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Resurgent Measles in Pakistan: A 5-Year Analysis of Vaccination Gaps, Surveillance Challenges, and Urban-Rural Disparities in Khyber Pakhtunkhwa

Abdul Nasir[1], Wasia Ullah[2*], Muhammad Izaz[3] and Zia Ul Islam[1]

[1]Department of Health, Dir Upper Khyber Pakhtunkhwa, Pakistan
[2]Department of Zoology, Abdul Wali Khan University, Mardan, Pakistan
[3]World Health Organization, Khyber Pakhtunkhwa, Pakistan

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***Corresponding Author:**
Wasia Ullah
Department of Zoology, Abdul Wali Khan University, Mardan, Pakistan
wasiullah.dir@gmail.com

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ABSTRACT

Measles remains a substantial public health concern in low and middle-income countries. **Objectives:** This study aimed to provide a comprehensive analysis of measles surveillance data from Khyber Pakhtunkhwa (KP) province in Pakistan from 2020 to 2024, examining epidemiological trends, vaccination coverage, and the effectiveness of the surveillance system. **Methods:** This retrospective descriptive study conducted a thorough surveillance analysis using several data sources, including weekly vaccine-preventable disease (VPD) reports, zero reports, and standardized case investigation forms provided to the EPI monitoring information system (EPI-MIS). For statistical analysis, Stata 17.0 and R 4.2.1 software programs were used. **Results:** 82% of cases comprised unvaccinated children (zero-dose) aged 6-59 months, suggesting severe gaps in regular vaccination. Laboratory testing verified 5,550 (39%) measles cases, whereas 6,398 (44%) were rejected, with a non-measles/non-rubella discard rate of 19.4/100,000, indicating a better differential diagnosis. The surveillance system achieved high performance indicators, with 97% district reporting completeness and 87% timeliness. However, case investigation adequacy decreased to 65% in 2024 ($p<0.001$), especially in low-compliance districts like North Waziristan and Peshawar. Urban centers administered fewer booster doses (Peshawar: 0) than rural areas (Charsadda: 21,155 doses; $p<0.001$). While specimen collection matched WHO standards (88%), South Waziristan's low rates indicated regional diagnostic shortcomings. **Conclusions:** The study concluded the critical need for tailored vaccination programs in high-risk areas, improved real-time surveillance, and health system improvement in KP to achieve measles control.

INTRODUCTION

Measles remains a substantial public health concern in low and middle-income countries (LMICs), despite the availability of an effective vaccine and global attempts to eradicate it [1]. Measles is a highly infectious viral illness that can cause serious consequences such as pneumonia, encephalitis, and death, especially in unvaccinated children under the age of five [2]. The World Health Organization (WHO) recommends at least 95% coverage with two doses of the measles-containing vaccine (MCV1 and MCV2) to achieve herd immunity and avoid outbreaks [3]. However, several places, particularly Pakistan's Khyber Pakhtunkhwa (KP) province, continue to experience recurring outbreaks due to low vaccination rates, gaps in surveillance, and logistical obstacles in vaccine distribution [4]. Measles is still common in Pakistan, with sporadic outbreaks linked to inadequate immunization rates, relocation brought on by conflict, and inadequate healthcare facilities [5]. The province of Khyber Pakhtunkhwa, which borders Afghanistan, has particular obstacles, such as vaccination reluctance, poor cold chain

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management, and trouble reaching isolated communities [6]. In Pakistan, the Expanded Program on Immunization (EPI) uses a surveillance system that uses laboratory confirmation and case-based reporting to monitor vaccine-preventable illnesses (VPDs), including measles [7]. Effective epidemic response is hampered, therefore, by disparities in vaccination coverage among districts, delays in case notification, and inconsistent data quality [8]. Recent epidemiological statistics from KP show a disturbing increase in measles infections, with incidence rates rising from 28 per million people in 2020 to 135 per million in 2024, considerably above the WHO's eradication objective of less than 5 cases per million [9]. Alarmingly, 82% of these cases are reported in zero-dose children (those who have not received measles immunization), with the majority (82%) occurring between the ages of 6 and 59 months [10]. This pattern indicates major deficiencies in routine vaccination programs, emphasizing the need for specialized interventions in high-risk regions. Furthermore, discrepancies in urban and rural vaccination coverage hinder epidemic containment, with urban centers like Peshawar reporting shockingly low booster dose delivery when compared to rural locations like Charsadda and Bajaur [11]. The performance of surveillance systems is also important in the control of measles. While KP has excellent reporting completeness (95%) and timeliness (80%) in weekly VPD monitoring, the adequacy of case investigations has decreased to 65% in 2024, indicating possible gaps in data accuracy and epidemiological follow-up [12]. Furthermore, laboratory confirmation rates vary by area, with South Waziristan reporting particularly poor specimen collection rates, which may result in underreporting or misclassification of cases [13]. The non-measles, non-rubella (NMNR) discard rate of 19.4 per 100,000 population, while indicating improved differential diagnosis, might potentially represent errors in case criteria or insufficient physician training in measles detection [14, 15].

The persistent resurgence of measles in Khyber Pakhtunkhwa reflects substantial gaps in routine immunization coverage, particularly among zero-dose children, alongside declining case investigation adequacy despite high reporting completeness. Urban–rural disparities, weak booster dose uptake in metropolitan districts, and inconsistent surveillance quality further hinder progress toward elimination targets. Strengthening targeted outreach for zero-dose populations, enhancing real-time digital surveillance integration within the EPI-MIS framework, and improving cold chain and district-level accountability mechanisms are urgently recommended. Focused interventions in high-risk districts such as Peshawar and border regions should be prioritized to achieve sustainable measles control. This study aims to provide evidence-based suggestions for boosting the region's measles control efforts by identifying high-risk districts, reviewing vaccine gaps, and investigating monitoring deficiencies. The findings may help to inform continuing conversations about improving EPI methods in LMICs, particularly in conflict-affected and hard-to-reach areas where measles poses a chronic danger to child health.

METHODS

A retrospective surveillance data analysis was carried out using all available records from the EPI Monitoring Information System (EPI-MIS). The study used a descriptive and analytical epidemiological approach evaluate trends in measles incidence, vaccination coverage, and surveillance effectiveness. Data on suspected, clinically verified, and laboratory-tested measles cases, as well as vaccination records, were collected from 1,851 health institutions throughout KP. The study was carried out in Khyber Pakhtunkhwa (KP), a region in Northwest Pakistan from July 2024 to December 2024, with 37 districts and a mixed urban and rural population. Disparities in healthcare access, relocation brought on by conflict, and low vaccination rates have all contributed to the region's repeated measles epidemics. With an emphasis on measles case reporting, vaccination records, and laboratory-confirmed diagnoses from 2020 to 2024, data were gathered from all districts taking part in the Expanded Program on Immunization (EPI) surveillance system. The ethical board does not need to conduct a thorough review of the study because the data did not include any patient-identifiable information. The data holders provided all necessary consents and permissions before the commencement of the study. The study conducted a thorough surveillance analysis using several data sources, including weekly vaccine-preventable disease (VPD) reports, zero reports, and standardized case investigation forms provided to the EPI Monitoring Information System (EPI-MIS). The collected data included key variables such as demographic characteristics (age, gender, and district of residence), vaccination status (categorized as zero-dose, MCV1, or MCV2 recipients), laboratory confirmation results (IgM-positive cases and discarded negative cases), and critical surveillance performance indicators (including reporting timeliness, data completeness, and specimen collection rates). For statistical analysis, Stata 17.0 and R 4.2.1 software programs were used. The analytical technique used descriptive statistics to calculate frequencies, proportions, and population-based incidence rates, resulting in a basic understanding of measles distribution patterns. Temporal trends were analyzed using linear regression modeling and Cochran-Armitage tests, while district-level differences in vaccination coverage were examined using Chi-square and Fisher's exact tests to uncover statistically significant discrepancies.

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Throughout all studies, a preset alpha level of 0.05 was used to evaluate statistical significance. Advanced visualization tools, such as heat maps and epidemic curves, were used to highlight spatiotemporal patterns of disease transmission. These were supplemented with logistic regression models that identified important risk variables linked with zero-dose measles cases in the community (Figure 1).

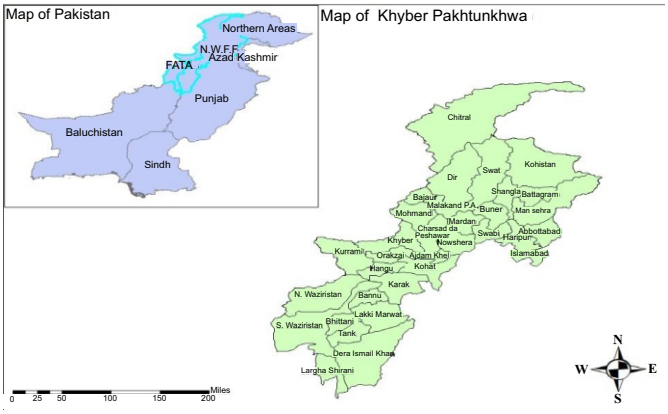

Figure 1: Study Area Map Showing Sampling Districts of Khyber Pakhtunkhwa

RESULTS

Measles surveillance statistics from Khyber Pakhtunkhwa (KP) for the reporting period showed key trends in case incidence, vaccination coverage, and system efficiency. Out of 37 districts, 36 (97%) reported surveillance data to the EPI-Monitoring Information System (EPI-MIS), indicating excellent reporting compliance. Furthermore, 95% of health institutions (1,763 out of 1,851) provided zero reports, demonstrating strong engagement in measles monitoring. A total of 18,075 probable measles cases were recorded, with 14,366 (82%) line-listed, indicating extensive case recording. In EPID Week 47 alone, 220 suspected cases were recorded, indicating that transmission is ongoing (Figure 3.1). A concerning rise in vaccination coverage was noted, with 82% of measles-infected cases being zero-dose children (unvaccinated) over the age of nine months, with the majority (82%) falling into the 6-59-month age category. Laboratory tests confirmed 5,550 (39%) cases as measles positive, while 6,398 (44%) were ruled out as negative. The surveillance system achieved 95% completeness and 80% timeliness in weekly VPD Zero reporting, with 35 out of 37 districts (95%) meeting the 80% completeness threshold. However, Kurram Lower and Central, North Waziristan, Palas Kohat, Peshawar, Dir-Upper, Hangu, and Kolai were designated as low-compliance areas. Cumulative data from Weeks 1-47 showed 97% completeness and 87% timeliness in VPD reporting, whereas AEFI surveillance reached 95% completion and 82% timeliness (Figure 2).

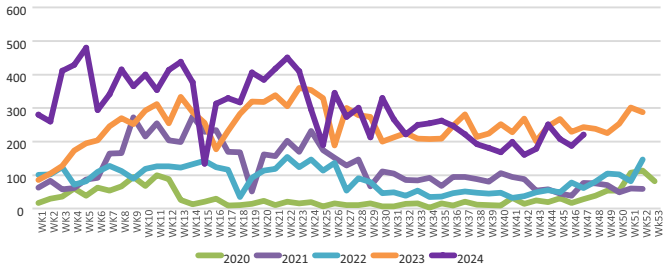

Figure 2: Weekly Trend of Measles Cases from 2020 to 2024

Measles incidence fluctuated, with 17,717 suspected cases reported between 2020 and 2024. The highest occurrence was in 2023 (12,675 cases), with a slight fall in 2024 (14,366 cases by Week 47) (Table 1).

Table 1: Measles Surveillance Performance Indicators (2020–2024)

Indicators	Target	2020	2021	2022	2023	2024 (Wk 1–47)	p-value (Trend Analysis)
Suspected Measles Cases	–	1,717	6,403	4,492	12,885	14,366	<0.001 (↑)
Lab-Confirmed Measles Cases	–	909	2,996	1,997	5,482	5,550	<0.001 (↑)
Measles Incidence Rate (/M)	<5	28	101	56	118	135	<0.001 (↑)
Rubella Incidence Rate (/M)	<5	1	1	2	1.7	0.6	0.112 (NS)
NMNR Discard Rate (/100K)	2	3	9	6	15.2	19.4	<0.001 (↑)
Specimen Collection Rate (%)	>80%	89%	97%	95%	99%	88%	0.003 (↓ in 2024)
Adequate Investigation (%)	>80%	82%	92%	93%	94%	65%	<0.001 (↓)

The measles incidence rate per million population increased from 28 in 2020 to 135 in 2024, well above the WHO objective of <5 cases per million. In contrast, rubella incidence remained low (0.6 per million), while the non-measles, non-rubella (NMNR) discard rate increased to 19.4 per 100,000 population, showing improvement (Figure 3).

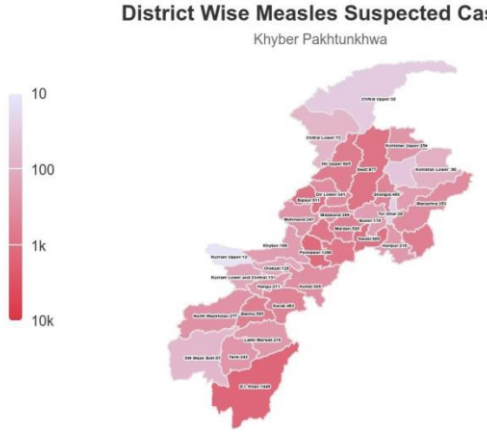

Figure 3: A Choropleth Map of Measles Cases in Khyber Pakhtunkhwa

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Vaccination efforts varied by district, with a total of 67,643 measles booster doses delivered. Charsadda had the highest MSL booster coverage (21,155 doses), followed by Bajaur (9,708) and Kohistan Upper (7,682) (Table 2).

Table 2: District-Wise Vaccination Coverage of Measles in Khyber Pakhtunkhwa

Districts	BCG	Penta -3	MSL -1	MSL -2	MSL Booster	Coverage Gap (%)	p-value (vs.Target)
Charsadda	118	503	831	774	21,155	12%	
Bajaur	0	0	203	0	9,708	28%	
Kohistan Upper	0	140	288	196	7,682	19%	
Peshawar	3	4	42	108	0	45%	
North Waziristan	170	205	1,870	1,601	318	23%	

However, variations were observed, with Peshawar, Nowshera, and Malakand reporting low doses, indicating poor immunization drives in urban areas (Figure 4).

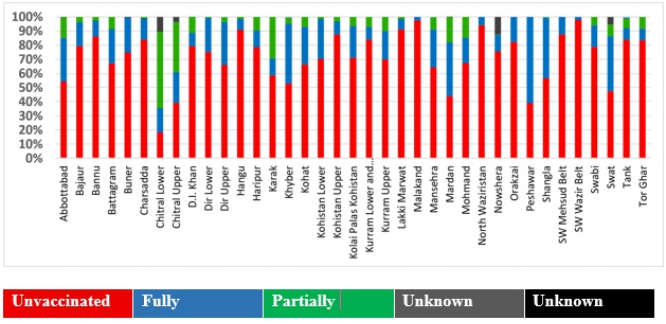

Figure 4: District-wise Vaccination Status of Suspected Cases

An epidemiological examination of measles surveillance data from Khyber Pakhtunkhwa (KP) suggests a disturbing rising trend in disease incidence, with 135 confirmed cases per million population in 2024, greatly exceeding the WHO-recommended threshold of <5 cases per million. This increase is mostly due to a high proportion of zero-dose children (82%) remaining unvaccinated against measles, as well as inadequate coverage of MCV1 and MCV2 doses across numerous districts. The majority of cases in the 6-59-month age group (82%) highlight a critical gap in routine immunization efforts, particularly among groups with poor healthcare access. Furthermore, the continually high incidence rate—a fourfold increase since 2020 (28 to 135 per million) indicates systemic inadequacies in achieving herd immunity, prompting an immediate review of vaccination policies and outreach initiatives. Despite high reporting completeness (95% in district-level monitoring), the adequacy of case investigations has dropped to 65% by 2024, showing significant gaps in data quality and epidemiological follow-up. This weakness is especially visible in low-compliance districts (such as Kurram Lower and Central, North Waziristan, and Peshawar), where delayed case verification and poor documentation impede effective outbreak response

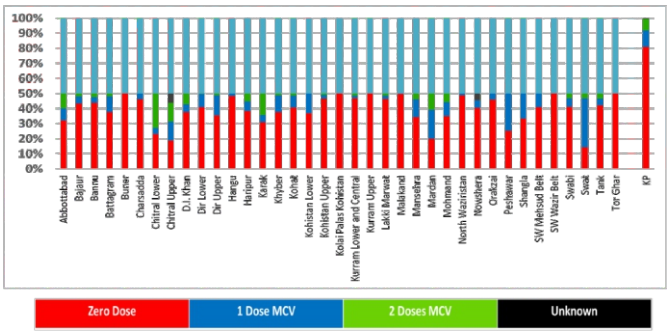

Figure 5: District-Wise Vaccination Status of Lab-Confirmed Measles Cases

A severe urban-rural difference in vaccination coverage exacerbates transmission dynamics, with urban areas (Peshawar, Nowshera) reporting dangerously low booster dose administration, whilst rural districts (Charsadda, Bajaur, Kohistan Upper) show higher but inconsistent uptake. Charsadda delivered 21,155 measles booster doses, whereas Peshawar received nil booster vaccines, highlighting inequitable resource allocation and logistical issues in metropolitan areas. Despite higher vaccination rates in rural areas, prolonged outbreaks suggest either cold chain issues, inadequate vaccine efficacy, or substantial population mobility, all of which contribute to long-term transmission (Figure 5).

DISCUSSION

The results of this extensive analysis of measles surveillance data in Khyber Pakhtunkhwa (KP) demonstrate serious gaps in vaccination coverage, surveillance performance, and outbreak response, necessitating immediate public health interventions. The rising measles incidence (135 cases per million in 2024) exceeds the WHO criterion of <5 cases per million, aligning with global trends of diminishing immunization rates leading to measles resurgence in previously controlled regions [16,17]. 82% of cases in zero-dose children highlight a fundamental failure in routine immunization regimens, which is consistent with research associating measles outbreaks with unvaccinated populations [18]. This tendency is especially concerning given that 82% of cases were among children aged 6-59 months, a group that is very susceptible to serious sequelae such as pneumonia and encephalitis [19]. The high reporting completeness (95%) and timeliness of 80% in weekly VPD Zero reporting imply a solid surveillance infrastructure, comparable to systems in other low- and middle-income countries (LMICs) with strong EPI frameworks [20]. However, the fall in case investigation adequacy (65% in 2024) indicates declining data quality, which could be related to personnel shortages or insufficient training, as shown in similar contexts [21]. The awaiting cross-notification of 34 diphtheria cases reveals systemic inefficiencies in inter-district cooperation, which mirrors issues seen during Pakistan's polio eradication

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efforts [22]. Disparities in healthcare access are reflected in the glaring differences in vaccination coverage between urban and rural districts. Peshawar recorded nil booster vaccinations, whereas Charsadda and Bajaur reported substantial booster doses (21,155 and 9,708, respectively). This is probably because of vaccine hesitancy, logistical challenges, or conflicting urban health goals [23]. This is consistent with research demonstrating that mobile populations, disinformation, and inadequate communication initiatives are frequently the cause of urban vaccination gaps [24]. Ironically, ongoing outbreaks despite greater vaccination rates in remote areas point to either increased population mobility, poor vaccine efficacy, or cold chain breakdowns, as observed in Afghanistan's border regions [25]. Although South Waziristan's low rates suggest regional diagnostic problems and may result in underreporting, the 88% specimen collection rate satisfies WHO criteria [26]. Due to vague case definitions, which are also a problem in Nigeria's measles monitoring, the high NMNR discard rate (19.4/100,000) may indicate either improved differential diagnosis or over-reporting [27]. Refining case confirmation requires strengthening laboratory networks and training clinicians in measles detection [28].

The persistent resurgence of measles in Khyber Pakhtunkhwa reflects substantial gaps in routine immunization coverage, particularly among zero-dose children, alongside declining case investigation adequacy despite high reporting completeness. Urban–rural disparities, weak booster dose uptake in metropolitan districts, and inconsistent surveillance quality further hinder progress toward elimination targets. Strengthening targeted outreach for zero-dose populations, enhancing real-time digital surveillance integration within the EPI-MIS framework, and improving cold chain and district-level accountability mechanisms are urgently recommended. Focused interventions in high-risk districts such as Peshawar and border regions should be prioritized to achieve sustainable measles control. This study was limited by its retrospective design and reliance on secondary surveillance data, which may be subject to underreporting, misclassification, and variability in district-level data quality. The absence of individual-level socioeconomic, mobility, and vaccine hesitancy data restricted deeper causal interpretation of zero-dose prevalence. Future research should incorporate prospective, mixed-method approaches, geospatial risk modeling, and community-based assessments to better understand barriers to vaccination and strengthen outbreak preparedness strategies across KP.

CONCLUSIONS

The findings of this study show a critical resurgence of measles in Khyber Pakhtunkhwa, which is primarily caused by inadequate vaccination coverage among zero-dose children, as well as systemic inadequacies in surveillance and outbreak response. Despite high reporting completeness, decreased case investigation adequacy, and urban-rural vaccination disparities, particularly in regions like Peshawar without booster doses, there are continuing gaps in measles management. The fourfold increase in incidence (2020-2024) highlights the critical need for targeted interventions. Addressing cold chain issues and increasing diagnostic capacity in underperforming locations (such as South Waziristan) is also critical. A multi-sectoral approach that includes digital surveillance and equitable resource allocation is required to meet measles elimination targets and safeguard vulnerable populations in KP and similar settings.

Authors' Contribution

Conceptualization: AN, WU
Methodology: AN, WU, MI
Formal analysis: MI
Writing and Drafting: AN, WU, ZUI
Review and Editing: AN, WU, MI, ZUI

All authors approved the final manuscript and take responsibilities of the integrity of the work.

Conflicts of Interest

The authors declare no conflict of interest.

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