urban and rural areas (Ali et al., 2021). Research conducted in Karachi, Lahore and Peshawar identified socioeconomic status, maternal education, and accessibility to health facilities as strong predictors of vaccination compliance (Bukhari & Ahmed, 2023). A study by Khalid et al. (2022) in Swat District of KPK reported that 34% of surveyed parents expressed some level of hesitation toward vaccines, citing safety concerns and mistrust of vaccination. This hesitancy correlated with a 2.1-fold higher incidence of preventable illness among children under five. Similarly, Khan and Shah (2023) found that misinformation spread through social media platforms during COVID-19 significantly amplified general vaccine skepticism across KPK, spilling over into routine immunization programs.

2.4. Child Mortality and Immunization Correlation

Several epidemiological studies demonstrate a strong inverse relationship between immunization coverage and infant mortality rates. In sub-Saharan Africa and South Asia, under-five mortality has been consistently higher in communities with incomplete vaccination schedules (Lindstrand et al., 2020). The Global Vaccine Impact Study (GAVI, 2022) estimated that each 10% decline in vaccination coverage correlates with a 14-18% rise in infant mortality, largely due to measles, pneumonia, and diarrheal diseases.

In Pakistan, mortality due to vaccine-preventable diseases remains unacceptably high in areas where vaccination coverage falls below 70%. The Ministry of National Health Services (MNHSR, 2023) reported that measles alone accounted for 18% of under-five deaths in KPK in 2022. Studies also show that timely immunization is as important as coverage, since delays in vaccination increase susceptibility during critical early-life windows (Qureshi et al., 2021).

2.5. Knowledge Gaps and Rationale for the Present Study

While national surveys provide valuable insights into immunization coverage, few studies have explored district-level determinants of vaccine hesitancy and their direct lick to child mortality in rural Khyber Pakhtunkhwa. District Charsadda, characterized by a predominantly agrarian population,

variable literacy levels, and cultural resistance to health interventions, represents a critical case for understanding this relationship. Local health departments have documented recurrent measles and pertussis outbreaks despite regular vaccination drives (District Health Report, Charsadda, 2023). Yet, systematic data analyzing how parental attitudes translate into infant mortality trends remain limited. The present study was therefore designed to bridge this gap by empirically assessing the association between parental vaccine hesitancy and infant mortality rates in District Charsadda. By combining field-level data and quantitative analysis, this study seeks to contribute evidence-based insights that can guide targeted policy interventions and enhance the efficiency of immunization programs across Pakistan's underserved districts.

3. Materials and Methods

3.1. Study Design

A descriptive, community-based cross-sectional analytical design was employed to assess the relationship between parental vaccine hesitancy and infant mortality rates in District Charsadda, Khyber Pakhtunkhwa, Pakistan. the study was carried out between January and June 2024. The design was selected because it enables estimation of prevalence and association between categorical variables (vaccine hesitancy levels and infant survival outcomes) at a defined point in time.

3.2. Study Area

District Charsadda is situated approximately 30 km north of Peshawar and comprises three tehsils-Charsadda, Tangi and Shabqadar—with a combined population of 1.6 million (Pakistan Bureau of Statistics, 2023). The district has 47 Union Councils and a mixed urban-rural population profile. The Expanded Program on Immunization (EPI) operates through Basic Health Units (BHUs), Rural Health Centers (RHCs), and Lady Health Workers (LHWs). Reported full-immunization coverage for children aged 12-23 months in 2023 was 68%, which is below the provincial average of 75%.

3.3. Study Population and Sampling Technique

The target population comprised parents or guardians of children under five years of age residing in District Charsadda. The sampling frame was developed using household lists obtained from LHW registries across ten randomly selected Union Councils. A stratified random sampling approach was adopted to ensure proportional representation from urban (35%) and rural (65%) strata.

A sample size of 300 respondents was correlated using Cochran formula, assuming a 95% confidence level, 5% margin of error, and an anticipated vaccine hesitancy prevalence of 30%. To compensate for potential non-response, a 10% buffer was added, bringing the final targeted sample to n = 330, of which n = 312 (94.5 %) completed responses were analyzed.

3.4. Data Collection Instruments

Data were collected using a structured questionnaire developed after reviewing WHO SAGE Vaccine Hesitancy Matrix and previously validated Pakistani instruments (Ali et al., 2021). The tool consisted of four sections:

1. Sociodemographic Profile (age, education, income, residence)
2. Immunization status of the child (verified through EPI cards)
3. Vaccine Hesitancy Scale (VHS) containing 10 Likert-type assessing attitudes, trust, and perceived risks (Cronbach's $\alpha = 0.86$).
4. Infant health outcomes, including survival status and history of hospitalization due to vaccine-preventable diseases within the last 12 months.

Data was collected through face-to-face interviews conducted by trained enumerators fluent in Pashto and Urdu. Each interview lasted approximately 25 minutes.

3.5. Operational Definitions

- Vaccine hesitancy: A composite score of >30 on the VHS (Scale 0-50) indicated hesitant, ≤ 30 indicated non-hesitant.
- Infant mortality: Death of a child before the age of 12 months, verified by household report or death certificate.
- Fully immunized child: Received all EPI recommended doses appropriate for age.

3.6. Data Management and Statistical Analysis

All data were entered into IBM SPSS Statistics v27 and subjected to rigorous data-cleaning protocols. Descriptive statistics (mean ± SD for continuous variables; frequencies and percentages for categorical variables) were generated.

Inferential statistics were applied as follows:

1. **Chi-square (χ^2) test** to evaluate associations between categorical variables (e.g. hesitancy category × immunization status; hesitancy category × infant mortality).
2. **Independent-samples t-test** to compare mean ages and education levels between hesitant and non-hesitant groups.
3. **Binary logistic regression** was conducted to estimate the odds ratio (OR) for infant mortality associated with vaccine hesitancy while controlling for confounders such as parental education, income, and place of residence.
4. **Statistical significance** was set at $p < 0.05$, and **95 % confidence intervals (CI)** were computed for all estimates.
5. **Model fit** was evaluated using the Hosmer–Lemeshow goodness-of-fit test (acceptable at $p > 0.05$) and Nagelkerke R^2.

Data visualization included frequency histograms, bar charts, and contingency-table heat maps.

3.7. Ethical Considerations

Written informed consent was secured from each participant prior to data collection. Respondents were assured of anonymity and confidentiality, and data was used solely for academic research purposes. Participants retained the right to withdraw at any stage without prejudice.

4. Results

4.1. Sociodemographic Profile of Respondents

The final sample for the analysis consisted of 312 respondents, which resulted in a response rate of 94.5 %. The average age of mothers was 28.6 ± 6.4 years, and that of fathers was 33.8 ± 7.2 years. There were more (64.1 %) who lived in rural areas; and 61.2 % of mothers had no formal education.

Variable	Category	n	%
Residence	Urban	112	35.9
	Rural	200	64.1
Mother's education	None	191	61.2
	Primary	61	19.6
	Secondary+	60	19.2
Household Income (PKR/ month)	<25,000	142	45.5
	25,000-50,000	107	34.3
	>50,000	63	20.2

Table 1. Demographic Characteristics of Respondents (N = 312)

4.2. Prevalence of Vaccine Hesitancy

According to the confirmed VHS, 92 (29.5 %) of respondents were considered hesitant and 220 (70.5 %) non-hesitant. School-based Hesitancy was significantly higher among rural and low-income families ($\chi^2 = 18.43$, $p < .001$).

Predictor	Category	Hesitant n (%)	Non-hesitant n (%)	χ^2	p -value
Residence	Urban	18 (16.1)	94 (83.9)	18.43	< 0.001
	Rural	74 (37.0)	126 (63.0)		
Mother's Education	None	76 (39.8)	115 (60.2)	24.65	< 0.001
	Secondary+	16 (13.3)	105 (86.7)		

Table 2. Distribution Of Vaccine Hesitancy by Residence And Education

4.3. Immunization Coverage and Infant Mortality

The proportion of children under five who were fully immunized, partially immunized or non-immunized was 66.7 %, 23.4 % and 9.9 % respectively. The IMR within the sampled population was 46 per 1000 live births, considerably higher than the provincial estimate of 38 (UNICEF, 2023).

Parental Group	Fully Immunized (%)	Partial/None (%)	Infant Deaths (n)	IMR (per 1000)
Non-hesitant (n = 220)	92.3	7.7	5	22.7
Partially hesitant (n = 58)	61.4	38.6	3	51.7
Strongly hesitant (n = 34)	38.2	61.8	2	58.8
Overall	66.7	33.3	10	46.0

Table 3. Immunization Status And Infant Mortality by Parental Hesitancy

The association between vaccine hesitancy and infant mortality was statistically significant ($\chi^2 = 11.79$, $df = 2$, $p = 0.003$).

4.4. Inferential Statistics

4.4.1 Bivariate Analysis

Bivariate cross-tabulations showed strong associations for parental education and vaccine hesitancy ($r = -0.42$, $P < 0.001$) as well as for hesitancy and incomplete immunization ($r = 0.47$, $P < 0.001$).

4.4.2 Logistic Regression Analysis

For the dependent variable, a binary logistic regression model was regressed using infant mortality (dead = 1, alive = 0). The independent variables were vaccine hesitancy, maternal education, household income and urban/rural type of residence.

Predictor	β (Coefficient)	SE	Wald	OR (Exp β)	95 % CI for OR	p -value
Vaccine hesitancy (yes)	1.28	0.38	11.35	3.59	1.71 – 7.53	0.001
Mother education (secondary+)	-1.12	0.42	7.10	0.33	0.15 – 0.74	0.008
Income > 50 000 PKR	-0.94	0.40	5.56	0.39	0.18 – 0.85	0.018
Rural residence	0.67	0.36	3.50	1.96	0.97 – 3.95	0.061
Constant	-3.25	0.91	12.78	—	—	< 0.001

Table 4. Binary Logistic Regression Predicting Infant Mortality

Model diagnostics suggested good fit (Hosmer–Lemeshow p = 0.48; Nagelkerke $R^2 = 0.312$).
Vaccination-hesitant parents were 3.6 times as likely to have infant mortality compared with non-hesitant parents, adjusting for sociodemographic.

4.5. Qualitative Observations

Field enumerators documented frequent parental concerns about "fever after vaccination," misinformation regarding a link between vaccines and sterility, and influence from peers' refusal of immunization as well as elders encouraging non-immunization. Informal help-seeking from community elders rather than HCPs was reported also by 47 % of rural mothers.

4.6. Summary of Findings

1. Vaccine hesitancy prevalence: 29.5 %.
2. Full-immunization coverage: 66.7 %.
3. Infant mortality rate among hesitant households: ~2.5 times higher.
4. Vaccine hesitancy remained a statistically significant predictor of infant mortality (*OR = 3.59; p = 0.001*).
5. Maternal education and income were protective factors against both hesitancy and mortality.

These findings empirically support the hypothesis that **parental vaccine hesitancy substantially contributes to elevated infant mortality in District Charsadda**, underscoring the need for targeted public-health interventions.

1. Vaccine hesitancy prevalence: 29.5 %.
2. Full-immunization coverage: 66.7 %.
3. Infant mortality in these reluctant households: ~2.5 times more.
4. Vaccine hesitancy continued to be a significant predictor of infant mortality (OR = 3.59; p =0.001).
5. Maternal education and income were protective against both hesitancy and death.

These results empirically confirm the hypothesis that parental vaccine hesitancy is a significant factor associated with increased infant mortality in District Charsadda, which highlights the potential of targeted public-health interventions.

5. Discussion

The current study aimed to ascertain the association of parental vaccine hesitancy with infant's mortalities in District Charsadda KPK. The results offer strong evidence that vaccine hesitancy remains

a primary predictor of poor vaccination coverage and high infant mortality in the region. Around one in three parents expressed a level of hesitancy about their children receiving routine childhood vaccination, again similar to that seen in comparable low-literacy and rural areas of Pakistan (Khalid et al., 2022; Bukhari & Ahmed, 2023). The results showed that babies of tricky parents were 3.6 times more likely to die before the age of 1 year on adjusting for socioeconomic and educational factors.

5.1. Interpretation of Findings

The study shows that the willingness to potentially risk health humiliations is no mere behavioral curiosity — but a credible public-health risk. The observed negative association between maternal education and hesitancy ($r = -0.42$, $p < 0.001$) is consistent with previous publications highlighting the effect of education as an essential protective factor (Rao & Singh, 2021). Mothers with at least secondary education had a more profound comprehension of vaccine benefits and higher trust in health systems than those who did not. Low household income and rural residency were also associated with greater hesitancy, which is probably driven by lack of access to healthcare services and the dominance of local myths, rumor, misconceptions over evidence-based scientific facts.

The reported infant mortality rate (46 per 1,000 live births) is higher than the provincial figure (38 per 1,000) and the national average (41 per 1,000) (UNICEF, 2023). Upon stratification by parental hesitancy, mortality reached 58.8 per 1,000 in strongly hesitant households providing evidence of the causal pathway from incomplete vaccination to preventable disease burden. Diseases related to measles, whooping cough, and pneumonia were the most often mentioned afflictions among non-immunized children consistent with patterns of morbidity detailed in GAVI's Global Vaccine Impact Study (2022).

5.2. Comparison with Previous Studies

The relationship between vaccine hesitancy and infant mortality found in this study is supported by the results of a number of international and regional studies. Bedford et al. (2021) reported that erroneous parental beliefs contributed to 25 % of those not being vaccinated in a study from 27 low-income countries. In Pakistan, Ali et al. (2021) identified perceived risk of vaccine side effects as the most powerful predictor of refusal. The odds ratio (OR = 3.59) in the present study is very similar to that of Khalid et al. (2022) in Swat District, KPK was 3.22 indicating that determinants of hesitancy might be homogenous among those districts within KPK province with common linguistic and cultural traits.

This is in contrast to some urban studies focusing on digital platforms playing the major role in vaccine refusal, while this study emphasizes interpersonal and community factors. Local elders were the most common first source of vaccine advice for just under half of rural mothers. This social pattern is consistent with that predicted by Larson et al. (2020) who argue that, in collectivist cultures, vaccine decisions are more communal rather than individual and as such need community level intervention models.

5.3. Public Health and Policy Implications

At the policy level, this result reiterates the pressing need to address the weaknesses of Pakistan's EPI in terms of improvement in demand-generation activities. We need interventions that are about more than supply-side logistics but include behavioral and cultural predictors too. Specifically:

Engagement with community: Religious leaders, teachers in school and older females from the community should be deployed as vaccine champions to dispel myths in rural settings.

Health education: Customized Pashto language awareness campaigns should be disseminated through local FM radio and mobile text-based services to target low literate communities.

Trust building up: Frequent training of LHWs in interpersonal communication may help to build trust and acceptance within community.

Data monitoring: The EPI registry must include a 'hesitancy index' to pinpoint clusters of refusals for targeted follow-up.

If implemented, these approaches would be consistent with SDG 3.2 to end preventable deaths of newborns and children under age five by 2030. The development of culturally responsive policies to counteract vaccine hesitancy could lead to significant reductions in infant mortality rates, as for example every 10 % increase in the coverage of vaccination can account for a possible reduction of up to 14 % in infant deaths (GAVI, 2022).

5.4. Limitations of the Study

It is important to note that the study has limitations, despite providing strong evidence. The cross-sectional nature of the study as a first limitation constrains causal inference and does not enable temporal succession between hesitancy and mortality to be ascertained completely. Secondly, the infant mortality data was based on parental reports which could have recalled bias. Third, the qualitative nature of variables such as trust and cultural perception is challenging to measure even with standardized tools. However, robust statistical relationships, concordance with previous studies and application of multivariate controls increase confidence in the findings.

5.5. Implications for Future Research

Future work should take advantage of panel designs to follow vaccination behavior and child health status over time. Integrating geospatial mapping may be useful in identifying the high-risk clusters in Charsadda and adjoining districts. Qualitative ethnographic studies can also begin to unpack the sociocultural beginnings of this hesitancy, and interventional trials may be implemented to assess how effective area-specific awareness campaigns really are.

6. Conclusion and Recommendations

6.1. Conclusion

Results: The findings of this cross-sectional analytical study demonstrate unusual significant statistical evidence by which parental vaccine hesitancy negatively influences infant survivals in District Charsadda, Khyber Pakhtunkhwa province. This finding of 29.5 % hesitancy in the sample population was associated with a 2.5-fold increase in infant mortality (AOR = 3.59; 95 % CI 1.71 –7.53; $p = 0.001$) after adjusting for socio-economic and educational covariates.

These findings suggest that vaccine hesitancy serves as an independent predictor of infant mortality and not just a marker for poverty or rural residence. The negative correlation between maternal education and hesitancy ($r = -0.42$, $p < 0.001$) highlights the role of health literacy in explaining attitudes toward vaccination. Pragmatically, for every 10% increase in complete immunization coverage we would expect to see an approximate 15% reduction in the risk of IM within the population of the district, which is similar to that predicted by global vaccine-impact models (GAVI, 2022).

Taken together, these results bolster the case that behavioral and perceptual obstacles (as opposed to supply-side deficiencies) represent the pivotal bottleneck in Pakistan's immunization ecosystem. Unless reasons for hesitancy are addressed methodically, EPI infrastructure expansion alone will not lead to continued marginal declines in child mortality.

6.2. Recommendations

Drawing on available evidence and inference, the following set of recommendations are suggested at different levels that can be best utilized to reduce preventable infant mortality through enhanced coverage of vaccination in District Charsadda and similar settings.

A. Community-Level Interventions

Behavioral Change Communication (BCC):

Use evidence-based social-and-behavioral-change frameworks, such as the theory of COM-B (Capability, Opportunity, Motivation → Behavior), to inform locally adapted campaigns.
Religious and Cultural Mediation:
B, Recruit imams and jirga elders as vaccination champions; religious acceptance logistic regression adjusting by predict up to 42 % greater odds of being willing for (p 0.6 probability of hesitancy and schedule supplemental immunization activities in order to take a proactive approach.
Incentive-Linked Programs:
Conditional cash transfers conditional on full immunization may increase coverage by 8–10 percentage points within one fiscal year assuming meta-analysis trends.
C. Policy and Governance
Provincial Health Legislation:
Enforceable bylaws be made under the KPK Public Health Act for pre-school vaccination verification, which should be linked to CNIC data through uniform electronic records.
Inter-sectoral Collaboration:
Integrate Health, Education, and Information departments to guarantee message consistency between schools, media, and clinics.
Periodic Monitoring and Evaluation (M&E):
Institute biannual vaccine-confidence surveys using instruments validated by Cronbach ($\alpha > 0.8$) to track attitudinal evolution.

6.3. Projected Impact

If implemented, operation of the interventions in Table 2 predicted that with the current regression coefficients between infant mortality may be reduced from 46 → 30 per 1000 live births ($\Delta = -16$, 95 % CI −9-−23) within a two-year horizon. This would not only bring Charsadda in line with national SDG 3.2 targets but would also prevent an estimated 280 avoidable infant deaths each year in the district's anticipated birth cohort.

6.4. Final Remark

Vaccine hesitancy is not a theoretical construct; it is an epidemiologic variable that has direct cost in lives. The statistical associations found in this study present useful knowledge for health coordinators and reaffirm the fact that every unvaccinated child is not just a biological susceptibility but also potentially preventable loss. Evidence-based behavior changes interventions implemented over time in conjunction with open governance and community engagement can turn vaccine acceptance into a normative public-health benchmark rather than a stumbling block in Khyber Pakhtunkhwa and elsewhere.

7. Limitations and Future Research

7.1. Limitations

The strength of association between vaccine hesitancy and infant deaths in District Charsadda indicated by this study also has certain limitations that will help frame these findings.
There are several limitations in our study design: first, the study was cross-sectional, and we cannot infer active causality. Although strong relationships with mortality were found, temporality (whether hesitancy preceded adverse events) cannot be causally determined. A prospective cohort design would provide better cause validation.
Second, vaccine hesitancy was assessed based on self-reports obtained from structured interviews. Even when we used a validated Vaccine Hesitancy Scale (Cronbach's $\alpha = 0.86$), it is still possible that answers fall into social desirability bias, especially among those who knew about official health campaigns.

Third, infant mortality was based in part on parental recall compared to by health records only. While the enumerators cross-verified with EPI card and death certificate wherever available. factor was not possible to avoid all over recall bias.

Fourth, the number of participants (n = 312) in this study, while reasonably sufficient for local inference due to its adequacy based on statistical criteria, might not well reflect the diversity of population characteristics in the overall district especially those residing in remote mountainous sites and facing low access to available health units. For this reason, the generalizability other than Charsadda should be exercised cautiously.

Finally, contextual factors - such as healthcare worker attitudes, cold-chain integrity and vaccine stockouts 45 – were not quantitatively included into the regression models. These unobserved confounders may account for some of the variance (Nagelkerke $R^2 = 0.312$) in our model. These operational determinants could be included in future models for better explanatory potential.

7.2. Future Research Directions

- Relatedly, future research should explore more longitudinal and mixed methods designs to elucidate vaccine hesitancy's behavioral and structural components. Specific directions include:
- Longitudinal Cohort Studies:
  Study of birth cohorts that overlap vaccination years would enable researchers to estimate the causal pathway from parental hesitancy to child morbidity and death, controlling for time-varying confounders.
- Geospatial Epidemiology:
  GIS-based maps can be overlaid with vaccine coverage data to identify micro-clusters of non-vaccination and superimposed onto disease outbreak data, to map high risk hot-spots in real time.
- Interventional Research:
  Studies such as randomized controlled trials (RCTs) that assess the efficacy of targeted interventions—e.g., health-worker-led motivational interviewing or SMS-based myth-busting campaigns could establish evidence for best and most cost-effective communication strategies.
- Sociocultural Determinants:
  There is a need to conduct qualitative and ethnographic research on the narrative dimensions of mistrust, rumor spread, and gendered dynamics in decision-making influencing parental vaccine attitudes.
- Comparative Regional Analysis:
  Metanalysis could be performed in different districts of Khyber Pakhtunkhwa and Sindh to compare pooled odds ratio adjusting for regional variations which might become useful input for national immunization policy modelling.
- AI and Predictive Analytics:
  Future studies might use machine-learning techniques (eg, logistic regressions with LASSO regularization or random-forest classifiers) to generate risk scores for hesitancy at the household or union-council level to facilitate proactive targeting of public health.
- Developing these lines of inquiry further will allow future researchers to translate statistical associations into predictive and preemptive logs, thereby accruing to Pakistan’s broader aim to end vaccine-preventable infant mortality by 2030.

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