EFFECTIVENESS AND OPERATIONAL CHALLENGES OF ENVIRONMENTAL SURVEILLANCE SYSTEMS FOR POLIO ERADICATION IN NIGERIA

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ABSTRACT

Environmental surveillance (ES) has become a critical complement to acute flaccid paralysis (AFP) surveillance in the global fight against polio. In Nigeria, where high-risk states continue to pose challenges to eradication, understanding the effectiveness and operational realities of ES is essential for sustaining progress. This cross-sectional study employed a structured questionnaire administered to 450 respondents across 21 Nigerian states. Data were analyzed using descriptive statistics, chi-square tests, and logistic regression to identify determinants of ES participation, perceptions of effectiveness, and operational barriers. Respondents were largely experienced professionals, with most having 5–10 years of service. Awareness, formal training, and familiarity with ES processes showed strong positive associations with participation ($p < .001$). Supervisory and data management roles reported higher engagement, while dual involvement in AFP and ES systems significantly boosted participation. State-level disparities emerged, with Zamfara (96.3%), Kebbi (85.0%), and Yobe (78.9%) showing strong ES contribution, while Rivers, Niger, Jigawa, Bauchi, and Anambra recorded little or none. Rivers stood out as a critical high-risk state due to low ES contribution, AFP faster detection, and multiple operational challenges. Overall, most respondents rated ES as more effective (24.9%) or equally effective (21.8%) compared to AFP, emphasizing their complementary role. Significant challenges included inadequate training, sample collection difficulties, laboratory delays, insecurity, logistics, and low community awareness, while poor funding showed no statistical significance. Logistic regression confirmed awareness (OR = 4.04), formal training (OR = 2.44), long experience (OR = 6.83), and AFP–ES dual involvement (OR = 1.99) as strong predictors of ES contribution. The study concludes that ES in Nigeria has strong potential but remains unevenly effective across states. Strengthening training, laboratory systems, logistics, and community engagement especially in particularly in high-risk states is essential to maximize its role in polio eradication.

Keywords: Environmental surveillance, Poliovirus, Acute flaccid paralysis, Nigeria, Operational challenges

Word Count: 300

<center>**CHAPTER ONE**</center>

<center>**INTRODUCTION**</center>

1.1 Background of the Study

Poliomyelitis is an infectious disease caused by the poliovirus that predominantly affects children under the age of 15 years (WHO, 2000; Baguune et al., 2024). The clinical outcomes vary from mild, non-specific illness to severe flaccid paralysis that can result in permanent disability (WHO, 2009; Baguune et al., 2024). Even in the absence of visible symptoms, poliovirus can replicate in the para-intestinal submucosal lymphatic tissue for weeks to months (WHO, 2004; Baguune et al., 2024). The Global Polio Eradication Initiative (GPEI), launched in 1988, has led to a reduction in global polio cases by more than 99% (CDC, 2011; Baguune et al., 2024). Since the withdrawal of type 2 and type 3 wild polioviruses in 1999 and 2012 respectively, wild poliovirus type 1 and vaccine-derived polioviruses (VDPVs) remain the main threats to eradication (Diop et al., 2017). VDPVs emerge when weakened strains of the oral polio vaccine circulate for extended periods in under-immunized populations or replicate in immunodeficient individuals, eventually regaining neurovirulence.

Nigeria historically bore the largest burden of polio cases in sub-Saharan Africa (Diop et al., 2017). The country reported its last case of wild poliovirus in 2016, and the African continent was certified free of wild poliovirus thereafter (Diop et al., 2017). Ghana achieved a similar milestone after detecting its last case in 2008 and was declared polio-free in 2015 (Odoom et al., 2014; Baguune et al., 2024). However, the emergence of circulating vaccine-derived poliovirus type 2 (cVDPV2) has become a major challenge to the eradication process (Odoom et al., 2014). By August 2020, 323 cases of cVDPV2 and 84 positive environmental samples had been documented

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across Africa (GPEI, 2025). Ghana, for instance, recorded its first cVDPV2-positive environmental sample in June 2019 and its first human case in August 2019, with 30 confirmed cases reported by the end of 2020 (GPEI, 2025).

Polio surveillance remains central to eradication efforts. Acute Flaccid Paralysis (AFP) surveillance is considered the gold standard for detecting poliovirus. An AFP case is defined as any child under 15 years with sudden onset of paralysis or weakness in the limbs, or any person at any age in whom poliomyelitis is clinically suspected (Hamisu et al., 2022). AFP surveillance is crucial for confirming polio cases, monitoring outbreaks, and certifying the absence of wild poliovirus circulation (Bassioni et al., 2003; Baguune et al., 2024). However, AFP captures only a fraction of infections since approximately one in every thousand poliovirus infections leads to paralysis, leaving many asymptomatic infections undetected (Kelly et al., 2006; Baguune et al., 2024). This silent circulation poses a risk of continued transmission.

Because poliovirus is excreted in stool for several weeks, it can be identified in sewage or wastewater contaminated with human fecal matter (Odoom et al., 2017). Environmental Surveillance (ES) has therefore been adopted to complement AFP surveillance. ES provides a non-invasive approach to detect poliovirus circulation in communities, regardless of whether individuals develop symptoms (WHO, 2003; Baguune et al., 2024). The Global Polio Eradication Initiative expanded the use of ES between 2013 and 2018, and by 2018, more than 45 countries had introduced ES as part of their national polio surveillance systems (Odoom et al., 2014; GPEI, 2025). Countries such as Nigeria, Kenya, South Africa, Senegal, Cameroon, Madagascar, and Ghana have implemented ES in high-risk areas to supplement AFP surveillance (Weldegebriel et al., 2015; Muluh et al., 2016; Baguune et al., 2024).

In practice, ES involves collecting sewage or wastewater samples from selected catchment areas and testing them for polioviruses and other enteroviruses (WHO, 2003; WHO 2025). Its sensitivity depends on the sewage network, site selection, sample handling, and laboratory processes (Diop et al., 2017; Odoom et al., 2017). When effectively implemented, ES can detect outbreaks earlier than AFP surveillance and guide public health interventions (GPEI, 2025). For instance, findings from ES in Egypt in the early 2000s triggered intensified immunization campaigns and strengthened AFP surveillance (GPEI, 2025). In Nigeria, ES has contributed to identifying circulating vaccine-derived polioviruses and guided targeted vaccination campaigns (Weldegebriel et al., 2015; Muluh et al., 2016).

Despite its promise, ES faces challenges in many African countries. Informal drainage systems, poorly documented catchment populations, and limited laboratory capacity hinder optimal sensitivity (Westmoreland et al., 2021). Nonetheless, ES remains a crucial tool in the final phase of eradication, particularly in settings where AFP surveillance alone cannot reliably detect silent transmission. This study therefore focuses on assessing the effectiveness and operational challenges of environmental surveillance for poliovirus in Nigeria.

1.2 Statement of the Problem

Despite the progress made under the Global Polio Eradication Initiative, poliovirus continues to pose a significant threat to public health in Nigeria. The country's certification as free of wild poliovirus in 2020 was a major milestone (Diop et al., 2017). However, the continued circulation of type 2 vaccine-derived polioviruses (cVDPV2) underscores the fragility of these gains (Odoom et al., 2014; GPEI, 2025). Between 2019 and 2022, Nigeria reported multiple outbreaks of cVDPV2, making it one of the highest-burden countries globally (GPEI, 2025). These outbreaks

reveal that silent transmission persists in communities, particularly in underserved and high-risk areas where routine immunization coverage remains suboptimal. Surveillance remains the backbone of polio eradication. Acute Flaccid Paralysis (AFP) surveillance, while still considered the gold standard, captures only the small fraction of infections that manifest with paralysis (Kelly et al., 2009; Baguune et al., 2024). This limitation creates a critical gap, as the majority of infections remain asymptomatic and undetected. Environmental Surveillance (ES) was introduced to bridge this gap, as it can identify poliovirus excreted in stool and present in sewage even when no AFP cases are reported (Odoom et al., 2017). In Nigeria, ES has been credited with early detection of poliovirus and has informed targeted immunization responses (Weldegebriel et al., 2015; Muluh et al., 2016)

Yet, important questions remain unanswered. Despite its potential, the effectiveness of ES in Nigeria is constrained by operational challenges such as weak sewage infrastructure, poor site representativeness, inconsistent sample collection, and limited laboratory capacity (Westmoreland et al., 2001; Odoom et al., 2017). The persistence of poliovirus transmission despite ES expansion raises concerns about whether the system is sufficiently sensitive and sustainable. Furthermore, while AFP and ES are designed to complement each other, there is limited evidence comparing their relative performance in Nigeria's high-risk states. Without such evaluation, it is difficult to determine the extent to which ES contributes to early detection and outbreak control in the Nigerian context. The critical gap, therefore, lies in the lack of systematic assessment of the effectiveness and operational challenges of environmental surveillance for polio eradication in Nigeria. Understanding this is essential not only for interrupting cVDPV2 transmission but also for sustaining Nigeria's polio-free certification. This study addresses this gap by examining the

contribution of ES to poliovirus detection, comparing it with AFP surveillance and identifying operational challenges, of surveillance systems in Nigeria.

1.3 Justification of the Study

Nigeria's certification as free of wild poliovirus in 2020 was a milestone for Africa, yet outbreaks of circulating vaccine-derived poliovirus type 2 (cVDPV2) continue to undermine progress (Diop et al., 2017; Odoom et al., 2014; GPEI, 2025). This persistence reflects weaknesses in detection systems and highlights the need for closer scrutiny of surveillance approaches. Acute Flaccid Paralysis (AFP) surveillance has historically driven case detection but cannot capture the vast majority of infections that remain asymptomatic (Kelly et al., 2006; Odoom et al., 2017). Environmental Surveillance (ES) was adopted to bridge this gap by testing sewage for polioviruses excreted in stool (Odoom et al., 2017). Its application in Nigeria has shown that it can reveal circulation even in the absence of AFP cases, providing a valuable signal for vaccination campaigns (Baguune et al., 2024). Yet, the Nigerian context presents unique operational difficulties. Unstructured sewage networks, uncertain catchment populations, and resource constraints reduce the sensitivity of the system (Odoom et al., 2017). Delays in sample transport and limited laboratory capacity further restrict timely detection. The recurrence of cVDPV2 despite the expansion of ES raises questions about how well the system is functioning on the ground (GPEI, 2025).

This study is justified for three reasons. Academically, it fills a gap in the literature by assessing the performance of ES in Nigeria, a country that remains central to global eradication goals (Hamisu et al., 2022). Programmatically, it documents the challenges of running ES in settings with weak infrastructure, where theory and implementation often diverge (Odoom et al., 2017).

Policy-wise, the findings will support Nigeria and its partners in refining strategies for surveillance, which is a priority in the Global Polio Eradication Initiative's endgame strategy.

1.4 Aims and Objectives

1.4.1 Aims

The aim of this study is to assess the effectiveness and operational challenges of environmental surveillance systems on polio eradication in Nigeria.

1.4.2 Specific Objectives

The specific objectives of the study are to:

   i.   Evaluate the contribution of environmental surveillance to the early detection of poliovirus in Nigeria.
   ii. Compare environmental surveillance with AFP surveillance in selected high-risk states.
   iii. Identify the operational challenges affecting environmental surveillance implementation.
   iv. Recommend strategies to improve polio surveillance effectiveness in Nigeria.

1.5 Research Questions

   i.   How effective is environmental surveillance in detecting poliovirus circulation in Nigeria?
   ii. How does environmental surveillance compare with AFP surveillance regarding sensitivity and coverage?
   iii. What operational challenges hinder environmental surveillance in Nigeria?

1.6 Research Hypothesis

H$_0$: Environmental surveillance does not significantly improve poliovirus detection compared to AFP surveillance alone.

H$_1$: Environmental surveillance significantly improves poliovirus detection compared to AFP surveillance alone.

1.7 Scope of the Study

This study is focused on assessing the effectiveness and operational challenges of environmental surveillance for poliovirus eradication in Nigeria. The research is limited to twenty-one states where structured questionnaires were administered: Bauchi, Kogi, Niger, Jigawa, Rivers, Anambra, Oyo, Ogun, Abia, Delta, Osun, Kwara, Katsina, Sokoto, Yobe, Kebbi, Zamfara, Gombe, Kaduna, Kano, and Borno. These states were selected because they are high-risk areas for poliovirus circulation, regions with varying levels of surveillance infrastructure, and states with recent histories of circulating vaccine-derived poliovirus detections. The study examines the role of environmental surveillance in early detection of poliovirus, its comparison with Acute Flaccid Paralysis (AFP) surveillance, and the operational challenges influencing its implementation. Respondents include stakeholders directly involved in polio surveillance activities such as state surveillance officers, environmental health officers, and laboratory personnel. The analysis is restricted to polio surveillance and does not extend to other aspects of immunization programs or surveillance systems for other diseases.

1.8 Operational Terms and Definitions

i. **Poliomyelitis (Polio):** A viral disease-causing muscle paralysis, primarily affecting children under five.

ii. **Environmental Surveillance (ES):** Testing of sewage and wastewater samples to detect poliovirus circulation.

iii. **Acute Flaccid Paralysis (AFP) Surveillance:** Monitoring of sudden onset paralysis cases to detect poliovirus infection.

CHAPTER TWO

LITERATURE REVIEW

This chapter detailed the relevant literatures review on the study which is to assess the effectiveness and operational challenges of environmental surveillance systems on polio eradication in Nigeria. The chapter includes the theoretical, conceptual and empirical review. The theoretical framework detailed the diseases surveillance theory in surveillance review while the conceptual review addresses the global efforts to eradicate poliovirus, surveillance approaches for poliovirus. The empirical review detailed the contribution of environmental surveillance to early detection of poliovirus, and comparison of environmental surveillance and AFP surveillance and operational challenges.

2.1 Theoretical Framework

2.1.1. Disease Surveillance Theory (DST)

Disease Surveillance Theory (DST) is a framework that explains how diseases are systematically detected, monitored, and controlled using structured public health systems (McNabb et al., 2002; Gomes et al., 2022). It emphasizes that outbreaks follow a predictable sequence and moves from origin and transmission to detection and institutional response. Surveillance functions as the critical mechanism that interrupts this cycle before widespread harm occurs. The theory builds on the principles introduced by Alexander D. Langmuir in the 1960s. who is widely recognized as the father of modern disease surveillance, described surveillance as:

"*The continued watchfulness over the distribution and trends of incidence through the systematic collection, consolidation, and evaluation of morbidity and mortality reports and other relevant data (Langmuir, 1963)*".

2.1.1.2 Application of DST in this study

The first stage is the origin of infection. Pathogens which are transmitted from animals, or anthropogenic arises within human populations. Most times, zoonotic diseases cross into humans through contact with wildlife or food sources, while anthropogenic origins spread through human-to-human transmission or hereditary traits. In addition, circulating vaccine-derived poliovirus type 2 (cVDPV2) has been repeatedly isolated in sewage systems even in areas with no acute flaccid paralysis (AFP) cases reported. This pattern points to reservoirs maintained in less immunized populations and shaped by gaps in sanitation interventions (Kalkowska et al., 2020).

The second stage involves transmission within populations. Infections spread through contact with body fluids, aerosols, contaminated food or water, and close interaction. Silent transmission, where carriers remain asymptomatic, is a defining feature. This hidden spread sustains outbreaks such as poliovirus, where circulation continues in environmental reservoirs without visible cases. Environmental surveillance (ES) has shown viral presence in sewage despite the absence of paralytic cases. A study of ES sites in Kano and Sokoto demonstrated that enterovirus isolation was more likely in urban catchments with high density and poor waste management (Hamisu et al., 2022). This shows how silent transmission sustains outbreaks.

The third stage is detection through symptomatic cases. Individuals report illness to local health facilities, which act as the frontline of surveillance. Initial case investigations may trigger alerts when clusters suggest a shared source. At this level, routine surveillance data provide the evidence for public health action, as seen with integrated disease surveillance systems across Africa (Muyembe et al., 2024). Between 2012 and 2015, ES in Nigeria detected 97 cVDPV2 and 14 wild poliovirus isolates, while AFP surveillance alone would have missed several events (Abdullalhi et al., 2015). Evidence from Kano also demonstrated that sewage monitoring provided early warning

signals months before clinical cases appeared, confirming ES as a more sensitive tool in certain areas (Kalkowska et al., 2020).

The fourth stage is institutional response. Public health authorities and epidemiologists expand investigations through laboratory analysis, contact tracing, and systematic analysis. Surveillance helps in strengthening this phase by identifying unusual signals that routine systems (AFP) may miss. This offer early insight into changes in host species, transmission settings, or viral persistence (McKnight et al., 2024). Especially Sensitivity in operational layer. Sensitivity depends on site selection, sampling frequency, and laboratory capacity (Impalli et al., 2025). Empirical work has shown that the quality of sample processing and the geographical distribution of ES sites determine how quickly outbreaks are recognized and thus addressed (Lickness et al., 2020). Insecurity in northern states further disrupted timely response and exposes gaps in implementation despite strong detection capacity (Akinola et al., 2021). These challenges reflect the third objective of identifying barriers to effective ES.
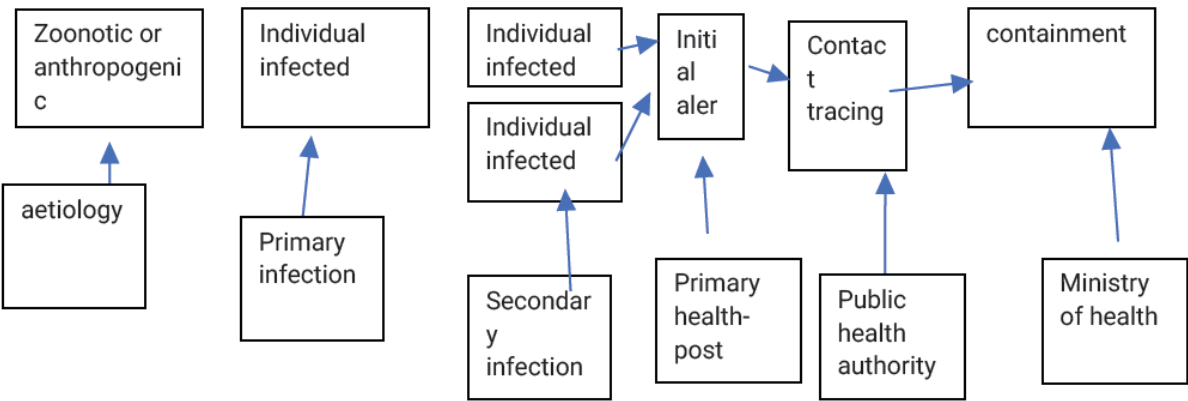

Figure 1: Public health surveillance theory framework (Dzirasah et al., 2024)

The fifth stage involves escalation to national and international levels. Ministries of health mobilize resources, establish containment policies, and coordinate cross-border actions where

necessary. Evidence shows that this stage is shaped not only by institutional capacity but also by community participation. Informal actors, such as traditional healers, have been pivotal in detecting and reporting suspected cases, extending the reach of formal systems (Kenu et al., 2024). Nigeria expanded ES to more states after initial gaps were revealed, and modeling has shown that this scale-up directly improved sensitivity to detect poliovirus circulation (Hovi et al., 2012). At national level, ES data have guided targeted immunization campaigns and informed the Global Polio Eradication Initiative's risk assessments (Hamisu et al., 2022).

These stages form a cycle that explains how surveillance functions in practice. In Nigeria, the persistence of circulating vaccine-derived poliovirus type 2 highlights failures in detecting and interrupting silent transmission between the second and third stages. Environmental surveillance and acute flaccid paralysis surveillance operate within this framework as mechanisms to identify pathogens early, trigger institutional responses, and prevent escalation into larger epidemics.

2.2 Conceptual Review

2.2.1 Poliovirus and Global Eradication Efforts

Poliovirus is a small RNA virus from the Picornaviridae family. It has stayed at the center of global eradication campaigns because it leaves children with paralysis that never heals and sometimes takes their lives (Thompson & Badizadegan, 2024). The Global Polio Eradication Initiative (GPEI) began in 1988 with a clear mission to eradicate polio. Since then, case numbers have collapsed worldwide. Not to zero. Not yet. However, between 2001 and 2023, reported cases fell sharply. WPV2 disappeared in 1999. WPV3 followed in 2012. But WPV1 refuses to vanish, this is still present in Afghanistan and Pakistan. These two countries remain the last endemic reservoirs. A different threat rose in their place which is circulating vaccine-derived polioviruses (cVDPVs). Since 2018, type 2 outbreaks have spread across continents. By 2021, cVDPV1 cases were higher

than WPV1. That changed the map of concern (Badizadegan et al., 2022). The tools against polio also shifted. At first, the oral polio vaccine (OPV) was the weapon of choice. Cheap. Easy to swallow. Strong mucosal immunity. Transmission blocked at the source (Tebbens et al., 2002; Tebbens et al., 2017). But OPV carried risks. Vaccine-associated paralytic polio. And worse, cVDPVs. The solution in developed countries was to turn to inactivated polio vaccine (IPV). Elsewhere, OPV stayed in use and this is supported by supplementary campaigns (Hamisu et al., 2022).

GPEI laid out six phases of strategy. The early years which is 1988 to 2000 pushed for full eradication by the millennium. Routine immunization. Mass campaigns. The payoff was regional: the Americas certified polio-free in 1994, the Western Pacific in 2000, Europe in 2002. Later plans looked harder at OPV risks. They called for new vaccines and the gradual pullback of OPV. In 2016, the world shifted from tOPV to bOPV. A landmark. But after that, cVDPV2 cases exploded. More than 3,300 infections across 48 countries between 2017 and 2023. Ten times higher than before the switch (Badizadegan et al., 2022).

Then came COVID-19. Campaigns were interrupted and widens the immunity gap. WPV1 reappeared. cVDPV2 spread fast. By 2024, eradication had stalled. WPV1 still present in Afghanistan and Pakistan. cVDPV outbreaks stretching across Africa and Asia (World Health Organization, 2022; Badizadegan et al., 2022). A new option has been deployed: novel OPV2 (nOPV2). Built to reduce the chance of the virus turning dangerous again. Released under emergency authorization. First data suggest promise. Fewer reversions. Yet gaps in coverage, weak health systems, and uneven results keep the world from closing the door on polio (Macklin et al., 2023; Yeh et al., 2020; Thompson et al., 2024).

2.2.1.1 Historical overview of the Global Polio Eradication Initiative (GPEI).

The fight against infectious diseases stretches back to centuries. Humanity has curbed epidemics, invented therapies, and added years to life expectancy. Yet only once has a human pathogen been wiped from the planet which is smallpox, certified eradicated in 1980. Polio became the next great target. An infection capable of killing or crippling children, polio carried a long and uneasy history. Vaccines developed in the 1950s changed the history. Their arrival made prevention possible, and early control efforts succeeded widely, though obstacles persisted (Plan, 2011).

Poliovirus belongs to the genus Enterovirus of the Picornaviridae family. It exists in three serotypes, each built of a single-stranded positive-sense RNA genome encased in a protein shell. Translation in host cells produces a large polyprotein, later cleaved into multiple structural and nonstructural proteins. These orchestrate viral replication and pathogenesis (Mick et al., 1999; Belov et al., 2012; Shen et al., 2012). Clinical outcomes vary. Most infections remain unapparent, a minority resemble influenza, and a smaller proportion lead to paralytic poliomyelitis. Paralysis can be spinal, bulbar, or mixed, with permanent disability in many survivors (Mayer & Neilson, 2010).

Epidemics have shadowed human history. Ancient Egyptian art depicts withered limbs thought to be polio. Medical descriptions first appeared in the 19th century. By the late 1800s, epidemics swept Europe and the United States. In 1952, more than 21,000 paralytic cases were reported in the U.S. alone (Valtanen et al., 2000; Alexander et al., 2004; CDC, 1981). The eradication movement gained momentum after smallpox's elimination. The World Health Assembly launched the Global Polio Eradication Initiative (GPEI) in 1988, inspired by early success in the Americas during the 1980s (Global Eradication Initiative, 2010a; Aylward & Tangermann, 2011). Immunization campaigns became some of the largest coordinated health interventions in history.

Still, imported wild polioviruses continued to spark outbreaks in countries that had already interrupted transmission, such as Finland, the Netherlands, Bulgaria, and Romania (Hovi et al., 1986; Bijkerk, 1979; Oostvogel, 1994; WHO, 1992; Strebel et al., 1994). Political collapse and weak health systems fueled re-emergence in parts of the former Soviet Union during the 1990s (Oblapenko & Sutter, 1997; Patriarca et al., 1997).

Vaccines defined the strategy. Jonas Salk's inactivated polio vaccine (IPV), licensed in 1955, provided systemic immunity without risk of vaccine-associated poliomyelitis. Albert Sabin's oral polio vaccine (OPV), introduced in 1961, was cheaper, easier to administer, and induced mucosal immunity in the intestine. OPV stopped transmission rapidly during mass campaigns, but it carried rare risks of vaccine-associated paralytic poliomyelitis (VAPP) and, over time, the emergence of circulating vaccine-derived polioviruses (cVDPVs) (Luther, 1962; Henderson, 1964; Schonberger et al., 1976; Kew et al., 2004). By the 2000s, high-income countries adopted IPV schedules, while low-resource and endemic regions continued with OPV because of cost and logistics (Global Polio Eradication Initiative, 2010b–e; Martin et al., 2013).

Despite setbacks, global coverage rose. By 2010, about 85 percent of children worldwide had received three doses of oral vaccine, though disparities remained at national and subnational levels (CDC, 2011d; Hopkins, 2013). India celebrated one year without a polio case in January 2012, a landmark given the country's previous burden (CDC, 2011a, 2011b, 2011c). Endemic transmission, however, persisted in Nigeria, Afghanistan, and Pakistan, driven by political instability, community mistrust, and fragile health systems (Hopkins, 2013). The cost of eradication was estimated at $9.5 billion from 1988 to 2013 (Global Polio Eradication Initiative, 2010d). Yet even with vast investment, new challenges arose. Genetic sequencing revealed poliovirus in Egyptian sewage linked to strains circulating in Pakistan, years after Egypt's

certification as polio-free (Roberts, 2013). Outbreaks of cVDPVs underscored the double edge of OPV. The disparity between IPV use in wealthy nations and continued reliance on OPV in poorer countries exposed a global fault line. By 2012, experts still aimed to interrupt wild poliovirus transmission, but fatigue among donors, political instability, and repeated outbreaks made the goal elusive.

2.2.1.2 Milestones in Nigeria's Polio Eradication Journey.

Nigeria's fight against polio shows how fragile progress can be when public trust collapses. Resistance in the north, especially in Kano and neighboring states, took root in the early 2000s. Rumors spread that the vaccine carried infertility drugs, HIV, or cancerous agents. Suspicion of Western medicine was strong, and campaigns faltered (Jegede, 2007; Mohammed et al., 2009). The pause in vaccination created gaps that allowed wild poliovirus to circulate.

Community engagement had to change. The CORE Group Partners Project (CGPP), introduced in 2014, relied on women recruited from their own towns and villages. These volunteer community mobilizers gained credibility through proximity and persistence. They visited homes. They listened. They countered misinformation in familiar language. Over time, their presence softened distrust and shifted local attitudes (Usman et al., 2019; Duru et al., 2019). Traditional rulers and religious leaders added their weight, lending legitimacy to the effort. Without this layer of social acceptance, eradication would not have advanced.

Surveillance became another cornerstone. Nigeria needed to track every case of acute flaccid paralysis, every missed child, every resistant household. The VCMs doubled as field observers. They joined NGOs and independent monitors to ensure gaps were exposed quickly. Health camps appeared in settlements displaced by conflict. House-to-house visits and compound dialogues kept the campaign visible. Data flowed upward, giving health workers and politicians little room to

ignore weaknesses (Hamisu et al., 2018; Nasir et al., 2016). Accountability followed. The National Polio Emergency Operations Centre forced states to defend their coverage rates before peers, governors, and even the president. If immunization fell below the 80 percent benchmark, corrective steps were imposed. This structure kept pressure on local authorities and gave donors evidence of transparency. Constant monitoring by groups outside government made it harder to dismiss failures (Duru et al., 2019). Partnerships carried the weight of resources. Nigeria's eradication drive leaned on the Bill & Melinda Gates Foundation, Rotary International, WHO, UNICEF, and CDC. Local NGOs filled staffing gaps and extended reach into communities that government could not cover. Immunization campaigns added incentives which includes bed nets, deworming tablets, vitamin A supplements that help to reassure parents that health workers brought genuine benefit (Abimbola et al., 2013; Perry et al., 2019).

2.2.2 Surveillance Approaches for Poliovirus

2.2.2.1 Acute Flaccid Paralysis (AFP) surveillance

Acute flaccid paralysis (AFP) surveillance is a standardized, case-based syndromic surveillance system used globally (WHO, 2024). It employs uniform tools, indicators, and reporting systems across all countries, thereby strengthening collaboration with immunization partners through the timely sharing of weekly data (WHO, 2023). This standardization enables early detection of risks and weaknesses and facilitates coordinated responses (Badizadegan & Thompson, 2025). AFP surveillance is critical because poliovirus infections are difficult to detect. Only about one in 200 infections with wild poliovirus (WPV) in non-immune individuals results in paralysis (WHO, 2024). Most infections are "silent," producing no clinical symptoms. Furthermore, when paralysis does occur, it may mimic other conditions such as Guillain-Barré syndrome (GBS). To address these challenges, the Global Polio Eradication Initiative (GPEI) adopted two key measures in the

1980s: (1) designating AFP as a reportable condition, and (2) confirming poliovirus through laboratory testing of stool specimens in World Health Organization (WHO)-accredited laboratories (WHO, 2024).

Prior to GPEI, polio was reported as a clinically confirmed condition within general disease surveillance systems, often only annually. This limited sensitivity and responsiveness in detecting outbreaks (Badizadegan & Thompson, 2025). By adopting AFP as the reportable syndrome, health systems became more sensitive to potential cases of poliovirus. An AFP case is defined as any child under 15 years presenting with sudden-onset floppy paralysis or muscle weakness from any cause, or any person with suspected poliomyelitis. This definition captures a wide range of conditions, including poliomyelitis, GBS, transverse myelitis, and traumatic neuritis. Laboratory investigation is therefore essential to confirm the underlying cause (WHO, 2024).

To measure sensitivity, the non-polio AFP detection rate serves as a key indicator. In polio-free contexts, surveillance systems are expected to detect at least one non-polio AFP case per 100,000 children under 15 years annually. In outbreak-affected or high-risk countries, the target is at least two cases per 100,000, while in endemic areas it is at least three per 100,000. Testing stool samples remains the gold standard for confirming poliovirus infection. Two specimens collected 24 hours apart, within 14 days of paralysis onset, must be sent to WHO-accredited laboratories. At least 80% of reported AFP cases should meet this standard to ensure adequate surveillance sensitivity (WHO, 2024).

Strategies for AFP Surveillance

AFP cases are identified using three main strategies:

1. **Routine (passive) surveillance:** Regular reporting by health facilities, sometimes referred to as zero reporting, where sites must submit weekly reports even if no cases are detected.

2. **Active surveillance (AS):** Surveillance officers visit reporting sites regularly to verify case reporting, strengthen compliance, and identify missed AFP cases.

3. **Community-based surveillance (CBS):** Community volunteers and non-traditional reporting networks assist in identifying suspected AFP cases, particularly in underserved or hard-to-reach populations.

Despite its strengths, AFP surveillance faces limitations such as incomplete reporting networks, inconsistent weekly reporting, high staff turnover, declining awareness about polio, and confusion between passive and active surveillance approaches (Badizadegan & Thompson, 2025). These challenges can delay detection and weaken the sensitivity of the system. Strengthening active surveillance and community engagement can help mitigate these weaknesses.

2.2.2.2 Environmental Surveillance (ES): Principles, Processes, and Added Value

Principles of Environmental Surveillance

Environmental surveillance (ES) involves monitoring the circulation of enteric pathogens in a population through sewage samples containing human fecal material (Hovi et al., 2012). Unlike acute flaccid paralysis (AFP) surveillance, which relies on symptomatic case detection, ES identifies pathogen shedding in stool, capturing both symptomatic and asymptomatic infections. This makes ES particularly valuable for detecting "silent transmission" that cannot be observed through clinical surveillance alone. Poliovirus eradication efforts increasingly rely on ES due to the limitations of AFP surveillance. As the incidence of paralytic polio declines, the majority of poliovirus infections remain asymptomatic, with only about one in 200 cases resulting in paralysis. Furthermore, the clinical presentation of AFP can overlap with other conditions, and laboratory

confirmation is often complex. In this context, ES has emerged as an essential complementary tool for early detection of poliovirus circulation and for monitoring the impact of immunization campaigns (Manor et al., 1999; Asghar et al., 2014).

Processes and Technical Considerations

The World Health Organization (WHO) first issued guidelines for poliovirus ES in 2003, recommending that sampling sites be located at inlets of sewage treatment plants or other major collector sewers (WHO, 2003). The success of this strategy depends on several conditions:

i. A functioning sewerage system that serves the majority of the population, including high-risk groups.

ii. Reliable transport of human fecal material into the sewerage system.

iii. Sufficient environmental persistence of the target pathogen.

iv. Sensitive and specific laboratory assays capable of detecting the pathogen in concentrated sewage samples.

Where sewerage networks are absent or fragmented, ES is more difficult to implement effectively. Challenges such as inconsistent sewage flow, pathogen dilution, and rapid viral decay can reduce detection sensitivity. In such contexts, models are needed to guide site selection and sampling strategies. For pathogens less environmentally persistent than poliovirus, such as *Salmonella Typhi*, ES may have more limited utility.

Added Value of Environmental Surveillance

The greatest contribution of ES is its ability to detect poliovirus transmission earlier and more comprehensively than AFP surveillance alone. Comparative studies highlight several advantages:

- Early detection: ES often identifies poliovirus circulation weeks or months before AFP cases are reported. In Pakistan, ES detected genetically related poliovirus strains more than 200 days before the onset of clinical symptoms in associated AFP cases (Cowger et al., 2017; Alam et al., 2014).

- Silent outbreak detection: ES has revealed circulation in the absence of reported AFP cases, as documented in Israel and Nigeria, demonstrating its capacity to detect silent transmission (Manor et al., 1999; Asghar et al., 2014).

- Reduced orphan viruses: The frequency of "orphan viruses" (isolates with significant genetic divergence, indicating prolonged undetected circulation) declines when ES supplements AFP surveillance. This suggests a more complete capture of transmission chains.

- Programmatic decision-making: Early signals from ES allow health authorities to implement timely immunization campaigns, strengthen routine immunization, and target high-risk populations more effectively. In Lahore, Pakistan, detection of WPV through ES informed rapid vaccination interventions that helped prevent wider spread (Asghar et al., 2014).

Strategic Integration with AFP Surveillance

While AFP surveillance covers entire national populations, ES is geographically limited to populations served by specific catchment areas. Nevertheless, ES can detect cross-regional or even cross-border transmission, as seen when viruses from Afghanistan were first detected in Pakistani ES sites before AFP confirmation (Shaukat et al., 2014).

Together, AFP and ES form a synergistic system: AFP provides wide national coverage, while ES offers enhanced sensitivity and early-warning capacity. The integration of both approaches has been critical for maintaining progress toward eradication in high-risk countries such as Pakistan, India, and Nigeria.

Table 1: Comparison of AFP and ES for Poliovirus

Feature	(AFP) Surveillance	Environmental Surveillance (ES)
Principle	Case-based syndromic surveillance targeting children <15 years with sudden-onset flaccid paralysis.	Monitoring sewage/wastewater for poliovirus excreted by infected individuals (symptomatic or asymptomatic).
Detection Scope	Detects only paralytic cases (about 1 in 200 infections).	Detects both symptomatic and asymptomatic infections through stool shedding.
Sensitivity	Limited; dependent on timely reporting, case investigation, and stool collection.	Higher; can detect silent circulation and outbreaks before AFP cases appear.
Timeliness	Often lags; relies on clinical presentation and reporting.	Provides early warning, sometimes months before AFP confirmation.
Laboratory Role	Stool specimens tested in WHO-accredited labs to confirm poliovirus.	Concentrated sewage samples tested in WHO-accredited labs to isolate poliovirus.
Coverage	National, as all health facilities are reporting sites.	Geographically limited to populations connected to sewerage systems or catchment areas.

Feature	(AFP) Surveillance	Environmental Surveillance (ES)
Key Indicators	- ≥1 non-polio AFP case per 100,000 children annually in polio-free areas. - ≥80% adequate stool specimen collection.	No universal quantitative indicator; sensitivity depends on sewage coverage, viral persistence, and laboratory performance.
Strengths	Standardized, globally adopted; ensures systematic detection and response; captures differential diagnoses.	Detects silent circulation; provides early signals; reduces "orphan viruses"; informs immunization campaigns.
Limitations	Cannot detect asymptomatic infections; prone to underreporting; delayed detection.	Requires functioning sewer systems; geographically limited; technical challenges in sampling and interpretation.
Programmatic Value	Provides broad national surveillance data to support certification of eradication.	Acts as an early-warning system; guides timely interventions and targeted immunization campaigns.
Best Use	Universal baseline surveillance for all countries.	Complementary tool in high-risk, endemic, or outbreak-prone areas to enhance sensitivity.

Source: Researcher's Computation from WHO (2023, 2024)

2.3 Empirical Review

2.3.1 Global Empirical Contributions of Environmental Surveillance (ES) to Polio

Manyanga et al. (2025) conducted an evaluation of environmental surveillance (ES) in South Africa to supplement acute flaccid paralysis (AFP) surveillance. The study assessed 16 ES sites across eight metropolitan health districts between 2020 and 2023 using both secondary data and

qualitative field visits. Findings revealed that 97.9% of collected samples reached the National Institute for Communicable Diseases within 72 hours, with monthly sampling increasing significantly from 18% in 2020 to 32.5% in 2021 (p = 0.0085). Although no significant differences were observed in enterovirus isolation rates between virtually and physically trained sites, operational variability was noted in densely populated cities. The study concluded that while ES is progressing in South Africa, attention to irregular sampling and peak-hour collection strategies is required to enhance performance and scalability across the region.

Similarly, Alam et al. (2014) reported on Pakistan's ES program, which began in 2009 and rapidly expanded to 27 sites across four provinces. Between 2011 and 2013, 668 samples were collected, with 40% testing positive for wild poliovirus type 1 (WPV-1). The highest detection rates were observed in Peshawar (82%), Karachi-Gadap (69%), and Rawalpindi (65%). Phylogenetic analysis revealed multiple WPV-1 lineages circulating across provinces and crossing into Afghanistan. The authors concluded that ES in Pakistan was a powerful tool for identifying poliovirus circulation in the absence of AFP cases, thereby strengthening cross-border eradication efforts.

Cowger et al. (2017) further demonstrated the critical role of ES in Pakistan between 2011 and 2013 by analyzing over 1,100 WPV isolates. Their study found that ES detected circulation before AFP in nearly 60% of polio cases, with an average lead time of 118 days. Importantly, combined ES and AFP surveillance reduced the proportion of "orphan viruses" (undetected circulation) from 7.7% under AFP alone to 3.3%. The study emphasized that ES provided earlier and more sensitive detection than AFP alone, reinforcing its strategic role in eradication endgame planning.

In Ghana, Baguune et al. (2024) evaluated the ES system in the Northern Region from 2019 to 2020 using CDC guidelines. Among 48 samples collected, one tested positive for circulating vaccine-derived poliovirus (cVDPV), which triggered enhanced AFP surveillance and subsequent

vaccination campaigns. The evaluation highlighted high completeness (97.9%) and timeliness in sample collection, as well as stakeholder commitment. However, feedback mechanisms from national to regional levels required strengthening. The study confirmed that ES was both useful and acceptable for outbreak detection and program response.

Evidence from China also illustrates the complementary role of ES. Chen et al. (2020) reviewed AFP and ES data from Shandong Province between 1991 and 2018. Of the 352 sewage samples collected, 61.6% were positive for poliovirus, including one detection of vaccine-derived poliovirus type 2 (VDPV2). While no wild poliovirus was isolated during the review period, ES proved valuable in identifying a wide diversity of enteroviruses and vaccine-associated polioviruses, thereby complementing AFP surveillance in monitoring poliovirus circulation during the polio endgame strategy.

At the global level, Hovi et al. (2012) provided an overview of ES contributions, emphasizing its sensitivity in detecting poliovirus excretion in both symptomatic and asymptomatic individuals. The study highlighted how WHO incorporated ES into its strategic plan for 2010–2012 as a supplement to AFP surveillance. Under optimal conditions, ES was found to be more sensitive than AFP, particularly in contexts where asymptomatic infections dominated transmission dynamics. Collectively, these empirical studies demonstrate the critical role of ES in enhancing the sensitivity, timeliness, and effectiveness of polio eradication programs worldwide. While AFP surveillance remains the gold standard, ES provides earlier detection, identifies silent circulation, and informs timely immunization responses. The global experience show the importance of integrating both surveillance approaches to sustain progress and achieve final eradication.

2.3.2 Empirical Contributions of Environmental Surveillance (ES) to Polio in Nigeria

Johnson et al. (2016) conducted a study titled *Contribution of Environmental Surveillance Toward Interruption of Poliovirus Transmission in Nigeria, 2012–2015*. The study examined how environmental surveillance (ES) complemented acute flaccid paralysis (AFP) surveillance in guiding key interventions against poliovirus transmission. Using the grab method, 1.75 L of raw sewage was collected every 2–4 weeks and analyzed in polio laboratories. Between 2012 and 2015, ES identified 97 circulating vaccine-derived polioviruses type 2 (cVDPV2) and 14 wild polioviruses. For instance, in 2014 alone, 54 cVDPV2 cases and one WPV1 case were reported. These findings triggered mass immunization campaigns in Borno and Yobe States, where over 4.7 million doses of oral and inactivated polio vaccines were administered. The study concluded that ES played a crucial role in early detection and informed rapid response strategies that contributed to the eventual interruption of transmission.

Hamisu et al. (2022) conducted a study titled *Characterizing Environmental Surveillance Sites in Nigeria and Their Sensitivity to Detect Poliovirus and Other Enteroviruses*. The study assessed how site characteristics affect ES sensitivity in a resource-constrained setting. Using quarterly data from 78 ES sites across 21 states between June 2018 and May 2019, the researchers matched 1,345 samples with site features such as catchment population, water quality, and sewage flow. Mixed-effects regression and machine learning models showed that higher pH, larger catchment populations, and elevated dissolved solids were significantly associated with higher enterovirus detection rates (average prevalence = 68%). The random forest model predicted high-performing sites (>70% prevalence) with 75% sensitivity and specificity. The study recommended simple measurement tools and population estimates as cost-effective strategies to strengthen surveillance sensitivity.

Dankoli (2019) conducted a study titled *Environmental Surveillance and Vaccine-Derived Poliovirus Type 2 Isolation, Gombe State, Nigeria*. The study compared ES and AFP surveillance yields between January 2017 and June 2018. A total of 309 sewage samples from five ES sites and 142 AFP stool samples were analyzed. ES detected three VDPV2 isolates (0.97%), 102 non-polio enteroviruses (33.01%), and 41 negative samples (13.27%). In contrast, AFP surveillance detected no VDPV2, with a much lower NPEV detection rate of 9.16%. The findings demonstrated the superior sensitivity of ES in detecting poliovirus circulation, even in the absence of AFP-confirmed cases. The study concluded that ES provided critical early warning capacity and should be expanded alongside AFP systems.

Nightingale et al. (2025) conducted a study titled *Sub-national Estimation of Surveillance Sensitivity to Inform Declaration of Disease Elimination: A Retrospective Validation Against the Elimination of Wild Poliovirus in Nigeria.* The study developed a statistical framework to estimate the sensitivity of ES and AFP in confirming elimination of WPV1 at the local government authority level. Retrospective validation was performed for two poliovirus-free intervals: 2014–2016 and 2016–2020. Results showed an 85% probability of freedom from infection (FFI) after 23 months of virus absence in 2014–2016 (95% UI: 77.1–90.2%), which underestimated true circulation since WPV1 reappeared in 2016. By contrast, the probability of FFI reached 98% (95% UI: 97.9–98.7%) by 2020, aligning with Nigeria's official elimination declaration. The study confirmed the utility of ES-derived sensitivity models for prospective eradication certification and outbreak monitoring.

Weldegebriel et al. (2015) conducted a study titled *Environmental Surveillance for Poliovirus in Polio High-Risk States of Nigeria, 2011–2012*. The study examined early ES implementation in Kano and Sokoto States using the grab sampling method. Between 2011 and 2012, 60 sewage

samples were collected in Kano and 80 in Sokoto. Laboratory analysis revealed in Kano that 39 isolates (63%) were Sabin strains, 16 (26%) were cVDPV2, 2 (3%) were WPV1, 4 (6%) were non-polio enteroviruses, and 1 (3%) was WPV3. In Sokoto, 33 isolates (35%) were cVDPV2, 27 (29%) were Sabin strains, 16 (17%) were WPV1, and 17 (18%) were NPEVs. The study demonstrated ES's capacity to detect both wild and vaccine-derived polioviruses missed by AFP surveillance, highlighting immunity gaps and the role of nomadic populations in sustaining virus transmission. The researchers recommended aggressive mop-up campaigns and targeted vaccination of underserved groups to close immunity gaps.

2.3.3 Research Gap

Although previous studies have provided substantial evidence of the importance of environmental surveillance (ES) in detecting poliovirus in Nigeria, several gaps remain. Early studies (Weldegebriel et al., 2015; Johnson et al., 2016) demonstrated that ES could detect wild polioviruses (WPVs) and circulating vaccine-derived polioviruses (cVDPVs) missed by acute flaccid paralysis (AFP) surveillance. However, these studies focused largely on descriptive detection outcomes without systematically quantifying ES's contribution to early warning compared with AFP. More recent works (Hamisu et al., 2022; Dankoli, 2019) evaluated ES sensitivity and site characteristics, but they were geographically limited and did not assess ES performance in the broader context of high-risk states where surveillance sensitivity is critical. Nightingale et al. (2025) advanced the discussion by modeling surveillance sensitivity for eradication certification, but their approach relied on retrospective probabilistic estimation rather than operational field-level realities. The reviewed studies indicate that while ES enhances detection capacity and provides early warning signals, there has been limited comparative evaluation of ES and AFP performance across high-risk states in Nigeria. Additionally, there is

insufficient analysis of operational challenges such as infrastructure gaps, site representativeness, and laboratory turnaround times. These gaps limit the translation of ES findings into actionable programmatic strategies for strengthening Nigeria's polio surveillance system.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter describes the methodology employed in the study. It is presented under the following sub-headings: Research Design, Study Area, Target Population, Sample and Sampling Technique, Research Instrument, Validity and Reliability of Instrument, Data Collection Procedure, Ethical Considerations, Data Analysis, and Limitations of the Study.

3.1 Study Area

The study was conducted in Nigeria, covering 21 states purposively selected to represent both high-risk and low-risk states for poliovirus transmission. The choice of these states was informed by historical polio epidemiology, the presence of environmental surveillance (ES) sites, and the classification of states by risk level for polio re-emergence.

3.2 Study Design

A descriptive cross-sectional survey design was adopted for this study. The design was appropriate because it allowed the researcher to obtain data from a diverse group of professionals involved in polio surveillance at a single point in time, thereby providing a comprehensive picture of the effectiveness and operational challenges of environmental surveillance in Nigeria.

3.3 Study Population

The study population consisted of professionals engaged in polio surveillance and related activities across the selected states. These included Environmental Health Officers, Laboratory Scientists, Physicians, Nurses, and other technical staff directly or indirectly involved in the operation of environmental surveillance and Acute Flaccid Paralysis (AFP) surveillance systems.

3.4 Inclusion and Exclusion Criteria

3.4.1 Inclusion Criteria

i. Professionals actively engaged in polio surveillance in any of the selected 21 states.

ii. Individuals with at least one year of experience in surveillance-related roles.

iii. Respondents who consented to participate.

3.4.2 Exclusion Criteria

i. Professionals not directly engaged in polio surveillance activities.

ii. Individuals who declined consent.

3.5 Sample Size and Sampling Technique

A total of 450 respondents participated in the study. The sample was determined to ensure adequate representation across the states and professional groups. A purposive sampling technique was employed to target professionals directly involved in surveillance activities, while proportional allocation was used to balance the representation across different cadres such as Environmental Health Officers, Laboratory Scientists, and other health workers.

3.6 Research Instrument

Data were collected using a structured, self-administered questionnaire developed by the researcher. The questionnaire comprised sections on respondents' demographic and professional characteristics, awareness and training on ES, perceptions of ES effectiveness compared with AFP, operational challenges faced in ES implementation, and recommendations for improvement.

3.7 Validity and Reliability of the Instrument

The questionnaire was subjected to expert review. It was first submitted to the study's supervisor, then other experts also contributed in the review. This includes specialists in epidemiology,

surveillance, and public health research to ensure face and content validity. A pilot test was conducted with 30 respondents in a non-participating state to assess clarity and reliability. Feedback was used to refine the instrument, and Cronbach's alpha was calculated for key Likert-scale sections, with a coefficient above 0.70 considered acceptable for internal consistency.

3.8 Data Collection Procedure

Permission was sought from relevant authorities, including State Primary Health Care Development Agencies. The researcher, with trained research assistants, distributed the questionnaires to respondents across the 21 states. In states with limited internet access, physical administration of questionnaires was carried out, while in others, electronic versions were used. Respondents were given adequate time to complete the questionnaire, and collection was done over a six-week period.

3.9 Ethical Considerations

Ethical approval will be sought from the Kwara State University Ethics Committee. Respondents were informed of the study objectives, assured of confidentiality, and told their participation was voluntary, with the option to withdraw at any stage without consequences. Verbal consent was obtained before participation.

3.10 Data Analysis

Completed questionnaires were coded and entered into the Statistical Package for the Social Sciences (SPSS) version 29. Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize demographic data and responses. Inferential statistics, including Chi-square tests, logistic regression, and odds ratio calculations, were used to examine associations and predictors of participation in environmental surveillance. Statistical significance

was set at $p \leq 0.05$. Results were presented using tables, charts, and narratives to align with the study objectives.

3.11 Limitations of the Study

The study relied exclusively on self-reported data from questionnaires, which may be subject to recall bias and social desirability bias. The use of purposive sampling may limit generalizability beyond the study states. Nevertheless, the inclusion of 450 respondents across 21 states and multiple professional groups strengthens the representativeness of findings.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Result Presentation

Table 2: Sociodemographic Characteristics of Respondents (N = 450)

Variable	*n*	%
Gender		
Female	244	54.22
Male	206	45.78
Age group		
18–30	96	21.33
31–40	195	43.33
41–50	124	27.56
51+	35	7.78
Current position		
Environmental Health Officer	194	43.11
Laboratory Scientist	113	25.11
Surveillance Officer	72	16.00
Health Facility Worker	66	14.67
Other	5	1.11
Years of experience		
Less than 5 years	86	19.11
5–10 years	210	46.67
11–15 years	111	24.67
Over 15 years	43	9.56

Sociodemographic Characteristics of Respondents

A total of 450 respondents participated in the study (Table 2). With respect to gender, 244 (54.2%) were female and 206 (45.8%) were male. In terms of age distribution, the largest proportion of respondents were aged 31–40 years (n = 195, 43.3%), followed by those aged 41–50 years (n = 124, 27.6%). Respondents aged 18–30 years accounted for 96 (21.3%), while those aged 51 years and above constituted the smallest group (n = 35, 7.8%). Regarding professional positions, Environmental Health Officers represented the largest category (n = 194, 43.1%), followed by Laboratory Scientists (n = 113, 25.1%), Surveillance Officers (n = 72, 16.0%), and Health Facility Workers (n = 66, 14.7%). A small proportion (n = 5, 1.1%) reported "Other" positions. With respect to years of professional experience, nearly half of the respondents (n = 210, 46.7%) reported 5–10 years of experience. This was followed by 111 (24.7%) with 11–15 years of experience, 86 (19.1%) with less than 5 years, and 43 (9.6%) with more than 15 years of professional experience.
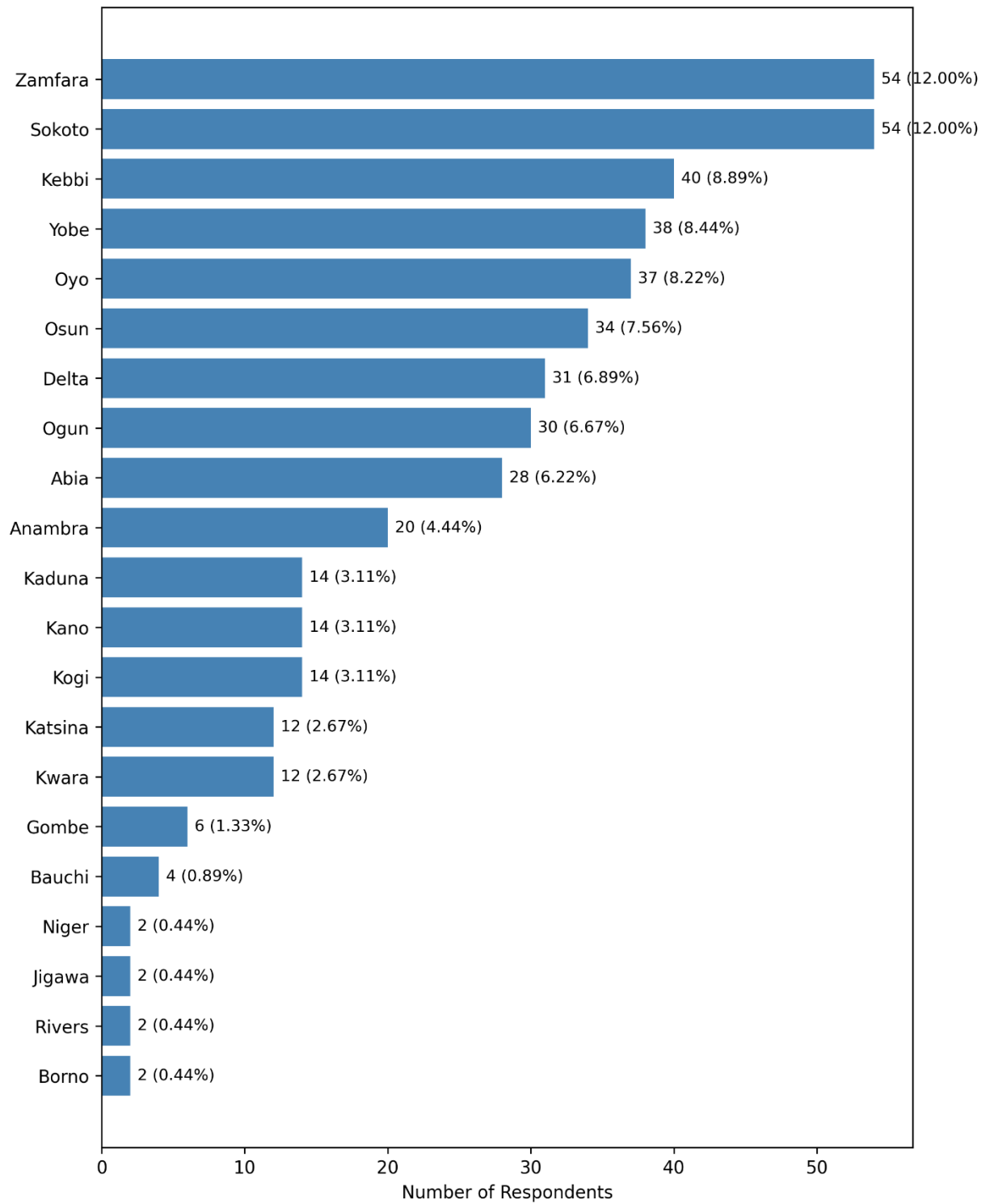
Figure 2: Location/State of Primary Assignment

State of Primary Assignment

Respondents were distributed across 21 states in Nigeria (Figure 2). The highest representation came from Zamfara (n = 54, 12.0%) and Sokoto (n = 54, 12.0%), followed by Kebbi (n = 40, 8.9%), Yobe (n = 38, 8.4%), Oyo (n = 37, 8.2%), and Osun (n = 34, 7.6%). Other notable states included Delta (n = 31, 6.9%), Ogun (n = 30, 6.7%), and Abia (n = 28, 6.2%). A smaller proportion of respondents were drawn from Anambra (n = 20, 4.4%), Kano (n = 14, 3.1%), Kaduna (n = 14, 3.1%), Kogi (n = 14, 3.1%), Katsina (n = 12, 2.7%), and Kwara (n = 12, 2.7%). Very few participants were from Gombe (n = 6, 1.3%), Bauchi (n = 4, 0.9%), Niger (n = 2, 0.4%), Jigawa (n = 2, 0.4%), Rivers (n = 2, 0.4%), and Borno (n = 2, 0.4%).

Table 3: Chi-Square Test of Association between Awareness/Training and Environmental Surveillance (ES) Participation

Variable	No (%)	Not Sure (%)	Yes (%)	χ^2	df	p-value
Awareness of ES activities				103.09	2	<0.001***
No	59 (13.1%)	50 (11.1%)	16 (3.6%)			
Yes	68 (15.1%)	43 (9.6%)	214 (47.6%)			
Formal training on ES				85.98	2	<0.001***
No	61 (13.6%)	56 (12.4%)	30 (6.7%)			
Yes	66 (14.7%)	37 (8.2%)	200 (44.7%)			
Familiarity with ES processes				104.93	4	<0.001***
Not familiar	15 (3.3%)	11 (2.4%)	27 (6.0%)			
Somewhat familiar	50 (11.1%)	37 (8.2%)	91 (20.2%)			
Very familiar	62 (13.8%)	45 (10.0%)	112 (24.9%)			

*** = p < 0.001; ** = p < 0.01.*

The results in Table 3 show a strong and statistically significant association between respondents' awareness, training, and familiarity with environmental surveillance (ES) activities and their participation in ES. Awareness of ES was significantly associated with participation, χ^2(2, N = 450) = 103.09, p < .001. Among those who reported awareness of ES, 214 (47.6%) confirmed participation compared with only 16 (3.6%) among those not aware. Similarly, formal training on ES showed a significant association, χ^2(2, N = 450) = 85.98, p < .001. Respondents who had received training were more likely to report ES participation (200, 44.7%) than those without training (30, 6.7%). Familiarity with ES processes (such as sewage sampling and laboratory testing) was also strongly associated with participation, χ^2(4, N = 450) = 104.93, p < .001. Respondents who reported being very familiar with ES processes showed the highest participation (112, 24.9%), followed by those somewhat familiar (91, 20.2%), while those not familiar had much lower participation (27, 6.0%). These results suggest that awareness, training, and familiarity with ES processes are critical predictors of active engagement in ES activities. Increased sensitization and capacity building may therefore enhance participation rates.

Table 4: Cross-tabulation of State-by-State Environmental Surveillance Contribution to Early Detection of Poliovirus

State	No (%)	Not sure (%)	Yes (%)
Abia	21.43	57.14	21.43
Anambra	80.00	10.00	10.00
Bauchi	0.00	100.00	0.00
Borno	0.00	0.00	100.00
Delta	54.84	19.35	25.81
Gombe	0.00	0.00	100.00
Jigawa	100.00	0.00	0.00
Kaduna	0.00	0.00	100.00
Kano	0.00	0.00	100.00
Katsina	33.33	16.67	50.00
Kebbi	10.00	5.00	85.00
Kogi	28.57	71.43	0.00
Kwara	0.00	50.00	50.00
Niger	100.00	0.00	0.00
Ogun	46.67	33.33	20.00
Osun	47.06	23.53	29.41
Oyo	70.27	18.92	10.81
Rivers	0.00	100.00	0.00
Sokoto	22.22	22.22	55.56
Yobe	5.26	15.79	78.95
Zamfara	3.70	0.00	96.30
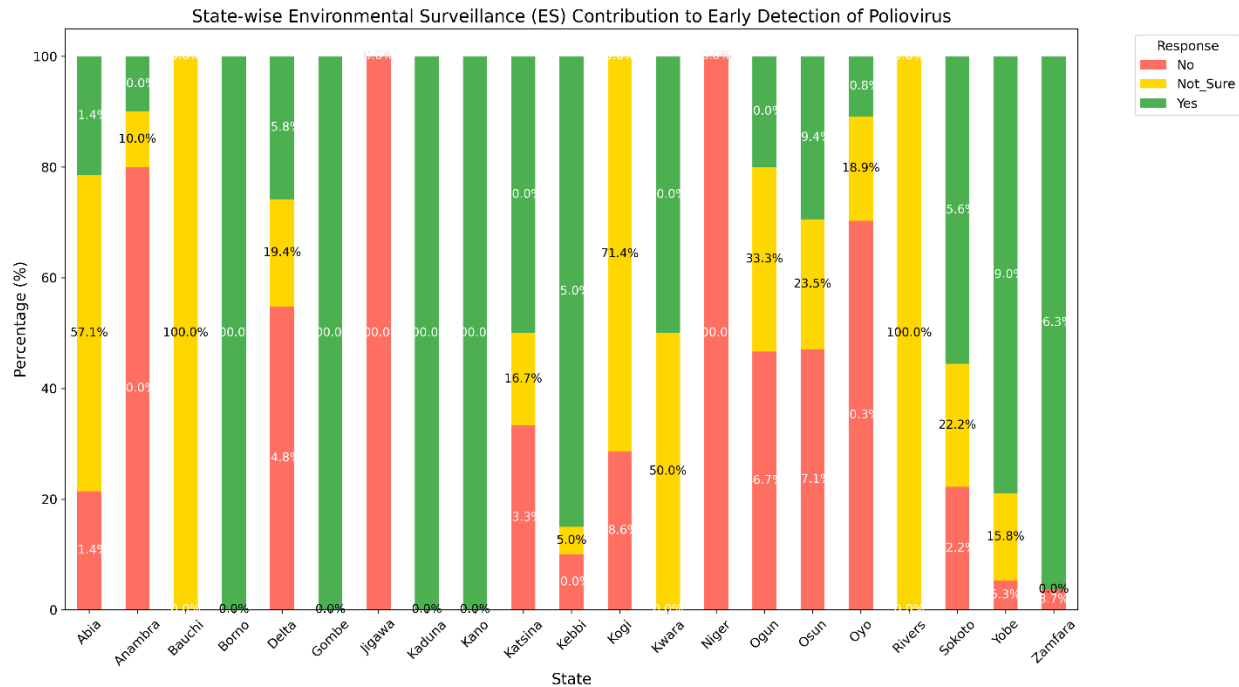
Figure 3: State-wise Environmental contributions to early detection of Poliovirus

Table 4 and figure 3 summarizes the perceived contribution of environmental surveillance to early detection of poliovirus across states. In states such as Borno, Gombe, Kaduna, Kano, Kebbi, Yobe, and Zamfara, respondents unanimously or predominantly reported that ES has contributed to early detection, with percentages ranging from 78.95% to 100%. Conversely, states including Anambra, Jigawa, Niger, and Rivers reported very low or zero affirmative contributions which show possible gaps in ES implementation or awareness. Several states, notably Abia, Delta, Ogun, Osun, and Oyo, showed substantial proportions of respondents unsure about ES contribution, ranging from 18.92% to 57.14%. These findings highlight significant variation in ES effectiveness perception by state, with some states demonstrating high operational contribution and others revealing either uncertainty or low impact. This state-level heterogeneity provides insight into geographical disparities in ES implementation and awareness.

Table 5: Chi-Square Test of Association between Roles/Effectiveness and Environmental Surveillance (ES)

Variable	No (%)	Not Sure (%)	Yes (%)	χ^2	df	p-value
Primary role in ES for polio eradication				36.64	10	<0.001***
Data management/reporting	36 (8.0%)	12 (2.7%)	62 (13.8%)			
Laboratory analysis	31 (6.9%)	20 (4.4%)	42 (9.3%)			
Nurse officer	0 (0.0%)	0 (0.0%)	2 (0.4%)			
Routine inspection	30 (6.7%)	37 (8.2%)	42 (9.3%)			
Sample collection	4 (0.9%)	13 (2.9%)	22 (4.9%)			
Supervision/coordination	26 (5.8%)	11 (2.4%)	60 (13.3%)			
Work with both AFP and ES systems				113.89	2	<0.001***
No	69 (15.3%)	72 (16.0%)	40 (8.9%)			
Yes	58 (12.9%)	21 (4.7%)	190 (42.4%)			
Effectiveness of ES vs. AFP	AFP (%)	Both (%)	ES (%)	Not sure (%)	128.07	9
Don't know	2 (0.4%)	7 (1.6%)	0 (0.0%)	22 (4.9%)		
Equally effective	48 (10.7%)	98 (21.8%)	18 (4.0%)	13 (2.9%)		
Less effective	16 (3.6%)	39 (8.7%)	5 (1.1%)	6 (1.3%)		
More effective	38 (8.4%)	112 (24.9%)	18 (4.0%)	8 (1.8%)		

*** = p < 0.001; ** = p < 0.01.*

Table 5 presents the associations between respondents' roles, engagement with AFP surveillance, and perceptions of ES effectiveness. There was a significant association between respondents' primary role in polio eradication and ES participation, χ^2(10, N = 450) = 36.64, p < .001. Those involved in supervision/coordination (60, 13.3%) and data management/reporting (62, 13.8%)

reported higher ES participation compared with sample collection (22, 4.9%) or nursing officers (2, 0.4%). Working across both AFP and ES systems was also significantly associated with participation, χ^2(2, N = 450) = 113.89, p < .001. Respondents engaged in both systems were far more likely to report ES participation (190, 42.4%) compared with those not working with both systems (40, 8.9%). Perceptions of effectiveness further revealed significant differences, χ^2(9, N = 450) = 128.07, p < .001. Most respondents believed ES was more effective (112, 24.9%) or equally effective (98, 21.8%) when compared to AFP, while only a minority rated ES as less effective (5, 1.1%). Notably, a substantial group considered both systems complementary in effectiveness. These findings highlight the importance of role specialization, integration of AFP and ES, and perceptions of comparative effectiveness. Respondents most engaged in supervisory and dual-system roles were significantly more likely to recognize and participate in ES, underscoring the synergistic value of combining AFP and ES in polio detection.

Table 6: Cross-tabulation of Environmental Surveillance (ES) Effectiveness vs. System with Faster Virus Detection

ES Effectiveness	Acute Flaccid Paralysis (AFP)	Both	Environmental Surveillance (ES)	Not sure
Don't know	6.45%	22.58%	0.00%	70.97%
Equally effective	27.12%	55.37%	10.17%	7.34%
Less effective	24.24%	59.09%	7.58%	9.09%
More effective	21.59%	63.64%	10.23%	4.55%

Table 6 presents respondents' perceptions of environmental surveillance effectiveness relative to the system that detects poliovirus faster. Among respondents who did not know the effectiveness of ES, 6.45% indicated that Acute Flaccid Paralysis (AFP) detects faster, 22.58% indicated both systems detect at the same speed, 0.00% indicated ES alone detects faster, while the majority, 70.97%, were unsure. For respondents who rated ES as equally effective, more than half (55.37%) perceived that both systems detect viruses at similar rates, 27.12% indicated AFP, 10.17% indicated ES, and 7.34% were unsure. Among those who viewed ES as less effective, 59.09% reported that both systems detect faster, 24.24% indicated AFP, 7.58% indicated ES, and 9.09% were unsure. For respondents who perceived ES as more effective, 63.64% considered both systems equally fast, 21.59% indicated AFP, 10.23% indicated ES, and 4.55% were unsure.

Table 7: Chi-Square Test of Association between Operational Challenges and Environmental Surveillance (ES)

Challenge	No (%)	Not Sure (%)	Yes (%)	χ^2	df	p-value
Poor funding	52 (11.6%)	38 (8.4%)	106 (23.6%)	1.23	2	.542
Inadequate training	38 (8.4%)	38 (8.4%)	110 (24.4%)	10.83	2	0.004**
Sample collection difficulties	100 (22.2%)	61 (13.6%)	126 (27.9%)	20.50	2	<0.001***
Delay in lab analysis	98 (21.8%)	63 (14.0%)	92 (20.4%)	52.24	2	<0.001***
Insecurity in sampling areas	113 (25.1%)	69 (15.3%)	118 (26.2%)	55.24	2	<0.001***
Logistical/transport issues	100 (22.2%)	53 (11.8%)	80 (17.8%)	64.59	2	<0.001***
Lack of community awareness	72 (16.0%)	33 (7.3%)	148 (32.9%)	22.43	2	<0.001***

*** = p < 0.001; ** = p < 0.01.*

The associations between operational challenges and ES participation are presented in Table 7. Poor funding was not significantly associated with ES participation, χ^2(2, N = 450) = 1.23, p = 0.542. This suggests that although funding constraints exist, they did not show a strong direct relationship with individual-level participation in ES activities. In contrast, inadequate training was significantly associated, χ^2(2, N = 450) = 10.83, p = 0.004. Respondents citing inadequate training were more likely to report participation (110, 24.4%), indicating that lack of skills influences engagement patterns. Other operational challenges also showed strong significant associations with participation. These include sample collection difficulties, χ^2(2, N = 450) = 20.50, p < 0.001; delays in laboratory analysis, χ^2(2, N = 450) = 52.24, p < .001; insecurity in sampling areas, χ^2(2, N = 450) = 55.24, p < .001; logistical/transport issues, χ^2(2, N = 450) = 64.59, p < 0.001; and lack of community awareness, χ^2(2, N = 450) = 22.43, p < .001. While funding was not statistically significant, most operational challenges which include training deficits, security risks, laboratory delays, logistics, and low community awareness were significantly associated with ES participation. These findings emphasize that strengthening technical capacity, ensuring timely laboratory analysis, addressing transport barriers, and engaging communities are crucial for effective ES implementation.

Table 8: High-Risk States Summary: ES Contribution, AFP Faster Detection, and Operational Challenges

State	ES Contribution (%)	AFP Faster (%)	Avg. Number of Challenges	High-Risk Flags
Bauchi	0.00	0.0	3.00	Low ES Contribution
Kogi	0.00	0.00	2.14	Low ES Contribution
Niger	0.00	0.00	5.00	Low ES Contribution, High Challenges
Jigawa	0.00	0.00	5.00	Low ES Contribution, High Challenges
Rivers	0.00	100.00	6.00	Low ES Contribution, AFP Faster than ES, High Challenges
Anambra	10.00	20.00	2.50	Low ES Contribution
Oyo	10.81	43.24	1.62	Low ES Contribution
Ogun	20.00	33.33	3.20	Low ES Contribution
Abia	21.43	14.29	2.57	Low ES Contribution
Delta	25.81	32.26	2.16	Low ES Contribution
Osun	29.41	23.53	2.09	Low ES Contribution
Kwara	50.00	16.67	3.00	None
Katsina	50.00	0.00	3.50	High Challenges
Sokoto	55.56	14.81	4.52	High Challenges
Yobe	78.95	31.58	2.74	None
Kebbi	85.00	10.00	3.80	High Challenges
Zamfara	96.30	29.63	3.93	High Challenges
Gombe	100.00	66.67	4.00	AFP Faster than ES, High Challenges
Kaduna	100.00	14.29	5.00	High Challenges

State	ES Contribution (%)	AFP Faster (%)	Avg. Number of Challenges	High-Risk Flags
Kano	100.00	14.29	4.29	High Challenges
Borno	100.00	0.00	4.00	High Challenges

Note. "High-Risk Flags" indicate states with low ES contribution, high number of operational challenges, or AFP detection faster than ES.

Table 8 integrates three dimensions which includes ES contribution, AFP faster detection, and the average number of operational challenges to identify high-risk states. Several states, including Bauchi, Kogi, Niger, and Jigawa, showed zero ES contribution, while others such as Rivers reported zero contribution combined with AFP detecting faster than ES which suggest potential gaps in ES efficacy. The average number of operational challenges ranged from 1.62 in Oyo to 6.00 in Rivers, show variable operational difficulty across states. The "High-Risk Flags" column identifies specific risk factors, such as low ES contribution, high operational challenges, and instances where AFP detects faster than ES. For example, Rivers is flagged for all three criteria, which is a critical need for targeted intervention. States like Kwara and Yobe, which do not exhibit significant high-risk indicators, represent more effective ES implementation. This table provides a synthesized overview of states requiring priority attention to strengthen poliovirus surveillance and highlight both operational and performance-related vulnerabilities.

Table 9: Model Fit Statistics for Logistic Regression Predicting ES Contribution

Statistic	χ^2	df	p	Pseudo R²
Model	143.74	17	<.001	.31

Table 10: Binary Logistic Regression Predicting ES Contribution (N = 357)

Predictor	B (SE)	Wald z	p	OR	95% CI for OR
Intercept	-2.92 (0.79)	-3.71	<.001	0.05	[0.01, 0.25]
Awareness of ES (Yes)	1.40 (0.41)	3.40	<.001	4.04	[1.81, 9.02]
Formal training on ES (Yes)	0.89 (0.40)	2.22	.026	2.44	[1.11, 5.37]
Familiar with ES (Moderate)	-1.49 (0.62)	-2.39	.017	0.23	[0.07, 0.77]
Familiar with ES (High)	-0.66 (0.63)	-1.04	.300	0.52	[0.15, 1.79]
Experience: 6–10 yrs	0.85 (0.45)	1.89	.058	2.35	[0.97, 5.69]
Experience: 11+ yrs	1.92 (0.61)	3.16	.002	6.83	[2.08, 22.47]
Works with AFP & ES (Yes)	0.69 (0.34)	2.05	.040	1.99	[1.03, 3.85]
Faster detection: ES	1.13 (0.55)	2.07	.039	3.10	[1.06, 9.03]
Faster detection: Both	0.71 (0.34)	2.12	.034	2.04	[1.06, 3.93]
Number of challenges	0.34 (0.12)	2.84	.005	1.41	[1.11, 1.79]

Note. OR = Odds Ratio; CI = Confidence Interval. Only statistically significant predictors at p < .05 are bolded in interpretation.

A binary logistic regression was conducted to examine predictors of respondents' perceived contribution of environmental surveillance (ES) to early detection of poliovirus. The overall model demonstrated good fit, χ^2 (17, N = 357) = 143.74, p < .001, with a Pseudo R² of .31, indicating that the predictors explained approximately 31% of the variance in ES contribution (table 9). The model showed strong discrimination, with an area under the ROC curve (AUC) of .86. Awareness of ES activities significantly predicted contribution, with those aware being over four times more likely to report ES contribution compared to those unaware (OR = 4.04, 95% CI [1.81, 9.02], p <

.001). (table 10) Similarly, respondents who had received formal ES training were more than twice as likely to report contribution (OR = 2.44, 95% CI [1.11, 5.37], p = .026). Familiarity with ES processes showed a mixed pattern. Moderate familiarity was associated with reduced odds of contribution (OR = 0.23, 95% CI [0.07, 0.77], p = .017), whereas higher familiarity was not significant (p = .300). Length of experience also mattered. Respondents with more than 15 years of experience had significantly higher odds of reporting ES contribution (OR = 6.83, 95% CI [2.08, 22.47], p = .002), while those with fewer years of experience showed non-significant effects. Those who worked with both AFP and ES systems were nearly twice as likely to report contribution (OR = 1.99, 95% CI [1.03, 3.85], p = .040). Perceptions of which system provided faster detection also mattered: selecting AFP (OR = 3.10, 95% CI [1.06, 9.03], p = .039) or both systems (OR = 2.04, 95% CI [1.06, 3.93], p = .034) was associated with significantly greater odds of contribution compared to other responses. Finally, the number of reported challenges significantly predicted contribution. Each additional challenge increased the odds of reporting ES contribution by 41% (OR = 1.41, 95% CI [1.11, 1.79], p = .005) (table 10).

4.2 Key Findings

Respondent Profile

- Total of 450 participants from 21 states.
- Majority were Environmental Health Officers (43.1%) and Laboratory Scientists (25.1%).
- Most had 5–10 years of professional experience (46.7%), reflecting an experienced workforce.

Determinants of Participation

- Awareness, formal training, and familiarity with ES processes were strongly associated with active participation (p < .001).
- Supervisory and data management roles recorded higher engagement compared to sample collection and nursing roles.
- Dual involvement in both AFP and ES systems significantly increased participation.

State-Level Disparities

- High ES contribution: Zamfara (96.3%), Yobe (78.9%), Kebbi (85.0%), Borno, Gombe, Kaduna, and Kano (all 100%).

- Low or no contribution: Rivers, Niger, Jigawa, Bauchi, and Anambra.

- Rivers flagged as critical risk: low ES contribution, AFP faster detection, and highest number of challenges.

- Kwara and Yobe showed stronger ES performance with fewer high-risk indicators.

Perceptions of Effectiveness

- Most respondents rated ES as more effective (24.9%) or equally effective (21.8%) compared to AFP.

- Majority emphasized the complementary role of combining ES and AFP for timely detection.

Operational Challenges

Statistically significant barriers: inadequate training, sample collection difficulties, delays in lab analysis, insecurity in sampling areas, logistical/transport constraints, and low community awareness ($p < .01$).

- Poor funding, though widely acknowledged, was not statistically significant.

- Predictors of ES Contribution (Logistic Regression)

- Awareness of ES (OR = 4.04, $p < .001$).

- Formal ES training (OR = 2.44, $p = .026$).

- Longer professional experience (OR = 6.83, $p = .002$ for 15+ years).

- Dual involvement in AFP and ES (OR = 1.99, $p = .040$).

- Faster detection perception (AFP or both systems) positively associated with ES contribution.

- Each additional operational challenge increased the odds of reporting ES contribution by 41% (OR = 1.41, $p = .005$).

4.3 Discussion of Findings

4.3.1 Sociodemographic Characteristics of Respondents

The study revealed that the majority of respondents were female (54.2%), with the largest age group being 31–40 years (43.3%). Most respondents were Environmental Health Officers (43.1%) and Laboratory Scientists (25.1%), while nearly half (46.7%) reported 5–10 years of professional experience (Table 2). This profile indicates that the ES system in Nigeria is staffed by mid-career professionals with substantial field experience. Comparable findings have been documented in related surveillance studies. In Ghana, Baguune et al. (2024) observed that the effectiveness of surveillance systems relied heavily on mid-level health workers who possessed practical experience in field logistics. Similarly, Hamisu et al. (2022) in Nigeria emphasized that site sensitivity in ES depended not only on infrastructure but also on personnel capacity. The implication here is clear: the age and experience distribution of Nigerian ES staff provides a solid human resource base. However, the concentration of responsibilities among Environmental Health Officers and Laboratory Scientists limit multi-sectoral collaboration. A more inclusive and diversity spread of responsibilities across nurses, clinicians, and community actors could enhance representativeness and strengthen cross-linkages between facility-based and environmental surveillance.

4.3.2 Contribution of Environmental Surveillance to Early Detection of Poliovirus

Findings from Table 4 and Figure 3 indicate sharp differences in the contribution of ES across states. Respondents in the Northern part of Nigeria including Borno, Gombe, Kaduna, Kano, Kebbi, Yobe, and Zamfara overwhelmingly affirmed ES contributions, with detection rates between 78.9% and 100%. By contrast, states such as Anambra, Rivers, Niger, and Jigawa recorded minimal or zero contributions. States like Abia, Delta, Ogun, Osun, and Oyo revealed high levels of uncertainty regarding ES effectiveness. These results align with earlier Nigerian studies. Johnson et al. (2016) reported that ES detected cVDPV2 isolates in multiple northern states where AFP did not, while Dankoli (2019) in Gombe also highlighted ES as more sensitive than AFP. At the global level, Cowger et al. (2017) in Pakistan demonstrated that ES detected poliovirus an average of 118 days before AFP signals, confirming its superior sensitivity. The Nigerian data therefore reinforce the international consensus on ES effectiveness but expose uneven operationalization within the country. The study revealed that ES in Nigeria has the

potential to detect transmission earlier than AFP but suffers from geographical inconsistencies. The zero contribution in Rivers and Niger indicates systemic weaknesses, possibly linked to poor site coverage, laboratory challenges, or lack of trained personnel. Unless these gaps are corrected, the system risks leaving critical blind spots in polio eradication.

4.3.3 Comparison of Environmental Surveillance and AFP in High-Risk States

Respondents' perceptions of comparative effectiveness showed that 24.9% rated ES as more effective, while 21.8% rated it equally effective with AFP (Table 5). The regression model further revealed that those perceiving AFP or both systems as faster were significantly more likely to report ES contribution (OR = 3.10 and OR = 2.04 respectively). High-risk analysis (Table 8) also flagged states such as Rivers, Niger, and Jigawa for low ES contribution and high operational challenges, while in Gombe, AFP was reported to detect faster than ES. This finding resonates with Nightingale et al. (2025), who modelled Nigeria's ES performance and concluded that AFP–ES complementarity was critical for confirming virus absence with high confidence. Similarly, Weldegebriel et al. (2015) stressed that while ES consistently detected both wild and vaccine-derived strains in Kano and Sokoto, AFP remained essential for case-based confirmation. The consensus is that neither system alone is sufficient. From a critical standpoint, this study underscores the complementary nature of ES and AFP but warns against over-reliance on perception-driven assessments. The finding that AFP sometimes appeared faster than ES in certain states should not be dismissed; rather, it reflects operational lapses such as delayed sample transfer and analysis. True complementarity demands synchronized efficiency, not parallel weaknesses.

4.3.4 Operational Challenges Affecting ES Implementation

The study identified multiple operational barriers significantly associated with ES participation, including inadequate training, sample collection difficulties, laboratory delays, insecurity, logistical issues, and lack of community awareness (Table 7). Interestingly, poor funding, though frequently cited in literature, did not emerge as statistically significant. These findings echo international experiences. Manyanga et al. (2025) in South Africa emphasized the centrality of timely sample transfer, with 98% of samples reaching labs within 72 hours which is a benchmark Nigeria struggles to meet. In Ghana, Baguune et al. (2024) highlighted the absence of feedback mechanisms as a systemic weakness, similar to Nigeria's community-level engagement gap. Hamisu et al. (2022) also confirmed that site sensitivity was often undermined by logistical and

infrastructural deficiencies. The opinion that arises here is that Nigeria's ES does not primarily suffer from lack of funding, as often claimed, but from weak operational discipline. Training, logistics, and security appear to be the true choke points. This challenges the narrative that more resources alone will fix the system. Without structural improvements in laboratory processes, transport, and security coordination, additional funds may not translate into better outcomes.

4.3.5 Strategies to Improve Polio Surveillance Effectiveness in Nigeria

Regression results (Table 9) revealed that awareness (OR = 4.04), formal training (OR = 2.44), longer experience (OR = 6.83), and dual involvement in AFP and ES (OR = 1.99) were significant predictors of ES contribution. Each additional operational challenge reported increased the odds of contribution by 41%, suggesting that those more embedded in the system were simultaneously more exposed to its weaknesses. These findings provide a roadmap for improvement. Internationally, Chen et al. (2020) in Shandong province showed that sustained training and systematic laboratory coordination enabled ES to detect not only poliovirus but a wide range of enteroviruses over time. In Nigeria, the lesson in this study is clear. Embedding ES within broader routine surveillance, backed by regular capacity-building and integration with AFP, will yield more stable outcomes. In critical reflection, the path forward is less about expanding the number of ES sites and more about consolidating system quality. A surveillance network that is aware, trained, experienced, and cross-linked with AFP will achieve the sensitivity and reliability required for eradication. Community awareness and engagement also remain vital, given that local skepticism and security challenges directly shape sample accessibility. The findings show that environmental surveillance in Nigeria is both indispensable and fragile. It has proven effective in early detection, particularly in northern states, but it lags and inconsistent in many states in Nigeria, in terms of operational depth, and community integration. Compared with Pakistan's lead-time advantage and South Africa's efficiency benchmarks, Nigeria's ES system is still reactive rather than preventive. The central lesson is that sensitivity without operational stability creates blind spots. Strengthening training, logistics, laboratory efficiency, and AFP–ES integration is the most credible strategy to sustain Nigeria's polio-free status.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study assessed the effectiveness and operational challenges of environmental surveillance systems for polio eradication in Nigeria. The research findings in chapter 4 show that environmental surveillance has contributed meaningfully to early detection of poliovirus in several high-risk states, particularly in the northern region, where outbreaks have historically persisted. However, there are significant differences across different states, with some reporting strong contributions and others demonstrating limited or no effectiveness. The findings also confirmed that environmental surveillance and acute flaccid paralysis surveillance are complementary. Neither system is sufficient on its own, but together they provide a more complete picture of poliovirus transmission. Operational challenges emerged as critical barriers to system effectiveness. These included inadequate training, weak logistics, delayed laboratory processes, insecurity in conflict-prone areas, and low community awareness. Funding gaps were noted, but the analysis showed that institutional discipline, operational coordination, and human resource capacity are the greater determinants of performance. The study demonstrated that experience, formal training, dual involvement in AFP and ES, and awareness of operational challenges significantly influence effectiveness. These factors show the importance of embedding environmental surveillance into a broader system of routine surveillance, with continuous investment in capacity-building, site quality, and community engagement. In conclusion, the study established that environmental surveillance is indispensable to sustaining polio-free status in Nigeria. However, its effectiveness remains inconsistent across states. The study concluded that environmental surveillance in Nigeria has great potential but it is not effective in many states in Nigeria.

5.2 Recommendations

The following recommendations are made in line with the study's objectives. The government is recommended to strengthen environmental surveillance for polio eradication through targeted actions at the federal, state, and local levels:

The Federal Government are recommended to:

i. Strengthen national coordination of environmental surveillance with emphasis on uniform standards for sampling, transportation, and laboratory processing.

ii. Expand national capacity for laboratory analysis to reduce turnaround delays and improve detection accuracy.

iii. Institutionalize continuous training programs for environmental health officers, laboratory scientists, and surveillance staff.

iv. Establish a national monitoring and evaluation framework that integrates both AFP and ES data for real-time decision-making.

v. Prioritize security support for surveillance teams operating in conflict-affected states to ensure safe access to collection sites.

The State Government are recommended to:

i. Provide adequate logistical support such as vehicles, sample transport systems, and protective equipment for surveillance officers.

ii. Strengthen collaboration between state Ministries of Health, water authorities, and local governments to ensure wider site representativeness.

iii. Facilitate periodic stakeholder review meetings at state level to assess ES contributions and identify bottlenecks early.

iv. Allocate dedicated budget lines for environmental surveillance activities within state health budgets to reduce reliance on donor funding.

The Local Government are recommended to:

i. Mobilize community participation and awareness campaigns to improve acceptance of surveillance activities.

ii. Support routine training for local staff and encourage dual involvement in both AFP and ES surveillance for skill transfer.

iii. Establish local surveillance task teams to monitor site functionality and provide feedback to state authorities.

iv. Ensure community security arrangements in partnership with traditional rulers and local organizations to safeguard sample collection teams.

5.3 Policy and Future Research Implications

The study shows important policy implications. First, environmental surveillance should not be treated as an auxiliary system but as a central pillar of Nigeria's polio eradication strategy. It should be very effective in all the states in Nigeria and not only in the Northern part of the country. Its integration with AFP should be institutionalized through policy directives that mandate joint reporting and shared resource planning. Second, governments at all levels should prioritize operational stability over site expansion. A smaller number of well-functioning, high-quality ES sites will contribute more to eradication than numerous poorly managed ones. Third, sustained investment in training and laboratory infrastructure should be codified in policy to avoid dependence on ad-hoc donor interventions. For future research, systematic evaluations of ES effectiveness should extend beyond descriptive detection outcomes. Studies should focus on cost-effectiveness analysis, real-time performance assessment, and integration with genomic sequencing to track virus evolution. Comparative research across states would help to identify why some perform consistently better than others and offer lessons for national scale-up. Finally, future investigations should examine the role of community acceptance, security challenges, and inter-sectoral collaboration in shaping surveillance effectiveness.

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