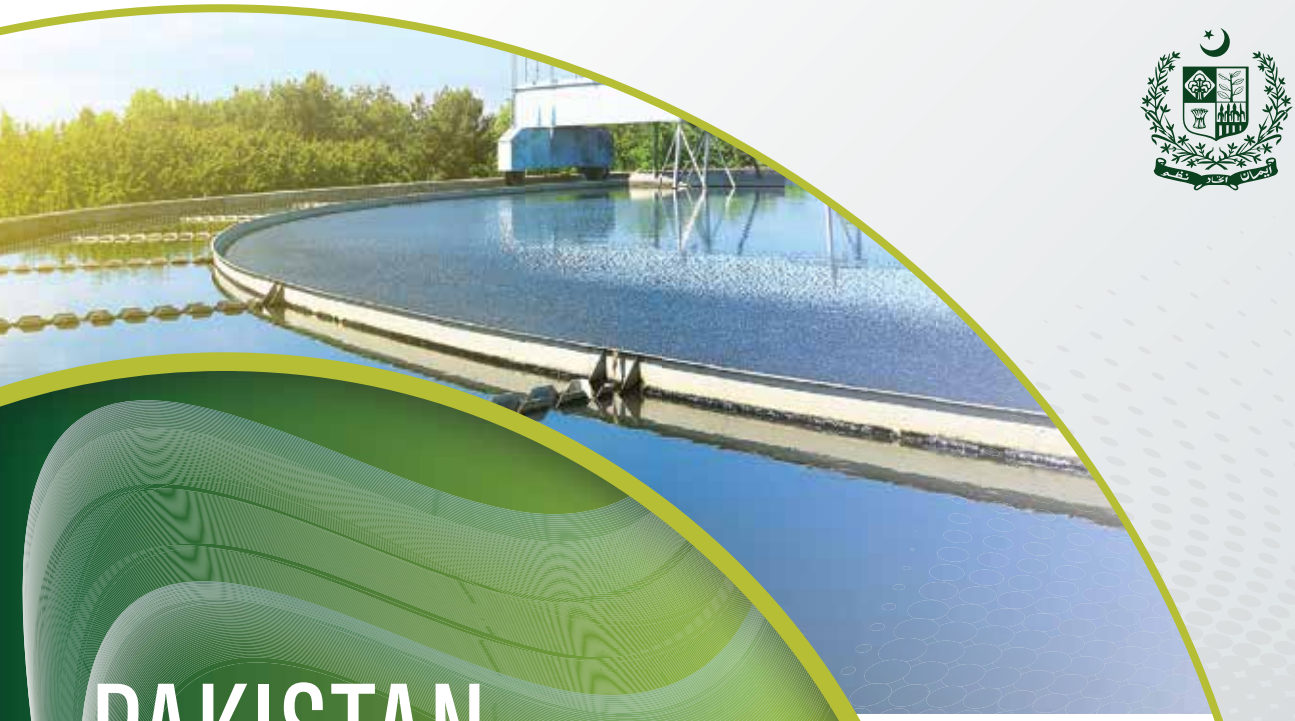



# PAKISTAN WASTEWATER ENVIRONMENTAL SURVEILLANCE STRATEGY

National Institutes of Health Pakistan

ASIA PATHOGEN GENOMICS Initiative

DukeNUS Medical School

THE AGA KHAN UNIVERSITY

# PAKISTAN **WASTEWATER ENVIRONMENTAL** SURVEILLANCE STRATEGY

National Institutes of Health Pakistan

CEO, National Institute of Health Park Road, Islamabad (44000) Pakistan
Email: ceo@nih.org.pk

Electronic copy is available at:
www.nih.org.pk

National Institute of Health, Park Road,
Chak Shahzad, Islamabad, Pakistan

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Tel: +92 (51) 9255110, +92 (51) 9255112-4
Fax: +92 (51) 9255099

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# Message from the

***Federal Minister for National Health Services, Regulations and Coordination, Government of Pakistan***

It gives me immense pleasure to present the **Pakistan National Wastewater Environmental Surveillance (WES) Strategy**, an important milestone in strengthening our country's public health surveillance system and preparedness for emerging and re-emerging health threats. Wastewater Environmental Surveillance has become an invaluable public health tool, complementing clinical and laboratory surveillance by providing timely, population-level information on the circulation of priority pathogens. It supports early warning, outbreak detection, disease trend monitoring, and evidence-based public health decision-making. The global experience during the COVID-19 pandemic further demonstrated the value of wastewater surveillance as an effective component of disease surveillance systems.

Pakistan has built a strong foundation through its long-established polio environmental surveillance programme. Building on this experience, the National Institute of Health (NIH), with support from the Gates Foundation and the Asia Pathogen Genomics Initiative (Asia PGI), has undertaken key initiatives to establish an integrated national WES programme. These include developing this National WES Strategy, prioritizing WES pathogens, strengthening laboratory and genomic capacities, standardizing sampling and analytical approaches, implementing pilot surveillance in Punjab and Sindh, and establishing a National WES Dashboard.

This Strategy provides a comprehensive roadmap for developing a coordinated, standardized, and sustainable national WES programme. Guided by the One Health approach, it sets strategic priorities for governance, laboratory systems, quality management, data integration, workforce development, research, and multisectoral collaboration. Its implementation will enable Pakistan to develop a fully integrated national WES system that strengthens early warning, supports timely public health action, and enhances national and global health security.

I commend all national and international partners, technical experts, and stakeholders whose valuable contributions through an inclusive consultative process have shaped this Strategy. Their commitment and collaboration have been instrumental in developing a practical and forward-looking roadmap for Pakistan. I am confident that the successful implementation of this Strategy will strengthen our capacity to prevent, detect, and respond to public health threats while contributing to Universal Health Coverage and the Sustainable Development Goals. I call upon all stakeholders to work together in realizing this shared vision for a healthier, safer, and more resilient Pakistan.

**Syed Mustafa Kamal**

# Message from

***Chief Executive Officer,***
***National Institutes of Health***

Wastewater Environmental Surveillance (WES) has emerged as a transformative public health tool, providing timely, population-level insights into the circulation of pathogens and complementing ongoing clinical and laboratory surveillance systems. By enabling early detection of disease trends and emerging health threats, WES has become an integral component of modern public health surveillance and pandemic preparedness. Pakistan is well positioned to expand its environmental surveillance capacity through its long-established polio environmental surveillance network and growing One Health collaborations. Building on these strengths, the National Institute of Health (NIH) has led the development of the **Pakistan National Wastewater Environmental Surveillance (WES) Strategy** through a comprehensive consultative process involving federal and provincial ministries, public health and environmental institutions, academia, development partners, and international technical organizations.

This Strategy assesses Pakistan's readiness for implementing a national WES programme, highlighting existing strengths while recognizing operational challenges, including fragmented wastewater infrastructure and varying laboratory capacities. It identifies priority pathogens for wastewater surveillance and provides a strategic framework covering governance, sampling site selection, laboratory and quality management systems, data integration, workforce development, and sustainable financing. Drawing upon WHO guidance and global best practices, the Strategy presents a phased and practical roadmap tailored to Pakistan's context.

The implementation of this Strategy will enable Pakistan to transition from pathogen-specific and project-based initiatives to a coordinated, integrated, and sustainable national WES programme. Such a system will strengthen early warning and outbreak detection, support WES priority pathogen detection, enhance pandemic preparedness, and generate evidence to inform timely public health action.

I sincerely appreciate the invaluable contributions of all national and international partners, technical experts, and stakeholders whose expertise and collaboration have made the development of this Strategy possible. I am confident that, through continued partnership and commitment, this Strategy will serve as a cornerstone for strengthening Pakistan's public health surveillance system and advancing national and global health security.

**Dr Muhammad Salman**

# Abbreviations and Acronyms

| Acronym | Full Form |
|---|---|
| **AJ&K** | Azad Jammu and Kashmir |
| **AKU** | Aga Khan University |
| **AMR** | Antimicrobial Resistance |
| **CDC** | Centers for Disease Control and Prevention |
| **COVID-19** | Coronavirus Disease 2019 |
| **EPA** | Environmental Protection Agency |
| **ES** | Environmental Surveillance |
| **GB** | Gilgit Baltistan |
| **GIS** | Geographic Information System |
| **GLASS** | Global Antimicrobial Resistance and Surveillance System |
| **IDSR** | Integrated Disease Surveillance and Response |
| **ICT** | Islamabad Capital Territory |
| **KEPS** | Karachi Enteric Pathogen Surveillance |
| **NGS** | Next-Generation Sequencing |
| **PCRWR** | Pakistan Council for Research in Water Resources |
| **PEPA** | Pakistan Environmental Protection Act |
| **PHED** | Public Health Engineering Department |
| **SOP** | Standard Operating Procedure |
| **SWOT** | Strengths, Weaknesses, Opportunities, and Threats |
| **WASA** | Water and Sanitation Agency |
| **WBE** | Wastewater-Based Epidemiology |
| **WES** | Wastewater Environmental Surveillance |
| **WHO** | World Health Organization |

# Introduction

## *Wastewater Surveillance as a Public Health Tool*

Wastewater Environmental Surveillance (WES) is a rapidly evolving field that analyzes community wastewater to monitor public health indicators. By capturing data from both asymptomatic and symptomatic individuals, WES offers a non-invasive, cost-effective, and real-time method for tracking a broad spectrum of pathogens at the population level. It serves as a powerful complement to ongoing clinical surveillance, capable of providing early warning of outbreaks, monitoring pathogen circulation in hard-to-reach populations, and guiding public health interventions.

## *Global WES Context and Relevance to Pakistan*

Wastewater environmental surveillance has emerged as a powerful tool for population-level monitoring of infectious diseases, offering a cost-effective and non-invasive complement to traditional clinical surveillance systems. By capturing pathogens and biomarkers shed in human waste, WES enables early detection of disease circulation at the community level, including asymptomatic and pre-symptomatic infections that may otherwise go undetected through routine healthcare-based reporting systems [1,2]. Over the past decade, WES has evolved from a niche epidemiological approach to a critical component of global health security frameworks.

The global relevance of WES was underscored during the COVID-19 pandemic, where it was widely deployed to monitor transmission dynamics of COVID-19 and detect emerging variants of SARS-CoV-2. Multiple studies demonstrated that viral RNA concentrations in wastewater strongly correlated with—and often preceded—clinical case trends, establishing WES as an early warning system for outbreak prediction and response [3–5]. This capability proved particularly valuable in settings with limited diagnostic capacity or delays in case reporting, reinforcing the role of WES in strengthening resilient surveillance systems.

The WHO document "Wastewater and environmental surveillance for one or more pathogens: Guidance on prioritization, implementation and integration" (2024) provides the core global framework for designing WES systems and is highly relevant for shaping Pakistan's national WES strategy. Drawing from this guidance, the Pakistan WES strategy is structured around several key elements. At its core, the WHO framework emphasizes risk-based prioritization, where pathogens are selected based on public health relevance, epidemic potential, feasibility of detection in wastewater, and national disease burden. It also highlights that WES should be integrated into existing surveillance systems, such as clinical surveillance, genomic surveillance, and broader One Health platforms, rather than functioning as a standalone activity. A second key element is system design and implementation, which includes strategic selection of sampling sites, standardization of sampling and laboratory protocols, and adaptation to local infrastructure (including both sewered and non-sewered settings). The framework also strongly emphasizes data management, interpretation, and use for decision-making, ensuring that wastewater data is translated into actionable public health intelligence such as early warning signals, trend monitoring, and outbreak detection. Results are intended to support timely public health

interventions at local and national levels. Another critical pillar is ethical, legal, and governance considerations, including strict safeguards for privacy, ensuring that wastewater data remains population-level and cannot be traced to individuals. The guidance also highlights the importance of clear governance structures, data access policies, and accountability mechanisms. Finally, the WHO framework promotes capacity building, sustainability, and international collaboration, including strengthening laboratory systems, workforce development, and integration with global surveillance platforms for pathogen sharing and comparative analysis. This ensures that WES contributes not only to national preparedness but also to global health security.

Pakistan's proposed a WES strategy which directly aligns with WHO guidance by focusing on prioritized pathogen selection, integrated surveillance design, standardized implementation, ethical governance, and actionable data use within a sustainable and globally connected One Health framework. Pakistan holds a strategic advantage in implementing WES due to its extensive Polio Environmental Surveillance Network, developed under the Global Polio Eradication Initiative. Environmental surveillance has been a cornerstone of polio eradication efforts, enabling the detection of silent transmission of Polio virus in the absence of reported clinical cases [6,7]. Pakistan's polio network represents one of the most robust environmental surveillance systems globally. During the COVID-19 pandemic, this platform was rapidly repurposed to detect SARS-CoV-2 in wastewater, demonstrating its adaptability for multi-pathogen surveillance and highlighting the feasibility of integrating additional targets into existing systems [8]. Despite these advancements, surveillance efforts in Pakistan remain largely fragmented and pathogen-specific. The country continues to face a high burden of infectious diseases, including Typhoid fever, Cholera, Dengue fever, and other viral pathogens. Concurrently, the rise of antimicrobial resistance poses a significant and growing threat to public health, limiting treatment options and increasing morbidity, mortality, and healthcare costs [9,10].

WES offers a transformative opportunity to address these gaps by enabling integrated, multi-pathogen surveillance. Advances in molecular diagnostics and metagenomic sequencing now allow simultaneous detection of viruses, bacteria, and antimicrobial resistance genes in wastewater samples [11]. This approach supports real-time monitoring of pathogen circulation, identification of emerging threats, and evaluation of intervention effectiveness at the population level. Importantly, WES can inform antimicrobial stewardship policies and outbreak response strategies by providing actionable, near real-time data. A coordinated, national WES strategy is therefore critical for Pakistan. Leveraging the existing polio environmental surveillance infrastructure provides a cost-efficient and scalable pathway for implementation, reducing the need for substantial new investments in field systems while maximizing existing capacity. Integrating WES into national public health frameworks would strengthen early warning systems, enhance outbreak preparedness, and support evidence-based policymaking. As Pakistan faces increasing risks from infectious diseases and antimicrobial resistance, investment in WES represents not only an opportunity but a necessity for advancing national and global health security.

# Vision of Pakistan WES Strategy

***To establish a sustainable, nationally coordinated, multi-pathogen wastewater environmental surveillance (WES) system that enables early detection of public health threats and supports timely, evidence-based public health action.***

The framework will provide actionable data for early warning of outbreaks, track the emergence and spread of priority pathogens and antimicrobial resistance, and inform evidence-based policy and interventions, ultimately contributing to a healthier Pakistan. The vision is underpinned by a One Health approach, fostering collaboration across human, animal, and environmental health sectors.

# Objectives of Pakistan WES Strategy

The strategy aims to provide a roadmap for establishing a sustainable, integrated, and multi-pathogen National WES System in Pakistan. The objectives are:

To consolidate and strengthen existing wastewater environmental surveillance (WES) capacities, including laboratory systems, field operations, and stakeholder networks across Pakistan.

To prioritize target pathogens for surveillance based on public health significance, epidemiological trends, and technical feasibility, ensuring alignment with national health priorities.

To develop and standardize operational protocols for wastewater sampling, laboratory testing, data analysis, and quality assurance to ensure consistency and comparability across sites.

To establish a clear governance framework and sustainable financing mechanisms to support long-term implementation and scalability of WES.

To integrate WES data into national public health decision-making systems, enabling timely outbreak detection, risk assessment, and evidence-based policy formulation.

# Current Landscape of Wastewater Surveillance in Pakistan

## *Existing Infrastructure*

Pakistan possesses a foundational asset for WES in its Polio Environmental Surveillance network. Led by NIH in collaboration with WHO, this network covers 127 sentinel sites, and has established protocols for wastewater sample collection, transport, and processing. This infrastructure was successfully adapted for COVID-19 surveillance and serves as a critical platform for expansion. Additionally, several academic institutions, including AKU have conducted pilot WES projects on pathogens like SARS-CoV-2, typhoid, and AMR, generating valuable local data and expertise.

## *Key Stakeholders*

The Wastewater Environmental Surveillance (WES) landscape involves a diverse range of stakeholders across the health, environment, water and sanitation, research, and development sectors. Effective implementation of a national WES programme requires coordinated engagement and collaboration among the following stakeholder groups:

**Government and Policy Stakeholders:** Key federal institutions responsible for policy development, public health leadership, environmental governance, water management, and One Health coordination, including the Ministry of National Health Services, Regulations and Coordination (MoNHSR&C), National Institute of Health (NIH), Ministry of Climate Change and Environmental Coordination, Ministry of Water Resources, and Ministry of National Food Security and Research.

**Implementation Stakeholders:** Institutions responsible for operationalizing WES activities, including provincial health departments, Water and Sanitation Agencies (WASAs), Public Health Engineering Departments (PHEDs), municipal authorities, wastewater management bodies, and public health and environmental laboratories.

**Technical and Scientific Stakeholders:** Academic institutions, research organizations, genomic and environmental laboratories, and technical experts contributing to methodology development, laboratory testing, genomic analysis, research, innovation, and capacity building.

**Supporting Partners:** International organizations, development partners, global health initiatives, and technical agencies providing strategic guidance, technical expertise, resources, and support for strengthening Pakistan's national WES programme.

A coordinated multi-sectoral approach among these stakeholders is essential for establishing a sustainable, integrated, and effective WES system aligned with the One Health approach.

# SWOT Analysis for Wastewater Surveillance

As part of the strategy development process, a comprehensive SWOT analysis was undertaken through national consultative workshops conducted in April and August 2025. The workshops brought together stakeholders from health, environment, water and sanitation, academia, and development partner organizations to assess Pakistan's readiness for implementing a national Wastewater Environmental Surveillance (WES) programme. The findings highlight key strengths, weaknesses, opportunities, and threats that informed the strategic priorities outlined in this document. The summary findings are presented below:

## Strengths

- Established Infrastructure: A functional Polio Environmental Surveillance network with labs, trained staff, and SOPs that can be repurposed.
- Policy & Governance Support: Existence of PEPA 1997 and the National Action Plan on AMR, One Health, providing a policy foundation. Showing strong governmental and international partnerships.
- Technical Expertise: Availability of expert consultants in AMR, genomics, and WES. Active academic engagement with ongoing pilot projects generating historical data.
- Data Tools: Existence of platforms like NHDC, IDSR, Genomics Dashboards, dashboard that can potentially integrate WES data.

## Weaknesses

- Infrastructure Gaps: Poorly organized and fragmented sewage systems, especially in remote areas. No centralized metagenomics lab for comprehensive wastewater testing.
- Governance & Funding: Limited sustained government financial commitment
- Coordination & Data Sharing: Siloed operations between health, environment, and animal sectors. Lack of a unified data platform and poor stakeholder communication.
- Operational Challenges: Lack of education and awareness.
- Untrained staff and gaps in WES

## Opportunities

- Technological Advancements: Utilize GIS mapping for site selection and data visualization. Adopt AI-driven pathogen detection and portable sequencers. Integrate WES with wastewater treatment plants.
- Stakeholder Collaboration: Form a centralized WES consortium to standardize protocols. Leverage existing field staff (e.g., polio, dengue eradication teams) and community leaders for outreach.
- Public Engagement: Launch behavior change campaigns via social media to build trust and awareness.
- Sustainability: Secure government commitment to embed WES in national health policies with dedicated funding.

## Threats

- Operational Risks: Funding instability from donor dependence. Climate change-induced floods and droughts disrupting sampling and infrastructure.
- Data & Security: Risk of fake reporting or data manipulation. Physical security threats to sampling teams. Biohazards from improper handling.
- Systemic Vulnerabilities: Lack of predictive disease models. Poorly maintained sewage systems and open drains posing contamination risks.

# Contextualizing WES in Pakistan's Epidemiological Landscape

The role of wastewater environmental surveillance varies according to the local epidemiological context. In endemic areas, WES primarily focuses on monitoring transmission hotspots, detecting genetic drift, and tracking antimicrobial resistance patterns. In post-outbreak settings, it is used to confirm the cessation of transmission and identify any silent or residual spread. In high-risk locations such as refugee camps and border crossings, WES functions as an early warning system for cross-border pathogen introduction, including threats like influenza and emerging enteroviruses. In low-risk areas, it helps establish baseline data and serves as a sentinel system to verify the absence of transmission. Additionally, in specific settings, targeted WES is deployed at zoonotic interfaces such as livestock markets, as well as in high-density institutions like prisons and large schools, to enhance early detection and risk mitigation.

# Operational Framework of the National WES System

## *Pathogen Prioritization for Wastewater surveillance*

A multi-criteria prioritization framework, adapted from WHO guidance, was applied to systematically assess and prioritize pathogens for inclusion in the National WES system.

### Criteria for Pathogen Prioritization

**Public Health Impact:**
Disease burden (mortality, morbidity), epidemic potential, impact on vulnerable populations.

**Prevalence & Seasonality:**
Frequency of detection in wastewater, known seasonal trends, and cross-border outbreak risks.

**Environmental Persistence:**
Ability of the pathogen to survive in wastewater and resist treatment.

**Transmission Routes:**
Priority for pathogens with waterborne, foodborne, or zoonotic transmission.

**Antimicrobial Resistance:**
Presence of resistance genes or organisms, guided by WHO priority lists.

**Emerging Threats:**
Novel or re-emerging pathogens with outbreak potential (e.g., new variants).

**Regulatory Alignment:**
Pathogens that are notifiable diseases or align with global reporting requirements.

**Analytical Feasibility:**
Availability of reliable, validated detection assays (PCR, sequencing).

**Socioeconomic Factors:**
Regional disease burden and economic impact

**One Health Relevance:**
Zoonotic pathogens at the human-animal-environment interface.

**Vaccine-Preventable Diseases:**
To monitor vaccine coverage and identify circulation in unvaccinated populations (e.g., measles, polio).

**Drug-Treatable Pathogens:**
To guide treatment protocols and monitor for emerging resistance.

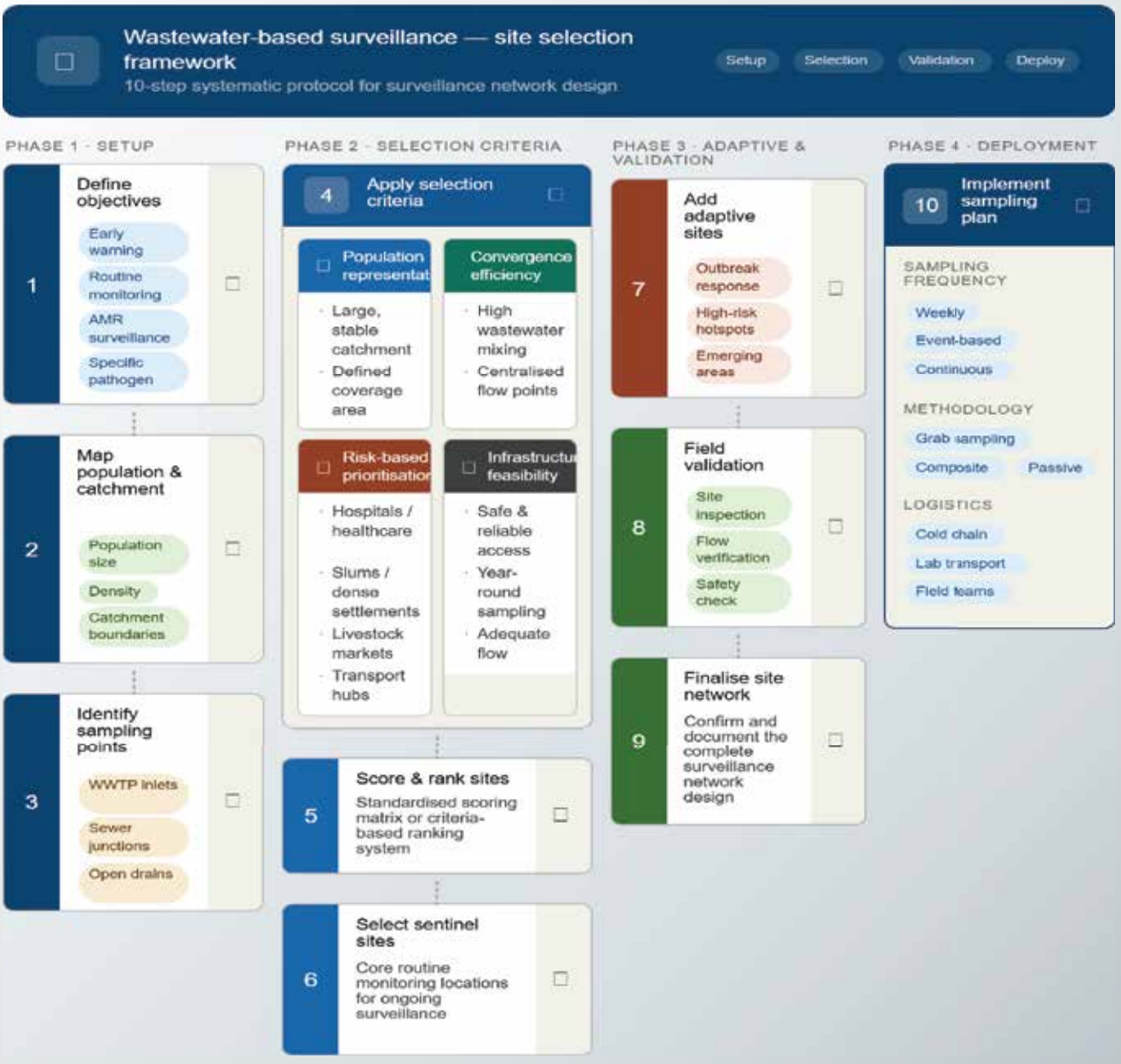
# List of Priority Pathogens for the Pakistan Wastewater and Environmental Surveillance

Following a comprehensive consultative process with key stakeholders, and in accordance with WHO recommendations and the prioritization criteria outlined in the table, the following pathogens were identified as national priorities for Wastewater Environmental Surveillance (WES) in Pakistan.

| Priority Pathogens for the Pakistan WES | | | |
|---|---|---|---|
| **Category** | **High Priority** | **Medium Priority** | **Low Priority** |
|  Bacteria | Salmonella typhi<br>Vibrio cholera<br>Klebsiella pneumoniae | Shigella spp.<br>Escherichia coli, Staphylococcus aureus, Enterococcusspp.<br>Campylobacter spp.<br>Pseudomonas aeruginosa, Salmonella spp., Salmonella paratyphi | |
|  Viruses | Influenza virus<br>Poliovirus<br>Norovirus<br>Rotavirus<br>Enterovirus, Adenovirus<br>Astrovirus<br>SARS-CoV-2, Human parainfluenza virus | Hepatitis A<br>Hepatitis E virus, Herpes simplex virus, Zika virus<br>West Nile virus | Ebola virus<br>Measles virus<br>Marburg virus<br>Dengue virus<br>Japanese encephalitis virus, Respiratory syncytial virus, Alphaviruses<br>Rhinovirus<br>Mpox virus |
|  Fungi | — | — | Candida auris |
|  Parasites | Cryptosporidium Giardia | — | Plasmodium falciparum, Plasmodium vivax |

# Guiding Principles for WES Sampling Site Selection

Sites selection is based on population size/demographics, convergence points (sewage treatment plant inlets, major drains), and specific risk factors (e.g., proximity to hospitals, slums, or poultry markets). A hybrid approach will be used: larger, city-level sites for population representativeness;




and smaller, targeted sites (e.g., drains serving a specific community) for higher sensitivity to detect low-level circulation.

# Programmatic Considerations

## *Integration*

Wastewater Environmental Surveillance should not operate as a standalone activity but must be formally embedded within existing national surveillance and public health systems to ensure effective coordination, routine data use, and long-term public health impact. Key integration pathways include the Integrated Disease Surveillance and Response (IDSR) system, where WES can provide early warning signals from environmental samples and help detect outbreaks before a rise in clinical cases is observed. It should also be aligned with national Antimicrobial Resistance surveillance systems to identify resistant organisms and resistance genes circulating in communities, thereby supporting trend analysis and the identification of transmission hotspots. In addition, environmental sequencing outputs from WES should be integrated into national genomic surveillance platforms to monitor pathogen evolution, emerging variants, and transmission dynamics over time. Finally, WES must be firmly linked with the broader One Health framework through coordination with human health, animal health, and environmental sectors via the national One Health Hub, enabling a unified approach to zoonotic diseases, AMR, and emerging infectious threats. Overall, such integration ensures that WES data is not siloed, but instead actively informs national decision-making, outbreak preparedness, response strategies, and evidence-based policy development.

## *Sustainability*

Sustainability of Wastewater Environmental Surveillance will be ensured through the development of a structured cost-sharing model that distributes financial responsibility across multiple stakeholders. This will include dedicated government budget allocations to anchor the program within national priorities, ensuring continuity beyond donor-funded cycles. International development partners will play a supportive role, particularly in the initial phases, by providing technical assistance, capacity building, and catalytic funding to establish systems and demonstrate impact. At the same time, public–private partnerships will be actively pursued to expand resource mobilization, improve operational efficiency, and encourage innovation in service delivery. A key component of this sustainability approach will be reducing long-term dependency on imported supplies by investing in local manufacturing of consumables and reagents required for laboratory and field-based surveillance. Strengthening domestic production capacity will not only lower operational costs but also enhance supply chain resilience and ensure timely availability of essential materials. Collectively, this multi-pronged financial and operational strategy is designed to make WES cost-effective, scalable, and sustainable within the national public health system.

## *Sampling Frequency & Logistics*

Sampling frequency and logistics will be tailored to epidemiological risk and surveillance objectives to ensure efficient and meaningful data generation. In high-risk or outbreak-prone areas, wastewater samples will be collected on a weekly basis to enable early detection and real-time monitoring of pathogen circulation. In contrast, low-risk settings or sites designated for routine trend analysis will follow a reduced sampling

schedule, with monthly or quarterly collections depending on surveillance priorities and resource availability. A combination of sampling methods will be employed to optimize pathogen recovery, including grab sampling for stable RNA viruses, as well as enrichment approaches such as nanotrap-based concentration and trap sampling using Moore swabs for bacterial detection. To maintain sample integrity and ensure reliability of downstream laboratory analysis, a robust cold chain system will be implemented, with all samples transported to central laboratories under controlled conditions of 2–8°C from the point of collection to processing.

### *Laboratory Processing*

Standardized protocols for sample concentration (e.g., PEG precipitation) and nucleic acid extraction should be adopted across the lab network.

### *Pathogen Detection & Characterization*

A tiered approach should be implemented to ensure both efficiency and depth of analysis in pathogen detection and characterization. In the first tier (screening), high-throughput multiplex PCR will be used for the rapid detection of priority pathogens, enabling timely identification across multiple targets simultaneously. In the second tier (confirmation and characterization), selected positive samples will undergo targeted sequencing or whole-genome sequencing (NGS) to enable detailed variant tracking, antimicrobial resistance gene analysis, and investigation of transmission dynamics and chains.

### *Data Reporting & Action*

A national, GIS-enabled public health dashboard should be used to visualize WES data in near real-time. Threshold-based alerts will be established to trigger public health responses (e.g., advisories, targeted vaccination campaigns).

### *Costing for the WES program*

A phased, activity-based costing model will be developed to ensure transparency and facilitate resource mobilization. Initial cost estimates will be developed for the following key areas:

**1. Capital Expenditure:**

Procurement of essential equipment for sample processing (centrifuges, thermocyclers) and sequencing (NGS platforms), and establishment/upgrade of laboratory infrastructure.

**2. Operational Expenditure:**

The cost components of wastewater environmental surveillance span multiple operational areas. Sampling costs include consumables such as bottles, swabs, and gloves, along with transportation expenses like vehicle fuel, maintenance, and sample courier services, as well as per diem allowances for field staff. Laboratory costs cover reagents and kits required for nucleic acid extraction, PCR, and sequencing, in addition to quality control materials and expenses for equipment maintenance and service contracts. Workforce-related costs include salaries for core WES personnel—such as coordinators, scientists, and field supervisors—as well as stipends for temporary field staff. Data management expenses involve software licensing for dashboards, data storage solutions, and cloud computing fees. Finally, training and capacity-building costs encompass the development and

delivery of training modules, organization of workshops, and travel expenses for participants.

**3. Cost-Efficiency Measures:**

The strategy will actively pursue cost-efficiency measures to ensure the long-term viability and scalability of Wastewater Environmental Surveillance. This will include leveraging existing infrastructure, particularly the established polio laboratory network, in order to avoid duplication of systems and reduce the need for additional capital investment. In addition, a multi-pathogen testing approach will be adopted to maximize the number of targets analyzed from a single sample, thereby reducing the cost per pathogen and improving overall analytical efficiency. Cost savings will also be achieved through centralized bulk procurement of high-volume consumables and reagents, enabling economies of scale and better negotiation of supply contracts. Furthermore, the strategy will explore the use of sample pooling approaches for routine surveillance activities, which can increase testing throughput while optimizing resource utilization and maintaining cost control. Collectively, these measures are designed to ensure that WES remains financially efficient without compromising data quality or surveillance effectiveness.

## *Legal, Ethics and Policy Framework for WES*

A robust legal and ethical framework is essential for the long-term success and social acceptance of the national WES system. In consultation with the Ministry of Health, the National Institute of Health (NIH) will develop comprehensive national policy guidelines to govern all aspects of wastewater surveillance. These guidelines will include clear provisions for wastewater sampling permissions by establishing a streamlined and standardized protocol for obtaining approvals from relevant authorities, including Water and Sanitation Agencies (WASAs), Public Health Engineering Departments (PHEDs), municipal committees, ensuring smooth and lawful access for sample collection. The framework will also define detailed data privacy and sharing protocols/SOPs to safeguard ethical use of surveillance data. This will include mandatory de-identification of all WES data, ensuring that information is aggregated at the community or catchment level with strict prohibition of any attempts to trace samples back to individual households or persons. In addition, a tiered data access system will be established, whereby publicly accessible dashboards will present only aggregated trends, while researchers may access more granular, de-identified datasets through a formal review and approval process, and public health authorities will retain full access for operational decision-making. Comprehensive data security SOPs will be implemented to ensure secure storage, transmission, and access to data, incorporating encryption standards and user authentication mechanisms across all digital platforms. Finally, structured protocols for international data sharing will be developed to enable timely submission of genomic data to global platforms such as GISAID and NCBI, in line with national and international agreements, while ensuring appropriate attribution and recognition of Pakistan's contributions to global surveillance efforts.

The Wastewater Environmental Surveillance (WES) framework will be fully aligned and harmonized with Pakistan's existing legal and policy environment to ensure regulatory compliance and institutional legitimacy. All data handling practices will adhere to national

data protection and privacy requirements, as well as any future comprehensive data protection legislation, to ensure secure and responsible management of surveillance information. The framework will also respect citizens' fundamental rights, with a strong emphasis on the use of anonymized, community-level data to minimize privacy concerns and maintain public trust. In addition, the policy will be formally linked to the Pakistan Environmental Protection Act (PEPA) 1997, with advocacy for targeted amendments to explicitly recognize public health pathogen surveillance in wastewater as a legitimate and mandated activity. This alignment will provide a stronger legal foundation for WES and clarify the roles and responsibilities of Environmental Protection Agencies in implementation and oversight. Furthermore, clear guidelines will be established regarding intellectual property generated through the program, including novel methodologies, protocols, and software tools, ensuring that ownership and use arrangements promote equitable access and prioritize public good and shared benefits.

# Strategic Recommendations for a National WES Framework

### *Policy & Governance*

The policy and governance framework for Wastewater Environmental Surveillance will focus on establishing strong institutional coordination, legal backing, and integration into national health priorities. A National WES Consortium will be formally established as a multi-sectoral platform bringing together key stakeholders such as the National Institute of Health (NIH), World Health Organization (WHO), Environmental Protection Agency (EPA), Public Health Engineering Department (PHED), and the Veterinary Wing to oversee strategy implementation, set technical standards, and support resource mobilization. In parallel, the relevant acts can be reviewed to explicitly recognize public health pathogen surveillance in wastewater as a mandated function, thereby strengthening the legal foundation for WES activities. Furthermore, WES will be embedded within national health policy and the broader One Health strategy, ensuring its formal recognition as a core public health function with dedicated budget allocations to support sustainable implementation and scale-up.

# Advocacy, Capacity Building, and Communication

Effective communication and stakeholder capacity are fundamental to the system's success.

Advocacy efforts will focus on developing targeted policy briefs and conducting high-level engagement meetings with key federal and provincial decision-makers to build strong political commitment and secure sustainable domestic funding allocations for Wastewater Environmental Surveillance. In parallel, WES findings, success stories, and evidence of public health impact will be actively disseminated on national and international platforms, including forums such as the WHO, UNEP, and global health security conferences. This dual approach will not only strengthen policy prioritization within Pakistan but also enhance the country's international visibility in environmental surveillance and public health innovation, thereby attracting additional technical assistance, partnerships, and financial support.

Capacity building will be a core pillar of the Wastewater Environmental Surveillance strategy, focusing on developing a skilled and sustainable national workforce. In this regard, standardized national certified training program will be developed for both field and laboratory personnel, covering areas such as sample collection, GIS mapping, molecular diagnostics, sequencing technologies, and quality assurance practices, with regular refresher trainings to maintain competency and update skills. To ensure scalability and sustainability of training efforts, a "Master Trainer" pool will be created by engaging national and international experts enabling cascade training across all provinces and ensuring consistent technical capacity throughout the country.

Communication and public engagement will be a critical component of the Wastewater Environmental Surveillance strategy to ensure transparency, trust, and public understanding. A sustained awareness campaign will be launched using both traditional and digital media platforms to clearly communicate the purpose, benefits, and public health value of WES. The messaging will be designed in simple, accessible language and supported by infographics and short videos to help demystify the scientific aspects of wastewater surveillance. In addition, community engagement will be strengthened by involving local leaders, religious scholars, and influential community figures as trusted advocates to promote acceptance of the program and address misinformation, particularly in high-risk or hard-to-reach areas. Furthermore, a structured mechanism will be established to ensure timely feedback of WES findings to communities through local health authorities and, where feasible, through a user-friendly public dashboard, thereby enhancing transparency and enabling informed public health action.

# Infrastructure Development

Infrastructure development is a foundational requirement for the successful implementation of Wastewater Environmental Surveillance. In this regard, efforts will be made to advocate for and collaborate closely with Water and Sanitation Agencies (WASAs) and the Public Health Engineering Department (PHED) to support long-term planning and gradual modernization of sewage systems, recognizing that robust wastewater infrastructure is essential for reliable and representative surveillance data. Alongside this, the laboratory network will be expanded and strengthened by designating and upgrading a tiered system of provincial and regional WES laboratories, leveraging existing infrastructure such as Public Health Reference Laboratories (PPHRLs) to avoid duplication and optimize resources. In parallel, a centralized national reference laboratory will serve as the apex facility for advanced metagenomic analysis, sequencing, quality assurance, and data validation, ensuring high-level technical support and standardization across the surveillance system.

# Data Integration and Utilization

Data integration and utilization will be a central pillar of the Wastewater Environmental Surveillance system to ensure that generated data is actionable and effectively supports public health decision-making. A unified, national GIS-based WES dashboard will be developed to integrate wastewater surveillance data with complementary datasets from clinical surveillance, environmental monitoring, and veterinary health systems, enabling real-time visualization and cross-sectoral analysis of disease trends and risks. In addition, clear data-to-action protocols will be established to define specific thresholds, indicators, and trigger points for generating public health alerts and initiating response measures based on WES findings. This structured approach will ensure timely interpretation of data and its translation into coordinated and evidence-based public health actions.

# Sustainability and Capacity Building

Sustainability and capacity building are critical to ensuring the long-term success of the Wastewater Environmental Surveillance program. To achieve financial sustainability, a phased budgeting approach will be developed with strong advocacy for increased domestic government funding, enabling a gradual transition from donor-supported activities to a fully nationally financed program. This will ensure continuity, ownership, and resilience of WES as a core public health function.

# Monitoring, Evaluation, and Learning

A robust Monitoring, Evaluation, and Learning framework will be established to track the progress of Wastewater Environmental Surveillance, ensure accountability, and support adaptive management across all levels of implementation. A core set of Key Performance Indicators (KPIs) will be defined and systematically monitored, including process indicators such as the number of active sampling sites, timeliness of sample collection, and turnaround time for sample transport and laboratory processing; output indicators such as the number of samples tested, pathogens detected, proportion of positive samples sequenced, and data uploaded to the national dashboard; and outcome indicators such as the number of public health alerts generated from WES data, documented interventions initiated in response (including vaccination campaigns or water quality advisories), and verified instances where WES provided early outbreak warnings. Regular governance and performance oversight will be ensured through quarterly reviews conducted by the NIH to assess overall progress, identify operational bottlenecks, and capture lessons learned. These findings will be systematically integrated into strategic and operational planning through an adaptive management approach, ensuring continuous improvement and relevance of the system. Furthermore, the M&E framework will also track progress toward phased expansion and sustainability targets, including resource mobilization efforts and the transition from pilot implementation to broader national scale-up, ensuring that all expansion is evidence-based and financially sustainable.

# Way forward

Pakistan has a strong opportunity to establish a comprehensive Wastewater Environmental Surveillance (WES) system by building on its existing public health infrastructure and aligning with global best practices. International programs provide important lessons for Pakistan, particularly the need for centralized coordination through a single national body such as the National Institute of Health to ensure standardized methods and comparable data across the country. These systems also highlight the importance of data accessibility through public dashboards, which enhance transparency, build public trust, and enable broader use of data by researchers and stakeholders, as well as the need for flexibility to incorporate new pathogens and adapt to evolving public health priorities. Equally important is proactive community engagement, which is essential to counter misinformation and ensure sustained cooperation from the public.

For Pakistan, these lessons can be effectively adapted by leveraging the existing and trusted Polio surveillance network as the backbone of the national WES system, while gradually expanding to include additional pathogens in a phased manner. The system should prioritize actionable data, focusing on pathogens where clear public health interventions exist, such as vaccination for polio and typhoid or water treatment responses for cholera. At the same time, implementation strategies must address infrastructure limitations by utilizing strategic sampling from open drains, nullahs, and other community convergence points in areas lacking centralized sewage systems. Overall, Pakistan has the technical capacity and institutional foundation to develop a robust wastewater and environmental surveillance system that not only strengthens ongoing Global Polio Eradication Initiative efforts but also evolves into a broader platform for detecting infectious diseases, monitoring outbreaks, and preparing for future epidemics and pandemics. This strategic document provides a clear roadmap forward, and its success will depend on sustained political commitment, coordinated multi-sectoral action, and strong collaboration among government institutions, academia, and international partners to translate this vision into a fully functional and impactful national system, ultimately contributing to a healthier and more resilient future for Pakistan.

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# ANNEX-A:

***Stakeholder List for Wastewater Environmental Surveillance Strategy Development***

| Name | Designation | Department |
|---|---|---|
| Dr. Muhammad Salman | Chief Executive Officer | National Institutes of Health Islamabad |
| Dr. Afreenish Amir | Co-PI WES Project, Project Director AMR (US CDC project) | National Institutes of Health Islamabad |
| Dr. Paul Pronyk | Professor of Global Health, Director Centre for Outbreak Preparedness, Co-Director SingHealth Duke-NUSGlobal Health Institute | Duke-NUS Medical School, Singapore |
| Dr. Pang Junxiong Vincent | Assistant Professor | Duke-NUS Medical School, Singapore |
| Dr. Muhammad Imran Nisar | Associate Professor | The Aga Khan University, Karachi |
| Mr. Parvez Ahmad Sheikh | Deputy Director | Department of Health, Sindh |
| Mr. Malik Jahangir Gul | Deputy Provincial Coordinator | Department of Health, Balochistan |
| Dr. Ejaz Ahmad Ghallo | Director Health Services | Department of Health, Punjab |
| Dr. Muhammad Afzal | Incharge PDSRU | Department of Health, Gilgit-Baltistan |
| Dr. Abdul Sattar Khan | Director, Health Services | Department of Health AJK |
| Mr. Usman Ali | Climate Finance Specialist | Ministry of Climate Change |
| Mr. Bisharat Hussain | Deputy Secretary | Public Health Engineering Department PHED, Sindh |
| Engr. Omair Nawaz | Sub-Divisional Officer | Public Health Engineering Department PHED, Punjab |
| Dr. Hifza Rasheed | Director General | Pakistan Council of Research in Water Resources PCRWR, Islamabad |
| Dr. Mohsina Zubair | Director | Environmental Protection Agency |
| Dr. Muhammad Abubakar | Senior Scientific Officer | National Veterinary Laboratories, NARC, Islamabad |
| Dr. Shumaila Manzoor | Scientific Officer | National Veterinary Laboratories, NARC, Islamabad |
| Mr. Salman Manzoor | Assistant Director | Water And Sanitation Agency WASA, Rawalpindi |
| Dr. Hamid Irshad | Senior Scientific Officer | PARC-National Agricultural Research Centre (NARC), Islamabad |

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| Dr. Iftikhar Ahmad | Principal Scientific Officer | PARC-National Agricultural Research Centre (NARC), Islamabad |
| Dr. Masroor Alam | Coordinator Regional Reference Lab for Polio | WHO/National Institutes of Health |
| Ms.Lubna Rehman | Virologist | WHO/National Institutes of Health |
| Dr. Ayesha Farooq | Head of Microbiology Department | National Institutes of Health Islamabad |
| Dr. Ribqa Akhtar | Virologist | WHO/National Institutes of Health |
| Mr. Syed Adnan Haider | Research Scientist | WHO/National Institutes of Health |
| Mr. Ghulam Mujtaba | Virologist | WHO/National Institutes of Health |
| Dr. Adnan Khurshid | Molecular Biologist | WHO/National Institutes of Health |
| Dr. Sonia Qureshi | Fellow Peadriatic Infectious Diseases | The Aga Khan University, Karachi |
| Dr. Samar Sultan | Epidemiologist | The Aga Khan University, Karachi |
| Mr. Furqan Kabir | Senior Manager, IDRL | The Aga Khan University, Karachi |
| Ms.Fatima Aziz | Manager | The Aga Khan University, Karachi |
| Dr. Shafi Kalhoro | Stakeholder Engagement Lead | The Aga Khan University, Karachi |
| Dr. Junaid Iqbal | Assistant Professor | The Aga Khan University, Karachi |
| Dr. Zoya Fatima | Project Manager | The Aga Khan University, Karachi |
| Dr. Imran Hashmi | Professor | National University of Sciences and Technology Islamabad |
| Dr. Azra Yasmin | Professor | Fatima Jinnah Woman University Rawalpindi |
| Ms.Farah Naz | Senior Research Officer | Pakistan Council of Research in Water Resources PCRWR, Islamabad |
| Mr. Waqar Hussain | Research Officer | Pakistan Council of Research in Water Resources PCRWR, Islamabad |
| Mr. Akram Aziz | Research Officer | Pakistan Council of Research in Water Resources PCRWR, Islamabad |
| Dr. Habib Bukhari | Professor | COMSATS University Islamabad |
| Dr. Muhammad Arshad | HOD, IESE, NUST | National University of Sciences and Technology Islamabad |
| Dr. Tahir Yaqoob | Professor | University of Veterinary & Animal Sciences - UVAS Lahore |

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| Dr. Abida Raza Rao | Professor | ARID Agriculture University |
| Dr. Hussnain Janjua | Professor | ASAB, National University of Sciences and Technology Islamabad |
| Dr. Sadia Andaleeb | Professor | ASAB, National University of Sciences and Technology Islamabad |
| Dr. Nazish Bostan | Associate Professor | COMSATS University Islamabad |
| Dr. Rabaab Zahra | Professor | Quaid-i-Azam University Islamabad |
| Dr. Saeed Khan | Professor | Dow University of Health Sciences Karachi |
| Dr. Maria Zahid | Assistant Professor | Dow University of Health Sciences Karachi |
| Dr. Shaper Mirza | Associate Professor | Lahore University of Management Sciences, Lahore |
| Dr. Aamir Ali | PI and Faculty Member | NIBGE, Faisalabad |
| Dr. Muhammad Nawaz | Professor | University of Veterinary & Animal Sciences - UVAS Lahore |
| Dr. Sulaiman Faisal | Faculty Member | CECOS, Peshawar |
| Dr. Mashkoor Mohsin | Associate Professor | University of Agriculture, Faisalabad |
| Dr. M.Farhan Ul Haque | Associate Professor | Punjab University, Lahore |
| Dr. Syed Abid Ali | ICCBS | University of Karachi |
| Dr. Aamira Tariq | Associate Professor | COMSATS University Islamabad |
| Dr. Rutaba Gul | Geneticist | Al-Shifa Eye Hospital, Rawalpindi |
| Dr. Zobia Noreen | Assistant Professor | COMSATS University Islamabad |
| Dr. Jamil Ahmad | Professor, Dean of IT | University of Malakand |
| Dr. Sundas Javed | Associate Professor | COMSATS University Islamabad |
| Dr. Babar Aslam | Faculty Member | College of Pharmaceutical Sciences-LHR |
| Dr. Maryum Nisar | Assistant Professor | Iqra University, Islamabad |
| Brig Kamran Afzal | Commandant | Armed Forces Institute of Pathology |
| Col. Sikandar Hayat | Medical officer Incharge Department of Molecular Diagnostics | Armed Forces Institute of Pathology |
| Dr. Fatima Sharif | Pathologist | Armed Forces Institute of Pathology |
| Dr. Maimoona Roghani | Consultant Chemical Pathologist | Armed Forces Institute of Pathology |
| Lt Col. Rafia Mamood | Consultant Hematologist | Armed Forces Institute of Pathology |

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| Dr. Humaira Nadeem | Professor | Riphah International University |
| Dr. Waseem Haider | Associate Professor | COMSATS University Islamabad |
| Dr. Rehan Zafar Paracha | Bioinformatician, WES Project | National Institutes of Health Islamabad |
| Mr. Kashif Saleem | Research Scientist, WES Project | National Institutes of Health Islamabad |
| Ms. Ambrin Malik | Research Scientist, WES Project | National Institutes of Health Islamabad |
| Mr. Bilal Jamshaid | Research Scientist, WES Project | National Institutes of Health Islamabad |
| Mr. Nazar Muhammad Din | Research Scientist, WES Project | National Institutes of Health Islamabad |
| Muhammad Talha | Manager Admin and Accounts | National Institutes of Health Islamabad |
| Mr. Aurangzaib Anjum | WES project | National Institutes of Health Islamabad |

National Institutes of
Health Pakistan