Master Thesis

ASSESSING THE ROLE OF BIOREPOSITORIES IN OUTBREAK MANAGEMENT IN NIGERIA

Submitted by

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Statutory Declaration

I declare on my honor that I have written this dissertation independently and without assistance, that no sources other than those cited were used and that the sources used verbatim or in substance have been marked as such.

Graz, December 14th 2024 *BABATUNDE AKEEM SAKA*

Foreword

Biobanking which has grown to become a critical tool to unveiling medical research particularly in therapeutics and diagnostics is still at infancy in Nigeria. This growth has resulted in unprecedented economic and research capacities in early adopters who have also gone ahead to establish structural frameworks around governance, access, benefit sharing and compliance. The availability of biobank samples has enabled researchers to explore retrospectively and make plans for even more futuristic situations.

The African continent though strewn with the highly desired heterogenous collection of people has struggled as always in playing catch-up to this new frontier to biomedical research.

A desire to situate current appreciation and utilisation of global standards for sample collection, storage and usage in a Low- and Middle-Income Countries (LMIC) drove this study. This is further accentuated with a tilt towards accessing the possibilities of a more optimistic appreciation if considered along with infectious diseases outbreak management which often draw more attention from government than other non-contagious diseases.

The results are a mix of expectations with an apparent inadequacy across all parameters surveyed. The term Low- and Middle-Income Countries as ascribed to countries struggling to catch up with developments as seen in most advanced western nations is in no better way applicable than the revelation of the gap in technical knowledge, infrastructure, governance and appreciation of biobanks in Nigeria.

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Abstract

Länder mit niedrigem und mittlerem Einkommen (LMICs) wie Nigeria sind besonders in großen Ballungszentren mit stetig steigender Bevölkerungszahl und ohne proportionalen Anstieg des Zugangs zu Versorgungsleistungen stark von Infektionskrankheiten betroffen. Dies macht die effiziente Bekämpfung von Krankheitsausbrüchen zu einer großen Herausforderung für die öffentliche Gesundheit.Es wird vorgeschlagen, dass die Integration von Biobanking-Praktiken in die Strategien der öffentlichen Gesundheit zu einem verbesserten Ausbruchsmanagement in Ländern mit niedrigem oder mittlerem Einkommen, einschließlich Nigeria, beiträgt.

Biobanken lagern wertvolle Bioproben unterschiedlicher Art, die rückblickend und aktiv vor und während eines Ausbruchs untersucht werden können, um Krankheitsmechanismen und Epidemiologie zu verstehen. Sie können auch Proben bereitstellen, die zur Entwicklung von Diagnoseverfahren und zur Erstellung neuer Behandlungsprotokolle verwendet werden.Der theoretische Rahmen dieser Studie kombinierte ein öffentliches Gesundheitsmodell, Biobank-Governance-Theorien und Systemtheorie. Die Studie verwendete ein Mixed-Methods-Design, bei dem rein quantitative Leistungszahlen durch kontextbezogene und Stakeholder-bezogene Daten ergänzt werden. Die untersuchte Population besteht aus Biobanken und relevanten Stakeholdern, die an der Bekämpfung von Krankheitsausbrüchen in Nigeria beteiligt sind. Es handelte sich um eine Querschnittsfragebogenumfrage. Zur Beschreibung der Leistungskennzahlen von Biobanken wurden grundlegende Statistiken wie arithmetische Mittelwerte und Standardabweichungen verwendet. Pearson-Korrelationen und multiple Regressionsanalysen wurden verwendet, um die Zusammenhänge unabhängiger Faktoren zu identifizieren.

Das Modell zeigt deutlich, dass es mehrere Faktoren gibt, die die Wirksamkeit von Biobanken bei der Bekämpfung von Krankheitsausbrüchen begünstigen. Der Bericht hebt die wesentliche Funktion von Biobanken bei der Bekämpfung von Krankheitsausbrüchen hervor und zeigt auch, dass die Wirksamkeit von Biobanken gestärkt wird, wenn Infrastruktur-und Verwaltungsprobleme durch landesweit einheitliche gute Managementpraktiken beseitigt werden, was sich positiv auf die Bekämpfung von Krankheitsausbrüchen auswirken wird.

Schlüsselwörter: Biobanking, Epidemiologie, Wirksamkeit, Ausbruch, Nigeria

Abstract

Low and Middle-Income Countries (LMICs) such as Nigeria have a high burden of infectious diseases occurrence particularly in major urban centres with consistently increasing population without a proportional increase in access to utilities. This makes the efficient management of outbreaks a significant public health challenge. It is proposed that an integration of biobanking practices into public health strategies predispose to an enhanced outbreak management in LMICs including Nigeria.

Biobanks store valuable biospecimen of different nature which can be studied retrospectively and actively before and during an outbreak to get to understand disease mechanisms and epidemiology. They are also able to provide samples used to develop diagnostics, and to create new treatments protocols. The theoretical framework for this study combined public health model, biobanking governance theories, and systems theory. The study deployed a mixed-methods design where pure quantitative figures on performance are complemented by contextual and stakeholder-related data. The population under investigation consists of biobanks and relevant stakeholders involved in disease outbreak management in Nigeria. a cross-sectional questionnaire survey. To describe biobank performance measures, basic statistics such as arithmetic means and standard deviations was employed. Pearson correlations and multiple regression analysis was used to identify the associations of independent factors.

The model clearly states that there are multiple factors driving biobank suggests that biobank efficacy in managing disease outbreaks. The report highlights the essential function of biobanks in managing disease outbreaks and also showed that biobanking effectiveness will be reinforced when infrastructural and governance issues are removed with consistent good management practices spread across the country and this will impact positive on outbreak management.

Keywords: Biobanking, epidemiology, effectiveness, outbreak, Nigeria

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Glossary und Abbreviations

LMICs: Low and Middle Income Countries

COVID-19: Coronavirus Disease of 2019

SARSCOV-2: Severe Acute Respiratory Syndrome Coronavirus 2

NCDC: Nigeria Centre for Disease Control

NIMR: Nigerian Institute of Medical Research

IHVN: Institute of Human Virology Nigeria

DNA: Deoxyribonucleic acid

ELSI: Ethics, Legal and Social Issues

ATCC: American Type Culture Collection

ECACC: European Collection of Cell Culture

KCLB: Korean Cell line Bank

DSMZ: Deutsche Sammlung von Mikroorganismen und Zellkulturen

B3Africa: Bridging Biobanking and Biomedical Research across Europe and Africa

UNESCO: United Nations Educational, Scientific and Cultural Organization

GDPR: General Data Protection Regulation

ISBER: International Society for Biological and Environmental Repositories

OECD: Organisation for Economic Co-operation and Development

GWAS: Genome wide associated studies

H3Africa: Human Heredity and Health in Africa

ClinGen: Clinical Genome Resource

HGRP: Human Genome Reference Program

PRIMED: Polygenic RIsk MEthods in Diverse populations

GA4GH: Global Alliance for Genomics and Health

ICDA: International Common Disease Alliance

NGOs: Non-Governmental Organizations

EHR: Electronic health records

DUA: Data Use Agreements

BBMRI-ERIC: Biobanking and Biomolecular Resources Research Infrastructure – European Research Infrastructure Consortium

BBRF: Biobanks/Biorepositories/Research Facilities

HCP: Healthcare Professionals

SRMR: Standardized Root Mean Square Residual

IDSR: Integrated Diseases Surveillance and Respone

SORMAS: Surveillance Outbreak Response Management and Analysis System

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INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The process of collection, storage, and management of biological samples for research purposes is known as biobanking and has taken a strategic role in handling infectious disease outbreaks globally (De Paoli, 2005). This organized process enhances the prompt detection and description of pathogens, which contributes to improved diagnoses, treatments, and preventive measures (Vandenberg et al., 2020). Modern biobanking has evolved to include large data curation, production of metadata, creation and application of governance frameworks around ethics, privacy, usability, and benefit sharing (Grewal et al., 2015). Low and Middle Income Countries (LMICs) such as Nigeria have year on year records of continuous infectious disease outbreaks especially in major urban centres where an increased population with non-proportional access to utilities makes the efficient management of outbreaks a significant public health challenge. This has been implicated in recurrent outbreaks of diseases such as Ebola, Lassa fever, Monkeypox, Cholera, and, more recently, COVID-19 (Elebesunu et al., 2023; Olumade et al., 2020a). It is suggested that integrating of biobanking practices into public health approaches suggests a promising possibility of enhanced outbreak management in LMICs including Nigeria (Olumade et al., 2020a).

Biobanks as a repository of samples and associated data play a vital role through the provision of samples for retrospective and prospective assessments of controlling infectious disease outbreaks (De Paoli, 2005). This affords epidemiologists and researchers opportunities to quickly establish causation and management strategies including treatments, and preventive measures (Vandenberg et al., 2020). Biobanks also create opportunities to study the genetic and phenotypic characteristics of the

pathogen as soon as detected (De Paoli, 2005). This capacity becomes imperative especially for rare or emerging pathogens, where constrained data may be available (Yuille et al., 2008). This position was perfectly exemplified during the COVID-19 pandemic, where biobanks played a vital role in research leading to vaccine development through access to samples and associated data (Juozapaitė et al., 2023a). This was also deployed in the management of the mutations witnessed in SARSCOV-2 virus over the course of the pandemic, thus helping public health authorities manage outbreaks better and identify potential outbreak hotspots with modelling (He & Han, 2021). Still using Covid-19 as an example, researchers were able to deploy biobank samples to look at the long-term impacts of infectious pathogens on infected individuals, which was referred to as Long-Covid (Mentzer et al., 2022).

Several biobanking initiatives have been established in Nigeria to support infectious disease research and outbreak management. Lagos State government established the first institutionalized biobank in the state known as the Lagos State Biobank, which is situated and directly associated with the Infectious Diseases Hospital, where haemorrhagic and other infectious diseases are frequently treated (Abayomi et al., 2021). Other biobanks in Nigeria include the Nigeria Centre for Disease Control (NCDC) biobank sited in Lagos, the Nigerian Institute of Medical Research (NIMR) also situated in Lagos, which collects samples across all human diseases including non-infectious diseases from various research, and the Institute of Human Virology Nigeria (IHVN) Biobank, which is a project of the H3Africa program initially focused on HIV/AIDS research but has expanded its scope to include other viral infectious pathogens (Abimiku et al., 2019). The contribution of biobanking to managing infectious disease

outbreaks in Nigeria as an LMIC along with the factors that influence the efficiency of these practices will be examined in this study.

1.2 Statement of the Problem

Biobanks' role as a vital tool to manage infectious disease outbreaks is global. In an LMIC such as Nigeria, the prospective benefits of biobanking have been recognized leading to the establishment of several biobanks in just about one decade (Igbe & Adebamowo, 2012). Nonetheless, the effectiveness of these biobanks in outbreak management is yet to be optimised due to substantial gaps in operational efficiency and governance. A study conducted reveals the general inadequacy in the knowledge and understanding of biobanking among Nigerians (Igbe & Adebamowo, 2012). The same study showed that the majority of the focused groups agree to donate their samples to a facility for research purposes especially where it involves therapeutic discovery. This position is also supported by several other studies, which also show willingness to give a broad consent for biological samples donated for research purposes among Nigerians (Akinyemi et al., 2019; Singh et al., 2022a; Tindana & De Vries, 2016). These reports lay a good foundation for biobanking to flourish in Nigeria. At the same time, the studies showed numerous challenges such as inadequate funding, unstandardized procedures, and insufficient public awareness (Akinyemi et al., 2019; Igbe & Adebamowo, 2012; Singh et al., 2022; Tindana & De Vries, 2016).

The observed challenges hinder the optimal use of biobanks during disease outbreaks. It was reported that the absence of biorepositories in Sub-Saharan Africa contributed to the continuous spread of the Ebola outbreak because the collected positive samples were kept in unsafe and uncertified places including refrigerators and freezers used for

everyday activities (Abayomi et al., 2021). The absence of appropriate facilities to keep generated biospecimen for current and future research also created ethical, legal and social issues, which required international intervention and further examination of the ethics around such intervention (Tindana & De Vries, 2016). Biobanks deployment around the research world has led to the development of diagnostic tests, treatments, and vaccines (Juozapaitė et al., 2023a). The use of samples collected provided by biobanks in the management of the COVID-19 pandemic showed possible opportunities lost because of the absence of such during the 2014-2016 Ebola outbreak in West Africa. This further shows that a coordinated biobanking system could provide more support to public health responses in Nigeria.

In order to address the identified gaps, this study seeks to investigate the specific roles and challenges of biobanking in outbreak management in Nigeria classified as an LMIC. Nigeria is the most populous country in Africa and was selected for this study due to its high population density, economic importance, and the presence of a number of biobanks. The study intends to provide information that exposes certain activities linked to biobanking thus enhancing public health responses to disease outbreaks in Nigeria.

1.3 Research Objectives

The study will seek to establish the following objectives:

1. Determine the specific roles of biobanks in managing disease outbreaks in Nigeria.
2. Determine the main challenges biobanks face in fulfilling these roles.

3. Identify how to improve the efficiency of the operations and governance of biobanks for enhanced effectivity in outbreak management in Nigeria.

1.4 Significance of the Study

This study is significant for several reasons:

1. It will show the extent of limitations for specific roles and challenges of biobanking in outbreak management in Nigeria.
2. The results will promote the development of more effective and efficient biobanking systems in Nigeria.
3. The findings of this study can be used for policy and direct the allocation of resources to support the development of biobanking infrastructure and capacity in Nigeria.
4. The study will contribute to the body of knowledge about biobanking in the light of infectious disease outbreak management locally and globally.

1.5 Scope and Limitations

The focus of this study will dwell on the roles and challenges of biobanking in managing disease outbreaks in Nigeria. The study will exclude surveillance, contact tracing, treatment, or vaccination as well issues such as ethical, legal, and social implications of biobanking, which are important but beyond the scope this study. Furthermore, the study will count on self-reported data from participants, which may be subject to bias.

To conclude, this study seeks to address the gaps in empirical evidence on the effectiveness of biobanking in managing disease outbreaks by exploring the specific roles and challenges of biobanking in Nigeria. The goal is to provide information that

enhances public health responses and supports the development of more effective and efficient biobanking systems in Nigeria.

2.0 LITERATURE REVIEW

2.1 Introduction

This is a review of the existing documented knowledge on biobanking and its impact in the management of infectious disease outbreaks. This includes conceptual, empirical, and theoretical frameworks, finding gaps and confirming the relevance of biobanking in the Nigerian context.

2.2 Conceptual Review

Infectious diseases are a major source of threat to the general public particularly in low- and middle-income countries (LMICs) with a high burden of diseases such as HIV/AIDS, TB, malaria, and other emerging and re-emerging outbreaks. Managing these public health outbreaks effectively depends largely on an excellent health system and access to enhance research capacity, which will include biobanking facilities. Biobanking involves the organized gathering, management, storage, and accessibility of biospecimens for research, which could be translational, preclinical and/or clinical (Simeon-Dubach & Henderson, 2020). Biobanks store biospecimens of different nature such as tissues, blood, cells, pathogens, other body components, and DNA often referred to as valuable biological materials, which are studied through different technologies to understand disease mechanisms, to develop diagnostics, and to create new treatments protocols (Asslaber & Zatloukal, 2007). No doubt, biobanking has significantly impacted medical research and practice in areas such as disease surveillance, epidemiological studies, and outbreak response (Byrne et al., 2021; Rush et al., 2020).

The provision of properly stored and well-detailed information of biological samples enables biobanks to play a crucial role in supporting research on infectious diseases, which is essential to researching infectious diseases in only well-managed biobanks. Due to the endemicity and frequency of infectious disease outbreaks in LMICs, a well-managed biobank will increase the research capacity for the pathogenesis, mutation, identification of genetic and environmental factors influencing susceptibility as well as

drug resistance in the populace. This was demonstrated during the West African Ebola outbreak in 2014 where biobanked samples were eventually used to characterized the virus further and develop vaccines to the diseases. Therefore, because biobanking supports the development of diagnostic tools, vaccines, and therapeutics, they can quicken the research and development of treatments and vaccines through the provision of samples and health information. The swift advancement of diagnostic tests particularly for mutant identification and vaccine development during the COVID-19 pandemic relied mainly on the contributions of samples from biobanks. In some LMIC cases, samples stored in research facilities and biobanks have been used to identify instances of genetic variation in the local populations that may affect vaccine or therapeutics efficacy. Another classical example was the use of biobanked samples to investigate Zika virus outbreak in affected populations (Sett et al., 2022).

As crucial as biobanking has become to managing infectious disease outbreaks and facilitating landmark biomedical research, the establishment and sustainability of biobanking in LMICs faces significant challenges. Infrastructure such as power, advanced laboratory facilities, technology as well as financial capacity all contribute to the challenges of establishing and maintaining a viable biobank in LMICs. These components are critical to maintaining the integrity of biobanked samples and not compromising the quality of research data. Although initial funding for biobanking projects may be accessed through international collaborations or disease-specific research grants, running costs which are associated with the sample collection, storage, and data management are often difficult to cover. This lack of sustained investment can result in biobanks becoming inactive or being underutilized, limiting their impact on managing infectious disease outbreaks.

In the same vein, LMICs are challenged around Ethics, Legal and Social Issues (ELSI) with considerably weak capacity. It is vital for LMICs to work around the complex ethical, legal, and social issues with regards to informed consent, privacy, and data sharing especially when working with unprotected people. In LMIC countries where biobanking laws may still be ‘embryonic’, meeting local and international ethics is critical. Mobilisation of trust among the people would be very important to allow

participation in biobanking, especially at times of disease outbreaks when fears and myths abound.

Low- and Middle-Income Countries need to fully put structure into biobanking in order to have the full potential of biobanking in managing infectious disease outbreaks. It needs to get intentional with capacity building for local researchers and healthcare workers in biobanking techniques, improving laboratory infrastructure, and establishing clear regulatory frameworks for biobank management. Similarly, there needs to be an enhancement in digital infrastructure for data management, including sample tracking and sharing.

Biobanking in LMICs holds the promise of advancing real time research, helping innovation and ensuring health security against outbreaks of infectious disease pathogens. In an era of innovation, the use of digital access to biobanks and artificial intelligence for outbreak response could be incorporated into the wider scope of outbreak management. Africa with less developed health systems, who have a lot of diseases will be contributing in most infectious disease research units in the world, if biobanks establishment and their sustainability issues are solved.

In summary, biobanks are expected to play a considerable role in disease outbreak management in LMICs, which is a major challenge at the moment. Biobanks can enhance prevention and control of infectious diseases by supporting research, enabling early containment and control measures or directing policy and interventions. This achievement can only be attained where funding, governance, ELSI and infrastructure are appropriately included into the system.

2.3 Biobanking: History and Evolution

As time passed, and medical research made progress with improvement in the knowledge about human biology, the potential value of biobanks became more obvious. Biobanks moved from a mere passive facility to a major engine that propels research and development. The creation of such large population-based biobanks as the UK Biobank collecting and banking biological samples from over hundreds of thousands of people, was surely a game changing step. The researchers can utilize these resources to get information on genetic, environmental as well as lifestyle factors to understand

the pathological processes involved in diseases, create new therapies and enhance preventative and management measures in the society.

The further development of biobanks was assisted by development of technology including but not limited to genomics, data management and cryopreservation. As technology advanced, the possibilities of biobanking increased to an extent where huge amounts of biological data could be stored, analyzed and distributed in ways that have never been done before. The advent of new -omics technologies for example high-throughput sequencing, proteomics and others has enabled researchers to extract very high amounts of information from biobanked samples making biobanks useful in personalized medicine, drug development and population health studies.

It is interesting to see that despite noted advancements in biobanking, it has as well encountered many difficulties. Issues about ethics, law, and social matters have become important crucial deliberations as biobanks increase in size and extend globally. Compliance to ethical practices in responsible manners has led to the development of strong regulatory frameworks in response to fears about informed consent, privacy, sample ownership, benefit sharing, and data exchange. Sustainable funding to initiate and operate biobanks is also a challenge in this realm. This is more obvious in low and medium earning countries with resource constraints. Maintaining a biobank requires some measure of funding on infrastructure, technology, and knowledge for long-term operations, manage large databases, and ensure that biobanked samples are in good state for use in future studies.

There are high hopes that biobanking will be dynamic and respond appropriately to novel scientific demands and technological advancement. This is possible with the merging of virtual and digital biobanks, where researchers will have access and exchange data globally without visiting the locations. Biobanking development across the timeline with attention on its key achievements, challenges and future opportunities were examined in this study.

2.4 Early Beginnings

The use of biological specimens and biological materials from human beings in medical research started gradually. The use of coroners to conduct autopsies was not immediately welcomed by many societies. Some societies and religious beliefs outrightly made it a taboo, which unfortunately is still observed in certain parts of Africa today. But historically, the inventiveness of trailblazing minds and unwavering progress have made it possible for biobanks to be established and developed, sparking a revolution in medical research.

Such acts can be seen in the instruction given by the United States Surgeon General to all medical officers during the 1862 American Civil war requesting them to collect and forward specimens gotten from regular medical processes done on the sick, from surgical procedures carried out on the injured, and from autopsies. All the specimens came with short explanatory notes as instructed and these contained information such as the name, regiment, and rank of the patient; dates of injury, treatment, and, when appropriate, death; the battle at which the soldier was injured and the location of their treatment inclusive of the course of treatment in some cases and then became the original accession file for each specimen (Barbian & Reznick, n.d.; Colwill et al., 2024). Further activity that can be linked to biobanking occurred with organ transplant where biospecimens were collected and stored with intent to reuse at some other time. Such biospecimens were always accompanied by medical reports which were considered before matching the donor to the user (Eisenga et al., 2018).

Additional activities that metamorphosed into specimen biobanking can be attributed to researchers linked to university-based laboratories who had access to samples from patients simply kept unused or inexhausted sample aliquots with the intention to use for some other studies which may be related or not. Such samples were just stored in freezers and the linked data written down in laboratory workbooks. These samples were stored and used without consent, often without clinical or metadata as well as an understanding of the right protocol needed for the storage of such samples (De Souza & Greenspan, 2013). With time, other kinds of biorepositories also began to emerge. These included biobanks focused on a specific condition, as seen in the AIDS specimen bank established in San Francisco in 1982. Researchers from a variety of professions

created a little biobank that may be used to identify the AIDS virus' causal agent. In subsequent years, biobanks purposed around other diseases, population-based biobanks, and biorepositories for plant seeds, animal tissue, and other materials were established. The last two decades have witnessed a significant increase in the number of population-based biobanks globally (De Souza & Greenspan, 2013).

In the same vein, cell line biobanking was reported to have started with the use of cancer cells excised from a patient (Henrietta Lacks) in 1951 and cultured in the lab without her consent to create the very popular HeLa cells which set the foundation for cell-line biobanking (Mauffrey et al., 2017). The Hela cells provide an optimally stable model for research and are easy to culture (Turner, 2012). Following this success, several other cell lines became established and utilized for several purposes. Examples of other cell lines include Vero cells (a monkey kidney cell line), Ptk2 cells, Jurkat cells (a human T lymphocyte cell line), HEK 293 cells (a human fetal cell line) etc. The proliferation of cell lines culture led to the demand for standardization in its culture and use, which informed the formation of the American Type Culture Collection (ATCC) that introduced certified model systems to cell culture collection, storage and processing. Other cell line biobanks include the European Collection of Cell Culture (ECACC), the Korean Cell line Bank (KCLB), the RIKEN Bioresource Center in Japan, and the Leibniz-Institute DSMZ (Coppola et al., 2019). These cell line biobanks have been variously deployed in the research on unique molecular or genetic mutations, karyotypes, immunoprofiles and pathogen testing (Corral-Vázquez et al., 2017).

2.5 Introduction of Population-Based Biobanks

Population-based biobanks collect, process, and store biospecimens and associated data to enable prospective research in the future. They prepare specimens to enable research into common and complex diseases, known and unknown. They are also able to provide samples for retrospective research into the prevalence or existence of a newly discovered disease in previously collected samples.

Population-based collections possess a longstanding history, especially within the domains of genetic anthropology and the examination of human population history.

These databases often sought to comprehend genetic variety, follow population migration trends, and examine the transformation of various populations across time. Initially, collections like this were frequently, began by researchers in academia and concentrated on certain ethnic groups, communities, or geographic areas. Samples were typically low in number, comprising a limited number of specimens gathered from individuals within a certain group (Sohail et al., 2021).

Modern large-scale high-tech biobanks had individual researchers or academic institutions initiate collections with limited resources. This was basically to collect genetic data to study the origins, relationships, and genetic changes among different human populations.

However, these early population-based biobanks were commonly affected by many limitations, such as insufficient funding, improper preservation methods, and an absence of standardised protocols for sample collection and storage. Consequently, the extent and magnitude of these collections remained comparatively limited, and the information they offered was sometimes confined to certain demographic segments or specific geographic locales.

With the progression of genetic research, data management, and biobanking technologies, the extent of population-based collections has significantly broadened. Currently, these biobanks are essential to wide research on genetic diversity, disease weakness, and environmental factors that affect health, improving our knowledge of these areas on a broader and more complete level.

Voluntary donations are often the sources of samples in population-based biobanks which is mostly done without any specific inclusion or exclusion criteria to donors (Coppola et al., 2019). Samples from population-based biobanks are often deployed for genome-wide associated studies (GWAS) to determine genetic factors linked to the incidence and pathogenesis of diseases in individuals and lack of such in other individuals with equal exposure. It was not until the late 1990s that the concept of large-scale, population-based biobanks emerged where they were classified as natural resources and population national branding (Cambon-Thomsen et al., 2003; Tupasela, 2017). The technological deployment in genomics set its foundation with the success of the Human Genome Project in 2003 which accelerated through the realization of what a

little sample can reveal (Argudo-Portal & Domènech, 2020; Lazareva et al., 2022). Since then, many population-based biobanks including the UK Biobank, the Danish national Biobank, the BBJ Biobank of Japan, the China Kadoorie Biobank and a host of others have been established as population-based biobanks (Zohouri & Ghaderi, 2020).

The sudden proliferation of biorepositories and biobanks exposed the absence of standardised processes for the collection and storage of biospecimens and their associated information. This led to the production of substandard samples with inadequately annotated data, which inadvertently impeded the advancement of studies on subjects such as cancer. This led to the necessity of developing standard operating procedures (SOPs) for the process of collecting, processing, and annotating samples. In order to achieve this objective, the International Society of Biological and Environmental Repositories (ISBER) was established in 2000. Established by an array of researchers, biobank administrators, patient advocates, and other professionals, their objective was to convene annually to exchange knowledge and experience in the field in order to establish specific guidelines. Their guide to best practices for repositories, which was initially published in 2005, continues to be one of the most significant publications and resources for biorepositories and biobanks. It encompasses a variety of topics, such as ethical issues, cost recovery, specimen collection, storage and retrieval, quality assurance, and apparatus.

2.6 Diseases-Oriented Biobanks

Another class of biobanks are the diseases-oriented biobanks which collect, process and store biological samples from donors who have been identified to have a pathological condition of interest.

Diseases-oriented biobanks often set inclusion or exclusion conditions while collecting the samples with the aim to examine definite exposure factors for a disease (Paskal et al., 2018). These donors are often identified during the process of diagnosis or treatment. Such biobanks often create a large repository of disease-specific samples for research purposes aimed at causal investigation or therapy. They often present the unique opportunity to investigate and unravel information for the different stages of the disease. Disease-oriented biobanks are the bedrock of research for precision medicine

to vary therapy according to the identified progression in known classes of people. The University of California, San Francisco AIDS Specimen bank, the National Cancer Institute and the Emory Cardiovascular Biobanks are examples of disease-oriented biobanks. Some remarkable results from disease-oriented biobanks include the discovery of biomarkers for susceptibility to Alzheimer's disease and identification of a differential regulation of tau exon 2 and exon 10 that could be useful biomarkers or possible therapeutic targets for Huntington's disease (Colwill et al., 2024).

2.7 Present state of Biobanking

Scientifically advanced countries have consistently allocated significantly high resources in human and capital to advance the course of biobanking in the last two decades (Chalmers et al., 2016). The global biobanking market was valued at approximately $141 billion in 2010 and was projected to experience a 30% growth within five years (Chalmers et al., 2016). More recently, the market size has been assessed at USD 76.97 billion in 2023, with projections indicating it will surpass USD 169.62 billion by 2033 while driven by a compound annual growth rate (CAGR) of 8.26% from 2024 to 2033 (https://www.precedenceresearch.com/biobanking-market as at 11:31am Oct 6th 2024). This investment cuts across public and private organisations. Biobank operations, which started as a simple process of sample collection and storage in freezers for subsequent use, has now metamorphosed into advanced use of equipment and methods to collect and process the samples for eventual use.

Currently, biobanks have expanded in both the diversity of biological samples they preserve and the complexity of their information-management structures, as well as the range of potential application areas. Initially, biobanks concentrated on the preservation of fundamental biological specimens, including blood, tissue, and DNA samples. Nevertheless, due to technological improvements and research requirements, contemporary biobanks today contain a diverse collection of materials, including cell cultures, organoids, microbiome samples, and other intricate biological datasets (Xu et al., 2024).

There is an introduction of robots and artificial intelligence to manage many operational processes in biobanking currently. These technological discoveries such as Laboratory

Information Management Systems (LIMS), automated sample processing machines and web-based communication applications give biobanks opportunities to handle larger volumes of specimens, maintain detailed records of samples and quality, and communicate more effectively with researchers and study participants.

Following the success of the Human Genome Project and advancements in genomic capability, omics science has been fully integrated and deployed into the biobanking field. The deployment of high-throughput sequencing technologies has offered researchers unique opportunities to explore biobank samples using molecular and genetic mechanisms. Novel developments in bioinformatics have made room for deeper interrogation of complex datasets derived from the use of next-generation sequencing and also allowed more efficient data management in biobanking (Xu et al., 2024). Similarly, technological advancement has also permitted the use of imaging biobanks in ways previously unknown where organized data of medical images and linked medical biomarkers get linked to biorepositories and shared amongst researchers for population or disease-based studies (Brancato et al., 2024). This is different from the previously known Picture Archiving and Communication System in hospitals which is individual based and often not associated with any biomarker. It is therefore sufficient to say that modern biobanking has established a dynamic system with more data-driven strategies (Brancato et al., 2024).

In view of this, biobanking involvement in health has considerably departed from simple biospecimen storage to complex and evolving multi-organisational infrastructural connections serving as an implement for present day biomedical investigations into disease cause, therapy and prevention (Zhu et al., 2022).

2.8 Biobanking and Infectious Diseases

Biobanking has become a pivotal tool in the fight against infectious diseases. It acts silently as a sentinel providing the much-needed archival samples for frequent interrogation of what could be going on even in the absence of an active known disease outbreak. It helps to create patterns often needed to characterize a pathogen’s infectiveness (Umpeleva et al., 2022). Interestingly, a clear distinction exists between samples obtained from human subjects having a clinical condition associated with an

infection (who may or may not be infected with or carriers of the pathogen) and samples of the infectious agent itself (Branković et al., 2014). Therefore, constant analysis of data and existing samples in the biobanks easily establishes a deviation from the known and serves as an early warning system. A sudden rise in a particular biomarker could indicate an outbreak or the appearance of a previously unknown pathogen and can be used to trigger the public health system to act.

Samples collected in a biobank are often more reliable for retrospective and prospective epidemiological studies because of the accompanying data and the assurance of an appropriate handling for the duration of stay in the biobank. These samples thus provide room for mapping the spread of the pathogen. The changes to the pathogen can also be determined using advanced genomic technology. It also permits serological surveys to determine the population's immunity level to a pathogen of interest from time to time. Samples in a biobank are also applied at different levels of therapy which includes personalized medicine (Betsou et al., 2011), drug and vaccine development including the monitoring of these drugs and vaccines.

In several places, biobanks have been established in response to infectious diseases to support the research and development of drugs. Such cases include The Lyme Diseases Biobank in the US, the Ebola Biobank in Sierra Leone (Bernie), the HIV HGM Biobank in Spain (Irene et al., 2022) and the Covid-19 Biobank in Lithuania (Juozapaitė et al., 2023b). Tuberculosis and HIV disease research has benefitted significantly form biobank services (Broger et al., 2020).

In LMICs, a biobank's role during an infectious disease outbreak also includes providing security for the safe keeping of samples particularly those confirmed to be positive for pathogens of high consequence away from the hands of non-state actors who could deploy such for sinister motives.

In recent years, the assembly, analysis, and evaluation of data from biorepositories have increasingly contributed to the comprehension of genetic vulnerabilities to infectious diseases. The reality of infectious illnesses and the ongoing

challenge they present to scientists and clinicians is evident in the significant incidence and fatality rates of both established and novel infectious diseases. Infectious diseases are a significant global health issue which particularly is a huge burden on LMICs (Branković et al., 2014).

2.9 Biobanking in LMICs

For a very long time, sample collection, storage and usage for research has been exploitative of LMICs with extremely low beneficial values to the people. Research with LMIC samples were either processed in-country with the scientists brought in from the developed world and isolated from local scientists for the duration of the work often referred to as parachute research on one hand or simply removing the samples out of the country without proper documentation and agreement with the source country, which was also referred to as the helicopter. Both instances simply leveraged on the absence of the right governance models for sample utilization, collaboration and benefit sharing.

This situation was also greatly enhanced by the inadequate infrastructural facilities and personnel to facilitate such advance research in Africa and other LMICs. This situation not only led to inequitable collaborative research for both research participants and scientists in Africa (Staunton & de Vries, 2020), it also bordered on ethical, legal and social issues such as privacy, consent and sample ownership (Yakubu et al., 2018).

In most LMICs, regulatory frameworks for medical sample governance are either non-existent or at best very scanty especially on specific concerns bordering on biobanking. Importantly, the rising awareness on the need for sample governance globally is leading to an isolation of the samples from LMICs in global research. Research collaboration is getting difficult where regulatory frameworks do not match existing structures in the developed worlds. Several international collaborations in biobanking have been instituted in Africa to address identified challenges. Such initiatives include the HapMap, MalariaGEN, H3Africa and B3Africa with the intention that these measures will correct the underrepresentation of Africans in genomic research and sample availability (Staunton & de Vries, 2020).

Interestingly, the introduction of these programmes also threw open ethical, legal and social issues in the African biobanking sphere. Biobanking governance spans across treaties, directives and agreements in the international sphere; legislation, regulations and ethical guidelines nationally; and rules and procedures locally, all of these must be aligned before international collaboration on sample ascension and utilization can take place (Staunton & Moodley, 2013). A good number of times, these are either not in place at the national level, too specific and quickly outdated where present or existing without key components (Staunton & de Vries, 2020).

2.10 Biobanking and Infectious Disease Management in LMICs: Challenges

2.10.1 Ethical and Legal Considerations

As biobanking grew in scale and complexity, ethical and legal issues surrounding the collection, storage, and use of human biological samples and associated data became increasingly important. There were questions regarding specimen ownership, informed consent, and the protection of participant privacy and confidentiality. In response to the growing ethical and legal issues in biobanking, the UNESCO Universal Declaration on Bioethics and Human Rights and the OECD Guidelines on Human Biobanks and Genetic Research Databases were established. These frameworks became vital to the importance of human dignity, the protection of individual rights, and the need for transparent governance structures in managing biobanks (UNESCO, 2005; OECD, 2009). The contents of these documents served as guides to the handling of donors while assuring their dignity, individual rights, and the importance of transparent governance structures in biobanking. Numerous countries have established national legislation to govern the collecting, storage, and utilisation of human biological samples. The European Union's General Data Protection Regulation (GDPR), effective since 2018, instituted stringent mandates for the processing and safeguarding of personal data, encompassing data obtained from biological samples (European Union, 2016).

2.10.2 Governance and Ethical Issues

Matters such as informed consent, privacy, compliance, access to samples and benefit sharing are some of the issues a proper governance mechanism will address. This

review explores main ethical issues in biobank governance, including informed consent, privacy and confidentiality, benefit sharing, return of individual research results, and governance.

2.10.3 Informed Consent

A vital and uncompromised aspect of biobank governance is the provision of an informed consent to the use of donors' sample and data (Yakubu et al., 2018). Informed consent involves giving consent for sample to be used by the biobank, research facility or hospital after a full description of the purpose of collection including the risks and the benefits of participating in the study. Informed consent should be obtained in a way that does not violate the individual's esteem, culture or belief system. While biobanks can get an informed consent at a specific time, the challenge is the use of the sample for non-specified research which could also be quite beneficial to human during the collection (Mikkelsen et al., 2019). Navigating this puzzle involves the collection of a broad consent which permits the biobank to use the samples for unspecified research (Maseme et al., 2024). Broad consent also comes with ethical challenges including how to determine the benefit sharing particularly where such unspecified research attracts a commercial value. Therefore, tiered consent was advocated to find a balance between a one-use consent and broad consent (Mikkelsen et al., 2019).

2.10.4 Privacy and Confidentiality

The fear of an invasion of the donor's privacy through unauthorized access to donor information both given and generated requires biobanks to put in place strict measures to prevent this (Resnik, 2018). Biobanks must inform participants of the process deployed to achieve this. De-identification, anonymization, access restriction and encryption of stored data are some ways biobanks protect the privacy of the donors (Laurie et al., 2010). Biobanks should also have very clear processes of remediation when there is a data breach. Instructively, there requires a way to identify donors when consent is required for subsequent research where consent is not broad following de-identification.

2.10.5 Benefit Sharing

Samples donated for research are often done for universal good. It has, however, become an issue where the result form certain usage of the samples attracts huge commercial value thereby turning into a profitable form. The issue here is if the donor deserves to benefit from such and where agreed, what form will the benefit be particularly where the donor is de-identified (Sudoi et al., 2021). There have been suggestions to facilitate ease of access to diagnostic tests or treatments developed, or support capacity building in local research institutions (Sudoi et al., 2021). Transparency and accountability achieved through consultation with participants and communities will produce fair benefit sharing process.

2.10.6 Return of Individual Research Results

Return of results particularly where participants were recruited for generic studies is important and biobanks should develop policies that will facilitate this (Sobel et al., 2020). It must also be stated during consent if the biobank will return results or not. Policies addressing this should be mindful of potential harm and donor's preference. It is also important for biobanks to state their limitation towards return of result during consent. This will help manage expectation of the donors from the biobank.

2.10.7 Standardization and Interoperability

The lack of adequate standards and inability to maintain consistency has been indicated as a key challenge in biobanking (Brancato et al., 2024). Differences in biobanking processes can result in compatibility issues particularly where the research project involves samples collected over a wide range of time in one biobank or requires accessing samples across different biobanks (Yuille et al., 2008). The varied processes in different biobanks or processes across a spectrum of time in one biobank limits interoperability which often affects possible extensive joint research and meta-analyses (Brancato et al., 2024). There are ongoing efforts to address this through organizations such as the International Society for Biological and Environmental Repositories (ISBER) and the Organisation for Economic Co-operation and Development (OECD) which have guidelines for the establishment and administration of biobanks (Annaratone et al.,

2021; Campbell et al., 2018). The guidelines aimed at promoting interoperability across biobanks have created standards addressing sample collection, processing, storage, and data management. However, differences in culture, institutional policies, infrastructure and local regulations have continued to negatively impact these efforts particularly in LMICs such as Nigeria.

2.10.8 Sustainability and Financial Support

Biobank financing is quite expensive in infrastructure and administration. Initiation requires huge capitals, maintenance and training of personnel also comes at huge costs (Sargsyan et al., 2015). Therefore, obtaining steady and adequate funding is a challenge especially for smaller or regional biobanks. The use of public-private partnership and collaborations with pharmaceutical companies, and biotechnology corporations can provide sustainable financing for biobanks. Service charge to researchers who accessed samples and data at minimal cost can also be a source of funding for biobanks (Rogier van der Stijl & Schaaij-Visser Rick van Nuland, n.d.; Vaught et al., 2011).

2.10.9 Interaction with Participants and Communities

Community engagement especially where population studies are involved is very important for the success of the project. This is a way of building trust and breaking barriers especially about culture and belief systems. Inability to conduct enough community engagement or individual enlightenment is often counter-productive as it breeds distrust, which can lead to a low level of participation and even withdrawal from such communities or individuals.

2.11 Empirical Review

Biobanks have grown significantly in recent years as an essential tool for enhanced medical research and improved healthcare outcomes (Coppola et al., 2019). In Nigeria, a country with a population of over 200 million, over 250 ethnic groups speaking more than 500 different languages (Udoh & Emmanuel, 2020), shows an outstanding diverse genetic pool, which is prime for biobanking as the tool to contribute to the understanding and management of various health conditions, including infectious diseases, non-

communicable diseases, and genetic disorders that could be present in this population. As recently as 2014, despite the burden of both infectious and noncommunicable diseases in Africa, Africans have only participated in seven (for HIV susceptibility, malaria, tuberculosis, and podoconiosis) genome wide associated studies (GWAS) conducted exclusively on African participants while four others on prostate cancer, obsessive compulsive disorder, and anthropometry included some African participants (Rotimi et al., 2014). This situation is due largely to challenges such as infrastructure, knowledge capacity of African scientists, research policy and governance, funding as well as inadequate technological advancement.

However, there has been a significant (although not comparable) change in this status with the conception and implementation of the H3Africa project. The Human Heredity and Health in Africa (H3Africa) program started in 2010 in collaboration with the UK Welcome Trust and the African Society for Human Genetics. The program was designed to develop a sustainable and collaborative African genomics research initiative. The program succeeded in promoting the creation of a vibrant network of genomicists, computer scientists, ethicists, health professionals, medical researchers, and research participants with capacity for genomics studies across Africa. Importantly, it was able to achieve the aim of enabling genomics studies in Africa with enhanced resources, knowledge, databases, and infrastructure facilities that is facilitating the work of researchers to understand how genomics influences the lives of Africans (Rotimi et al., 2014). The H3Africa concept has come to an end after 10 years but has succeeded in birthing many other programs like it. These may not match H3Africa in funding and resources but it has created the sustainability ambience desired to continue to foster growth in African omics research as well as inclusion in accessed samples for global scientific interrogations. Some of such programs include the Clinical Genome Resource (ClinGen), the Human Genome Reference Program (HGRP), and Polygenic RIsk MEthods in Diverse populations (PRIMED). Internationally, H3Africa is a part of the Human Cell Atlas, the Global Alliance for Genomics and Health (GA4GH) and the International Common Disease Alliance (ICDA).

In spite of these programs, especially that Nigeria was one of the prominent sites of the 3 for H3Africa, the development of biobanking in Nigeria still faces several challenges,

such as limited infrastructure, lack of standardized procedures, and ethical and legal concerns. A focus on existing literature on biobanking in Nigeria, concentrating on the attitudes and perceptions of stakeholders, the challenges faced, and the likely benefits of establishing a robust biobanking system in the country, will guide this empirical review.

2.11.1 Attitudes and Perceptions towards Biobanking in Nigeria

Igbe & Adebamowo (2012), in their cross-sectional survey conducted among Nigerians spread across four geopolitical regions of the country to assess their knowledge, attitudes, and willingness to participate in biobanking, reported that while most participants (87%) were willing to donate samples for biobanking, there were varying attitudes towards specific elements such as consent. The majority (78%) preferred broad consent, which allows for future unspecified research, while a significant proportion (22%) preferred specific consent for each research project (Igbe & Adebamowo, 2012). In another cross-sectional survey conducted among community-dwelling laypersons from seven sites in the course of the SIREN (Stroke Investigative Research and Education Network) from Ghana and Nigeria revealed that a third of the participants were aware of blood sample storage for research (biobank) and 90% of participants were unaware of any guidelines regulating blood sample storage for genomic research (Singh et al., 2022b). The same study also showed that awareness of brain and other tissue donation for research as well as guidelines regulating such was at about 40%. A positive correlation could be deduced between level of education and willingness to donate blood, brain or any other tissue in the respondents for research or storage for prospective research (Singh et al., 2022b). Low and middle-income countries have very low and insufficient participation due to a lack of understanding of the need and again due to financial capabilities. Unfortunately, these areas are also carrying the highest burden of infectious diseases prevalence. The establishment of viable biobanks with sustainable finances could help LMICs manage disease outbreaks and also preserve knowledge (Croxton et al., 2023).

2.12 Establishing Biobanks in Nigeria

The development of biobanking in Nigeria is faced with numerous challenges, which include limited infrastructure, lack of standard procedures, ethical, social and legal issues.

2.12.1 Infrastructure Challenges

Nigeria's healthcare system faces many challenges with regards to infrastructure, limited access to modern medical facilities and equipment, especially in peri-urban and rural areas (Oleribe et al., 2019). This situation is a major challenge to establishing a biobank that requires modern infrastructure and consistent power supply. The lack of reliable transportation networks and cold chain logistics also hinders the efficient collection and transportation of samples from various locations to centralized biobanking facilities (Yakubu et al., 2018). Biobanks frequently receive insufficient attention in the development agendas of low- and middle-income countries (LMICs), leading to limited financial resources dedicated to their creation and upkeep. Inadequacy in financial support is because all the biobanks in Nigeria are supported financially by government and government is more focused on treatment, staff salary and a bit of reagents for the laboratories. Therefore, this inadequate funding greatly affects the progress and sustainability of biobanking ideas in Nigeria.

2.12.2 Lack of Standardized Procedures

The nonexistence of standardized procedures and guidelines for biobanking in Nigeria is another major challenge. Although all facilities and biobanks have their own protocols for sample collection and storage, these are not harmonized across the country (Rotimi et al., 2014). Such lack of standardization can lead to differences in sample quality and integrity, thus making it difficult to ensure the reliability of the samples and the comparability of the results of similar researches across the country particularly when results are different, too. This challenge extends to data management, research collaborations across the country and internationally (Yakubu et al., 2018).

2.12.3 Ethical and Legal Issues

Ethical, legal, and social matters are an additional significant challenge in the establishment of biobanks in Nigeria. This is aggravated by the composition of the country with many different ethnic groups resulting in a proportional cultural difference, which makes the use of universal guidelines and regulations very difficult. In some of these cultures, a woman is not allowed to give consent for anything on her own, some cultures do not permit even a man to agree to anything strange until the clan/group have met to agree or otherwise. Some belief systems do not attend hospitals, give blood for test or even donate to research. Healthcare workers are being trained to address this; however, this has led to the utilization of different approaches to achieve the objectives. In most cases there have been ethical issues violated as a result of not being able to overcome local requirements. This makes such samples unavailable to groundbreaking research, which is strict on adhering to universal ethics (Rotimi et al., 2014). The Nigerian biobanking system again lacks appropriate legal and technological structures to ensure compliance in privacy and data protection matters as the knowledge of these requirements in government circles is quite limited (Yakubu et al., 2018).

2.13 Potential Benefits of Biobanking in Nigeria

There are so many benefits biobanking can bring to Nigeria's healthcare system and research fields. This will require building a robust biobanking infrastructure, which can contribute to the understanding and management of different health conditions prevalent in the country (Igbe & Adebamowo, 2012).

2.13.1 Improved Understanding of Disease Epidemiology

Biobanking can contribute to a better understanding of the outbreak of different diseases across the country including infectious diseases, non-communicable diseases, and genetic disorders (Rotimi et al., 2014). Samples collected and analysed across the country of diverse origin can give information critical to the prevalence, risk factors, and genetic foundations of these diseases thereby leading to a better prevention, intervention and treatment strategy in these diseases (Yakubu et al., 2018).

2.13.2 Facilitating Pharmaceutical Research

Biobanks are able to provide samples to research facilitating treatment to certain diseases in Nigeria including COVID-19 (Ogun, 2022). An adequately supported biobank can encourage research across a diverse population like Nigeria to facilitate personalized treatment after determining genetic markers of individual donors (Yakubu et al., 2018). This will lead to an improvement in treatment results and a reduction in adverse reactions.

2.13.3 Promoting Collaborative Research

In Nigeria, multiple medical research studies are going on from time to time including clinical trials. These researches generate many samples, which when isolated do not bring maximum benefit to the research fields as each study has had to collect samples at different times and sometimes with participants who overlapped between studies or were even the same. Biobanking has the capacity to eliminate this and foster more and better collaborative research among Nigerian researchers particularly where broad consent is obtained and institutional review boards are able to harness this potential (Rotimi et al., 2014). When biobanks provide access to well-characterized samples and associated data, it eases the task of researchers, reduces the time taken to complete such research and eliminates multiple approaches to sample donors. Where these facilities exist, researchers are able to attract more grants especially in the international community where ethical restrictions guide sample access (Yakubu et al., 2018).

2.14 Theoretical Framework

2.14.1 Public Health Models

Public health models serve as a framework for understanding and addressing health issues in a population. They frequently focus on preventive measures, good health advocacy, and outbreak disease management. By including public health models into the theoretical framework, researchers can get information into the broader impact of disease outbreaks and the effectiveness of interventions in the population (Mcleroy et al., 1988). Public health models also employ epidemiological principles where infectious

diseases are involved. This frequently involves the distribution and determinants factors of infectious disease pathogens in a population (Gao et al., 2022).

2.14.2 Biobanking Governance Theories

Biobanking governance theories lead the creation of policies and regulations governing the biobanking processes for research purposes. These governance measures include sample collection, creating access review boards, compliance committee, quality assurance and any other issues raised during the consideration of ethical, legal and social issues. This is not universal as issues could be peculiar to each country. However, there are governance processes made mandatory by international guidelines, which include informed consent and benefit sharing (Campbell et al., 2018). A well implemented governance structure always ensures transparency and accountability in the operations of a biobank (Argudo-Portal & Domènech, 2020).

2.14.3 Systems Theory

Systems theory provides a complete approach to understanding the way the different components of biobanking and use of its product influence each other. In this study, systems theory will be deployed to investigate the disease outbreak management and how it is influenced by biobanking practices. It will show the impact of regulations whether existing or not, infrastructure and stakeholder management as factors that determine the relationship between biobanking practices and infectious disease outbreak management (Xia et al., 2017).

2.15 Application to Biobanking in Nigeria

During the last pandemic, the Lagos State Biobank served as a coordinating point for sample collection for the state. Because of the existence of some governance structures such as the Biosecurity Governing Council, which served like an institutional review board and as well had a sample accession committee from within it, it was easier to coordinate some research collaboration among the researchers interested in different things. The Governing Council after engagement with the State ministry of health

secured a broad consent over collected Covid-19 samples in the interest of public good for the duration of the pandemic. This is one of the advantages a well-structured biobanking sector will deliver in Nigeria (Akinyemi et al., 2018).

The Lagos State Biobank, supported by the Lagos State Government and the Government of Canada, exemplifies the application of systems theory by utilizing solar power as its primary energy source, thereby ensuring sustainability and resilience (Abayomi et al., 2021). Moreover, the biobank's adherence to biobanking governance theories ensures ethical practices and public trust are priority. Through the Lagos State's Data and Safety Monitoring Board, it was able to provide an added layer of oversight on research that got samples from the State Biobank.

2.16 Conclusion

The theoretical framework for this study integrated public health models, biobanking governance theories, and systems theory to provide a broad understanding of disease outbreak management and biobanking practices.

3 METHODOLOGY

This chapter includes a presentation of the rationale of the given research, as well as of its specific objects and participants, sampling methods, controlled and independent variables, and research instruments, as well as the methods for data collection and analysis. It also explains the ethical issues and the reasons for the methods used in responding to the research question.

3.1 Research design

The study used a mixed-methods (quantitative and qualitative) design where pure quantitative figures on performance are complemented by contextual and stakeholder-related data (Creswell & Cresswell, 2018). Objective data through explorative and confirmative analysis is collected and quantified with the use of quantitative methods, as opposed to the qualitative methods that enables the researchers to get deeper understanding of the operational factors and issues as well as the experiences of the key players and stakeholders in the biobanks (Creswell & Plano Clark, 2018). This approach guarantees balanced perceptions about the utility of biobanks in management of disease outbreaks by considering various aspects of biobank performance. Quantitative methods shall be used to offer measurable indices of efficiency of the biobank, while qualitative methods shall be used to assess diverse perceptions of stakeholders and policies in place (Creswell & Cresswell , 2018). The selected methods are needed as the study requires both medical data (concurring disease outbreaks, genomic stability, and pathogen resistance) as well as operational data (concerning biobank performance). The data was collected through questions under structured questionnaires, interviews and documents. The total number of biobanks in Lagos and Abuja is used to define the sample size in order to have the widest coverage.

3.2 Population

The population under investigation consists of biobanks and relevant stakeholders involved in disease outbreak management in Nigeria. The study focuses on biobanks because of their critical role in collecting, processing, and storing biological samples, which are essential in understanding and managing disease outbreaks (Henderson et al., 2019). The populations under study consist of different biospecimen facilities in Nigeria. Some of them include; IHVN H3Africa Biorepository in Abuja and other regional biobanks developed under the H3Africa program (Rotimi et al., 2014). Stakeholders to be involved in the study are the physicians, biomedical laboratory workers, epidemiologists, scientific researchers, health department staff of the state and federal ministries, and staff of all health-related NGOs involved in campaigns. By means of questionnaires, data are collected from staff working at biorepositories and other key stake holders involved in the biobanking system.

3.3 Participants

Participants include managers and operational staff of biobanks, healthcare professionals, and other key stakeholders directly involved in disease outbreak management, including policy makers and laboratory scientists (Hirtzlin et al., 2003). The focus on this group ensures a comprehensive understanding of the factors affecting biobank performance and disease management in the study regions.

3.4 Sample Size Calculation

It is a census method, where all the existing biobanks in any part of Nigeria are included for a comprehensive study. Since the number of working biobanks in these regions is still comparatively small and the access to participants is relatively easy, it is possible to include all entities into the sample. The number and type of biobanks and stakeholders was revealed after mapping active institutions and interested parties who would be willing to participate in the study.

3.5 Sampling Method

The survey targets individuals and institutions known to be involved with the research areas and therefore is a purposive sampling method (Etikan, 2016). This is to make

sures the participants have the required knowledge and are able to give valuable information in the various categories of interest by the study. By focusing on biobanks in Nigeria, the study aims for regional representativeness, capturing the practices and challenges unique to these key urban centers.

3.6 Variables

3.6.1 Dependent Variables

- Biobank performance indicators: These are the time it takes to process samples, the ethicality and functionality of the business and the availability of obtained data.
- Efficiency of disease outbreak management: Diagnostic speed, genomic stability, pathogen and disease resistance are some of the issues deemed important in understanding how biobanks can enhance disease management in cases of outbreaks.

3.6.2 Independent Variables

- Infrastructure conditions: Equipment and facility lay down of biobanks have effects on the performance of the biobanks in question.
- Logistical efficiency: The mechanisms employed by biobanks in transportation of samples, storage and sample retrieval access.
- Stakeholder engagement: The level of participation of main actors, such as the health care personnel, the policy makers and the laboratory technicians in the decision making.

3.7 Instruments

To achieve the above objectives, a cross-sectional questionnaire survey was developed in which the respondents were asked quantitative and qualitative questions concerning outbreak management and the biobanking processes in Nigeria. It is comprised of Multi-Choice question type, Rating Scales and Opinion/Comprehensive type of questions as well.

1. **Demographic Information:**

Participants reported information about gender, age, position, years of work experience and the type of facility. The present section comprised of 9 items.

2. **Assessment of Disease Outbreak Management and Biobanking Practices:**
   These questions formed a section that assessed the viability of outbreak solutions on the outbreak, the diagnostic techniques applied and the utility of the biobanks in outbreak frameworks. This comprised 21 items using both rating scales where the number of existing items ranged from one to five, and yes/no questions.
3. **Operational Aspects and Ethical Considerations:**
   Technical questions were those engaged on specimen collection, processing, storage, tracking mechanisms, ethical issues, and issues facing biobanks. There were 30 questions in this section where some of the questions were multiple choice and others where the participants were supposed to provide qualitative data in regard to the prompts given. In total the questionnaire contained 60 questions, which allowed for the collection of a broad range of data, while not overstating the response burden to the participants.

3.8 Validity and reliability

The questionnaire tested in a pilot to check its validity and reliability with a pool of respondents. It was also assessed by some epidemiologists who have had introduction studies of biobanking as well as a technical member of the Lagos State Biosecurity Governing Council who also doubled as the secretary to the Data and Safety Monitoring Board for validity. Methods for comparing internal consistencies of the items was done through statistical evaluation such as Cronbach's alpha, Total item correlation and Average Variance Extracted (AVE) (Tavakol & Dennick, 2011). Preliminary questions were clearly stated to the respondents with assurances made to the respondents that responses would be kept anonymous. These questionnaires were expected to capture the realities concerning biobanking alongside general perceptions of outbreak management in Nigeria, which would in turn inform the general improvement of practices that address the improvement of public health.

3.9 Data Collection Method

This kind of questionnaire was delivered electronically through e-mail or online questionnaires to increase access to the participants. Participants was made aware that they are enrollees in the study and their identity would be kept discreet. All the biobanks and main stakeholders in Nigeria were contacted and extended an invitation to join the study and contribute to biobanks research. Insights was also collected quantitatively through surveys that involved biobank staff and health care practitioners. Qualitative data was obtained through semi-structured interviews with managers, policymakers, and stakeholders (Etikan, 2016). Information from essential papers which include operational reports, policies on disease management as well as international biobank guidelines was used to explain biobanking in the management of diseases. Self-administered questionnaires were analyzed by coding and entering the results into statistical analysis software package IBM SPSS 27 (Field, 2013).

3.10 Method of Data Analysis

To describe biobank performance measures, basic statistics such as arithmetic means and standard deviations was employed (Field, 2013). Pearson correlations and multiple regression analysis was used to identify the associations of independent factors (e.g., infrastructure, logistics) to biobank performance (Creswell & Cresswell , 2018). This will determine the extent to which variables are related as well as the nature of these relations (Miles et al., 2014). Interview data was analyzed with the help of thematic analysis in order to define such most frequent qualitative patterns as those that are connected with the biobank efficiency and disease outbreak management. Policies regarding the biobank and disease management were studied through documents to establish the impact they have on the biobank and the disease management process. The study acted on the use of quantitative and qualitative data to ensure validity and to infer that there is an understanding of biobanking practices during disease outbreaks.

3.11 Ethical Considerations

Ethical approval for this study is not required, as indicated by the Ethics Committee ("Not Required"). Issues of ethics as a consideration are well captured in this study. Participants' consent was sought, making them understand the purpose and objectives

of the study, outlines of the procedures to be used in the course of the study including the risks and benefits involved in the study (Resnik, 2018). Participants were setup with pseudonyms to ensure the total anonymity and confidentiality of the data collected in the study (GDPR, 2016). The study adheres to the following ethical guidelines, ensuring informed consent, maintaining confidentiality, and protecting the data from unauthorized access:

- **Informed Consent**: Participants were fully informed of the study's purpose and procedures before giving consent.
- **Confidentiality**: All personal and institutional data was anonymized using pseudonyms, and access to sensitive data was restricted.
- **Data Protection**: In compliance with the Data Protection Act, no identifiable patient data was shared, and all data was stored securely with access limited to project personnel.

4 RESULTS AND DISCUSSION

This chapter presents the analysis of survey data regarding various characteristics of participants, including their regional and state distribution, demographics (gender and age), job designation, years of experience, and involvement with biospecimen or biorepository facilities. This analysis offers insights into the landscape of biospecimen storage and biorepository management in different regions, the type and establishment year of the facilities, and the specific types of biorepositories operated by these facilities. Data interpretation is structured through frequency and percentage tables, followed by a narrative analysis.

4.1 Descriptives of Demography and Professional Attributes

Table 1 Participant Demographics and Professional Attributes

Category	Sub-Category	N	%
Region	North-Central	33	13.2%
	North-East	23	9.2%
	North-West	17	6.8%
	South-East	24	9.6%
	South-South	15	6.0%
	South-West	138	55.2%
State	Abia	9	3.6%
	Akwa Ibom	2	0.8%
	Borno	23	9.2%
	Edo	24	9.6%
	Ekiti	5	2.0%
	Enugu	7	2.8%
	FCT – Abuja	15	6.0%
	Kaduna	2	0.8%
	Kano	6	2.4%
	Katsina	6	2.4%
	Kebbi	3	1.2%
	Kwara	12	4.8%

	Lagos	34	13.6%
	Ogun	4	1.6%
	Osun	68	27.2%
	Oyo	24	9.6%
	Yobe	6	2.4%
Gender	Female	54	21.6%
	Male	196	78.4%
Age Group	Early Career (22-30 years)	60	24.0%
	Mid Career (31-40 years)	121	48.4%
	Late Career (41-50 years)	51	20.4%
	Senior Career (51+ years)	18	7.2%
Job Designation	Lab Scientist	4	1.6%
	Medical Doctor	14	5.6%
	Medical Epidemiologist/Public Health Specialist	6	2.4%
	Medical Laboratory Scientist	54	21.6%
	Medical Laboratory Technician	1	0.4%
	Molecular Biologist	17	6.8%
	Nurse	29	11.6%
	Medical Researcher	34	13.6%
Years of Experience	0-5 years	85	34.0%
	6-10 years	92	36.8%
	11-20 years	67	26.8%
	21+ years	11	4.4%

The participants in this study are predominantly from the South-West region, accounting for 55.2% of the total sample (N=138) as seen in Table 1. This is expected as this part of the country is the most developed region and also includes Lagos State, which is the commercial nerve centre of the country. Interestingly, Lagos State also has three of the formally classified biorepositories in the country. These are the Lagos State Biobank (LSB), the Nigerian Institute of Medical Research Biobank (NIMR) and the Nigerian

Centre for Disease Control Biobank (NCDC). The fourth classified biobank is the Institute of Human Virology of Nigeria (IHVN), which was instituted through the H3Africa project. Additionally, the distribution of health care centres as well as health care laboratories is predominant in the South-West of the country. The North-Central region follows with 13.2% (N=33), while other regions are represented in smaller proportions, with North-East and South-East regions having 9.2% (N=23) and 9.6% (N=24), respectively. This regional skewness towards South-Western participants indicates that the sample might reflect the practices or preferences prominent in that region, suggesting potential regional influences on the healthcare insights derived.

Male participants constitute the majority of the sample, making up 78.4% (N=196), while females account for only 21.6% (N=54). This disparity may reflect occupational gender trends within healthcare and biomedical fields in the region or may indicate a gendered distribution in the sampled roles. Table 1 also shows that most participants are in the "Mid-Career" age group (31-40 years), representing 48.4% of the sample (N=121). This age distribution suggests a largely mid-career workforce involved in the survey, which can impact perspectives on certain topics such as innovation adoption, experience with protocols, and openness to emerging trends. Only 7.2% (N=18) fall into the "Senior Career" category (51+ years), potentially limiting insight from more seasoned professionals within the sample.

Medical Laboratory Scientists make up the largest job category at 21.6% (N=54), followed by Nurses at 11.6% (N=29) and Researchers at 13.6% (N=34). The strong representation of laboratory-based professionals suggests that the sample's insights may be particularly relevant to laboratory practices and the technical aspects of biorepository or biobank management. The majority of participants have between 6 to 10 years of experience (36.8%, N=92), with a substantial number in the 0-5 years range (34%, N=85). Participants with over 20 years of experience are the least represented (4.4%, N=11). This distribution might impact the responses and attitudes, with less input from highly experienced professionals, which could affect insights into long-term operational strategies and policy development.

4.2 Descriptives of Facility Types, Biorepository Types, and Operational Characteristics

Table 2 Overview of Facility Types, Biorepository Types, and Operational Characteristics

Category	Sub-Category	N	%
Facility Type	Academic Research Facility	37	14.8%
	Biobank/Biorepositories	16	6.4%
	Diagnostic Facility	98	39.2%
	Healthcare Facility	97	38.8%
	Private Research Facility	2	0.8%
Biorepository Type	Cell/Organ-Specific Biobank	28	11.2%
	Disease-Specific Biobank	19	7.6%
	Environmental Biobank	12	4.8%
	Genetic Biobank	13	5.2%
	Infectious Diseases Biobank	65	26.0%
	Population-Based Biobank	54	21.6%
	Rare Disease Biobank	8	3.2%
Year of Facility Establishment	1968–1999	32	12.8%
	2000–2010	20	8.0%
	2011–2020	70	28.0%
	2021–2024	78	31.2%
Experience in Biobank Operation	Yes	173	69.2%
	No	77	30.8%
Biospecimen/Biorepository Storage	Yes	172	68.8%

Availability	No	78	31.2%

Based on the result displayed in Table 2, the majority of facilities surveyed operate as diagnostic facilities (39.2%) and healthcare facilities (38.8%), reflecting a primary focus on clinical diagnostics and patient care. Academic research facilities account for 14.8%, highlighting their role in advancing medical and scientific research. Dedicated biobank/biorepository facilities represent 6.4%, which indicates a limited number of specialized facilities exclusively handling biospecimen storage and management. Private research facilities are minimal at 0.8%, signifying less involvement of independent entities in this field. The most common biorepository type is for infectious diseases (26.0%), emphasizing a focus on addressing infectious disease challenges, especially in resource-limited settings. Population-based biobanks (21.6%) follow closely, signifying efforts toward large-scale, diverse population research. Cell/organ-specific biobanks (11.2%) and disease-specific biobanks (7.6%) also contribute to targeted medical studies. Less prevalent biorepository types, such as rare disease biobanks (3.2%) and environmental biobanks (4.8%), reflect niche research areas.

A significant proportion of facilities were established in the past decade (2021–2024: 31.2%; 2011–2020: 28.0%), indicating rapid growth in biorepository-related activities. Older establishments (pre-2000) comprise only 12.8%, underscoring a relatively recent expansion of infrastructure and investments in biospecimen management. A majority (69.2%) of respondents report experience in biobank operation, suggesting substantial familiarity and expertise within the field. However, a notable minority (30.8%) lack operational experience, indicating opportunities for capacity building and training. The availability of biospecimen storage facilities is high (68.8%), demonstrating that most institutions have the infrastructure to support biobank operations. However, the remaining 31.2% lack such resources, underscoring gaps in facility readiness that could impede research and healthcare delivery.

The high prevalence of infectious disease and population-based biorepositories aligns with priorities in global health and epidemiological studies, especially in regions prone to infectious outbreaks. The notable percentage of facilities without storage capability highlights the need for investment in infrastructure to support modern biobank systems.

The lack of operational experience in a third of facilities underscores a pressing need for workforce training in biobank management to optimize utilization. This is also recognized by (Yakubu et al., 2018). Recent establishment trends suggest an expanding landscape for biospecimen research, with potential for integrating advanced technologies in newer facilities. This data provides a foundation for strategic planning in biospecimen resource management and enhanced collaboration between healthcare and research sectors.

4.3 Assessment of the Effect of Biobanking on Disease Outbreak Management Efficiency in Nigeria

Table 3: Assessment of the effect of biobanking on disease outbreak management efficiency in Nigeria

Variable	Response Options	Frequency (N)	Percentage (%)
Efficiency of Disease Outbreak Management	Very Inefficient	4	1.6%
	Inefficient	41	16.4%
	Neutral	93	37.2%
	Efficient	99	39.6%
	Very Efficient	13	5.2%
Reasons for Efficiency Ratings (n=35)	Weak healthcare infrastructure, inadequate emergency preparedness	8	22.9%
	Average management of disease	6	17.1%
	Effective COVID-19 outbreak management	6	17.1%
	Prompt response, strong NCDC collaboration	3	8.6%
	General lack of essential facilities, skills	7	20.0%
Observed	Yes	134	53.6%

Variable	Response Options	Frequency (N)	Percentage (%)
Differences in Regional Management	No	116	46.4%
Diagnostic Testing Effectiveness During Outbreaks	Very Ineffective (1)	8	3.2%
	Ineffective (2)	36	14.4%
	Neutral (3)	59	23.6%
	Effective (4)	122	48.8%
	Very Effective (5)	25	10.0%

The data on disease outbreak management and diagnostic testing effectiveness provides a nuanced picture of public perception and systemic performance during health crises as reflected in Table 3.

In terms of efficiency of disease outbreak management, the largest proportion of respondents (39.6%) rated it as "Efficient," followed closely by those who felt neutral about it (37.2%). These figures indicate that while there is significant satisfaction with the response to disease outbreaks, a substantial portion of individuals remain undecided or indifferent. A smaller percentage (16.4%) found the management "Inefficient," and only 1.6% deemed it "Very Inefficient," signaling that outright dissatisfaction is limited. Conversely, those rating the management as "Very Efficient" (5.2%) represent a minor but significant share, reflecting that there are pockets of excellence within the system. The reasons behind these ratings, based on 35 responses, highlight systemic challenges and occasional successes. Weak healthcare infrastructure and inadequate emergency preparedness emerged as the most frequently cited issues (22.86%). Similarly, the general lack of essential facilities and skills accounted for 20% of the responses, emphasizing persistent gaps in readiness. However, there were positive observations as well, such as the effective management of the COVID-19 outbreak and strong collaboration with the Nigeria Centre for Disease Control (NCDC), each receiving 17.1% of mentions. The results in Table 3 clearly agree

with the study of (Olumade et al., 2020b), which attributed the successes to the establishment of the NCDC and the use of the Nigeria Field Epidemiology and Laboratory Training Program (NFELTP) Fellows in disease outbreak response. The study also stated that the limitation to outbreak response in often due to inadequate infrastructures and health care personnel locally. Competing priority due to economic reasons, weak leadership and weak accountability in outbreak reporting are other reasons attributed to low efficiency during outbreak management (Omoleke et al., 2018).

When it comes to regional differences in outbreak management, a majority (53.6%) noted variations, indicating disparities in resource availability, local governance, or strategic execution. This perception suggests that certain regions may have benefited from stronger capacities or tailored responses, whereas others lagged behind. Interestingly, 46.4% of respondents did not observe any regional differences, hinting at potential consistency in some aspects of disease outbreak handling across the country. Regarding the effectiveness of diagnostic testing during outbreaks, nearly half (48.8%) rated it as "Effective," which is a strong indicator of confidence in testing measures. Another 23.6% adopted a neutral stance, suggesting neither significant satisfaction nor dissatisfaction. Lower ratings of "Ineffective" (14.4%) and "Very Ineffective" (3.2%) were relatively rare, while 10% of respondents found the testing to be "Very Effective," showcasing exemplary instances of testing efficacy. This distribution reflects a general approval but also states areas for improving the accessibility, accuracy, and speed of diagnosis of diseases during outbreak response. This can be seen as reported in the National Health Security Evaluation by the NCDC during a self-administered assessment using the WHO Joint External Evaluation and Benchmark Tools. In the 19 focus areas covered by this assessment, there were positive changes in eleven, negative changes in three and no change in five areas of assessment over a period of time (Fasominu et al., 2022).

4.4 Frequency Table Analysis: Diagnostic Testing During Disease Outbreaks

This section presents responses on the performance, accuracy, and challenges of diagnostic testing during disease outbreaks. The data illustrates the responses

regarding the time required to submit the results after the test, the proportion of precision, the factors that contribute to delays or inaccuracies, the success rates in identifying drug-resistant strains, and the practices for monitoring pathogen resistance patterns. The results indicate different levels of efficacy and challenges among these parameters.

4.4.1 Average Turnaround Time for Diagnostic Tests

Table 4: Average Turnaround Time for Diagnostic Tests

Turnaround Time	N	%
Longer than a few days	26	10.4
Within a day	68	27.2
Within a few days	70	28.0
Within hours	86	34.4

Most of the respondents (61.6%) preferred relatively quick turnaround times, with 34.4% reporting results within hours and 27.2% within a day as presented in Table 4. Meanwhile, over a quarter of the respondents (28.0%) reported turnaround times of a few days, and a 10.4% stated longer delays. This data shows that an alarming fraction of about 39% do not possess rapid testing capacities and therefore face extended delays for results during outbreaks. This also aligns with the JEE report of NCDC where the highest score was in the laboratory testing thematic area (Fasominu et al., 2022).

4.4.2 Accuracy Rates Compared to Established Standards

Table 5: Accuracy Rates Compared to Established Standards

Accuracy Comparison	N	%
Much higher	14	5.6
Higher	93	37.2
Comparable	124	49.6
Lower	19	7.6

Outbreaks diagnostic test accuracy is in agrees with established standards. This is seen in Table 5 where over 86% of the participants stated that accuracy as comparable to reference standards, leaving about 8% of observations stating lower accuracy levels.

4.4.3 Factors Contributing to Delays and Inaccuracies

Table 6: Factors Contributing to Delays and Inaccuracies

Factor associated with Delays and Inaccuracies	Frequency (N)	Percentage (% of Total Mentions)
Resource constraints	162	22.9%
Laboratory processing delays	88	12.5%
Sample collection issues	95	13.4%
Sample handling issues	70	9.9%
Technical limitations	84	11.9%
Others	35	5.0%

Table 6 shows that resource constraints is the most commonly admitted challenge. This accounts for close to a quarter (22.9%) of all responses. Sample collection issues and laboratory processing delays were significant, represented by 13.4% and 12.5% of total submissions, respectively. Factors such as sample handling issues and technical limitations highly contributed to over 20% of the challenges the respondents selected. Unlisted factors classified as “Other factors” was ranked lowest in challenges, which is enough to interest further examination. This report emphasizes the multifaceted nature of testing challenges, showing a necessity for improvement in resources and operational efficiencies.

4.4.4 Success in Identifying Drug-Resistant Strains

Table 7: Success in Identifying Drug-Resistant Strains

Success Level	N	%
Not applicable	6	2.4
Not successful	9	3.6
Somewhat successful	95	38.0

Success Level	N	%
Successful	136	54.4
Very successful	4	1.6

Table 7 results show a largely favourable outcome in the identification of drug-resistant strains of pathogens. A very low number of respondents (3.6%) stated insufficiency in the efforts to identify drug-resistant strains indicating room for improvements.

4.4.5 Monitoring Pathogen Resistance Patterns

Table 8: Monitoring Pathogen Resistance Patterns

Monitoring Method	N	%
Others	28	11.2
Regular surveillance	100	40.0
Research studies	122	48.8

As seen in Table 8, regular surveillance of antimicrobial resistance patterns (40.0%) and research studies (48.8%) are listed as the main methods for monitoring pathogen resistance patterns. A smaller proportion (11.2%) indicated using other methods. The prevalence of these monitoring systems (research and regular surveillance) shows an intention to establish antimicrobial use stewardship. One of the thematic areas where NCDC JEE lacked a change in capacity is antimicrobial resistance (Fasominu et al., 2022).

4.5 Perception and experiences of healthcare professionals and researchers about biobank/repositories

Table 9: Perception and experiences of healthcare professionals and researchers about biobank/repositories

Survey Question	Response Category	Frequency (N)	Percentage (%)
Perceived Benefit of Biobanks in Disease Outbreak Management	Extremely Beneficial	65	26.0%

Survey Question	Response Category	Frequency (N)	Percentage (%)
	Moderately Beneficial	37	14.8%
	Neutral	70	28.0%
	Not Beneficial at All	4	1.6%
	Slightly Beneficial	74	29.6%
Satisfaction with Biobank Integration	Dissatisfied	24	9.6%
	Neutral	95	38.0%
	Satisfied	113	45.2%
	Very Dissatisfied	4	1.6%
	Very Satisfied	14	5.6%
Perceived Effectiveness of Biobanks in Disease Outbreak Management	Moderately	46	18.4%
	Neutral	73	29.2%
	Not at All	4	1.6%
	Significantly	104	41.6%
	Slightly	23	9.2%
Confidence in Reliability of Biobank Data	Moderately Confident	71	28.4%
	Neutral	63	25.2%

Survey Question	Response Category	Frequency (N)	Percentage (%)
	Not Confident at All	4	1.6%
	Slightly Confident	39	15.6%
	Very Confident	73	29.2%
Optimism about Impact of Biobank Practices on Disease Outbreak Management Efficiency	Moderately Optimistic	48	19.2%
	Neutral	52	20.8%
	Not Optimistic at All	10	4.0%
	Slightly Optimistic	13	5.2%
	Very Optimistic	127	50.8%
Perceived Impact of Biobanks on Faster Response Times	Moderately	35	14.0%
	Neutral	48	19.2%
	Not at All	4	1.6%
	Significantly	156	62.4%
	Slightly	7	2.8%
Likelihood of Biobanks Improving Diagnostic Accuracy	Likely	52	20.8%
	Neutral	30	12.0%
	Unlikely	24	9.6%
	Very Likely	140	56.0%

Survey Question	Response Category	Frequency (N)	Percentage (%)
	Very Unlikely	4	1.6%
Confidence in Biobanks Contributing to Better Understanding and Management of Outbreaks	Moderately Confident	28	11.2%
	Neutral	42	16.8%
	Not Confident at All	4	1.6%
	Slightly Confident	16	6.4%
	Very Confident	160	64.0%

The survey data in Table 9 reflects a generally positive view of the integration of biobanks into disease outbreak management, though with some nuances in the responses. A significant proportion of respondents (55.6%) perceive the integration of biobanks into disease outbreak strategies as either “Extremely Beneficial” or “Slightly Beneficial,” indicating that most healthcare professionals and researchers see value in their role during outbreaks. However, 28% of participants remained neutral, suggesting that some are uncertain about the overall impact, possibly due to logistical challenges or lack of direct experience. Only a small fraction (1.6%) considered the integration “Not Beneficial at All,” which points to a general consensus in favor of biobanks, even if their potential is not fully realized across all settings.

In terms of satisfaction with the integration of biobanks, the majority of respondents (45.2%) indicated being “Satisfied,” while a substantial number (38%) remained “Neutral.” This suggests that while biobanks are generally appreciated, their integration may still have some gaps or inefficiencies that leave healthcare professionals and researchers feeling only moderately satisfied. About a tenth of all responses expressed dissatisfaction which indicates the existence of possible areas of competence or infrastructural improvements.

Eighty percent of respondents agreed that biobanks either “Significantly” or “Moderately” contributed to improving disease outbreak responses. This shows the critical role that biobanks have played in outbreak management some of the respondents have knowledge of. This can also be due to the fact that biobank samples always have complete data, which makes epidemiological works easier during outbreaks. This may also be due to the availability of samples in the biobanks, affording epidemiologists a chance for retrospective studies to determine more properly the onset of the outbreak. A minute percentage (1.6%) of participants asserted that they have no impact. The consistent perception that biobanks are valuable in outbreak management aligns with the reasons adduced above in this paragraph.

A strong confidence in the reliability of data obtained from biobanks was also evident, with 57.6% of participants expressing either “Very Confident” or “Moderately Confident” views about the quality of data. The low percentage of respondents who expressed a lack of confidence (1.6%) indicates trust in the integrity of the data biobanks’ produce, which is essential for ensuring accurate disease surveillance and research outcomes.

Respondents showed optimism with 70% agreeing about huge gains when biobank practices are integrated to improve disease outbreak management. This indicates a strong sense of believe that biobanks could play an evolving role in increasing the efficiency and effectiveness of outbreak responses in Nigeria.

Additionally, the table indicates general agreement that improved biobank practices could significantly bring down the response times during outbreaks. Over sixty percent of responses stated that they believed that biobank improvements would lead to “Significantly” quicker responses, which is a position also supported by (Ilesanmi et al., 2021).

The likelihood of biobanks to improve diagnostic accuracy during outbreaks was another area where there was overwhelming support. More than half of the respondents (56%) felt that enhancing biobank practices would “Very Likely” improve diagnostic testing accuracy. This indicates a strong belief that access to high-quality samples and data from biobanks is essential for ensuring the reliability and precision of diagnostic tests, which is critical during fast-paced outbreaks.

Finally, confidence in the ability of biobanks to contribute to a better understanding and management of disease outbreaks was remarkably high, with 64% of respondents expressing “Very Confident” views. This shows that biobank practices besides being seen as valuable tools for managing individual outbreaks, are also perceived to be instrumental in the long-term fight for disease surveillance.

In conclusion, the results in Table 9 show extensive support for the role of biobanks in disease outbreak management, with responses largely positive about their potential to improve response times, diagnosis precision, and outbreak management. However, the study also shows that there are areas for improvement which could be the reason for the minority negative perception.

4.6 Biorepository Focus and Specialization

Table 10: Respondents on Biorepository Focus and Specialization

Primary focus or specialty area	Response Option	Frequency (N)	Percentage (%)
What is the primary focus or specialty area of your facility? (N=107)	Population-Based	31	29.0%
	Disease-Specific	25	23.4%
	Tumor Centre	5	4.7%
	Stem Cell	4	3.7%
	Environmental	6	5.6%
	Rare Disease	14	13.1%
	Cohort	4	3.7%
	Infectious Diseases	18	16.8%

The primary focus of the facilities surveyed highlights a variety of specialization areas as shown in Table 10. Population-based studies at 28.97% is the most abundant, disease-specific research at 23.36% follows closely, while rare diseases, tumor centers

and stem cell research at 5.6%, 4.67%, and 3.74%, respectively, appeared less frequently. This is an indication that biorepositories in Nigeria are more focused on broad populations and specific diseases. This result also shows relatively lower priority for more specialized areas like stem cell research and rare diseases, which is likely attributable to the absence of treatment centres for these conditions.

4.6.1 Specimen Collection and Processing

Table 11: Specimen Collection and Processing

Question	Response Option	Frequency (N)	Percentage (%)
Biological specimens' facility collected (N=56)	Tissue samples	18	32.1%
	Blood	20	35.7%
	Urine	6	10.7%
	Cell lines	6	10.7%
	Environmental Samples	4	7.1%
	Plants	2	3.6%
Methods used for specimen collection	Surgical procedures	17	7.1%
	Minimally invasive techniques	92	38.7%
Specimens processed upon collection (N=238)	In situ	17	7.1%
	Separated into constituents	64	26.9%
	Formalin-fixed	38	16.0%
	Paraffin-embedded (FFPE)	10	4.2%

Biorepositories collect a diverse range of biological specimens, as shown in Table 11. Among the 56 facilities surveyed, the most commonly collected specimens are blood samples, accounting for 35.7%. Blood is a widely studied biological material due to its rich informational content and relative ease of collection. Tissue samples are the second most frequently collected specimens (32.1%), reflecting their critical role in diagnostic and research applications, such as histopathology and molecular studies. Urine and cell

lines each represent 10.7% of collected specimens, indicating their specific utility in metabolic studies and genetic research, respectively. Environmental samples (7.1%) and plants (3.6%) are less commonly collected, suggesting their niche applications in environmental biology or botanical studies.

Specimen collection predominantly employs minimally invasive techniques, cited by 38.7% of respondents. These methods are preferred due to their reduced risk and discomfort for participants, making them suitable for a broad range of studies. In contrast, surgical procedures are used less frequently (7.1%), likely reserved for specific applications requiring access to internal tissues or organs. The low reliance on invasive techniques reflects an emphasis on participant safety and sample accessibility. Upon collection, specimens are processed using various techniques. Among 238 responses, the most common method is separation into constituents (26.9%), a practice essential for isolating specific components (e.g., plasma, serum, or cells) for targeted analyses. Formalin fixation is also widely used (16.0%), primarily for preserving tissue integrity for histological examination. In situ processing, where specimens are analyzed or preserved in their natural state, accounts for 7.1%, often used in specific experimental setups. Paraffin embedding (FFPE), a technique commonly employed in pathology for long-term tissue preservation, is less frequent at 4.2%, reflecting its specialized application.

4.6.2 Availability of Specimen Storage and Management

Table 12: Availability of Specimen Storage and Management

Question	Multiple response option	Frequency (N)	Percentage (%)
25. What storage facilities and conditions are available for long-term specimen preservation?	-80°C Freezers	88	35.2%
	Liquid nitrogen tanks	7	2.8%
	Regular Freezers	127	50.8%
	None of the above	11	4.4%

Question	Multiple response option	Frequency (N)	Percentage (%)
26. Are specimens tracked and managed using a standardized system?	Yes	224	89.6%
	No	26	10.4%
27. If yes, which of the following does your facility use? (N=188)	Barcoding	14	7.5%
	Electronic databases	76	40.4%
	Laboratory Information Management System (LIMS)	98	52.1%
28. How often are specimens checked for viability, contamination, or degradation? (N=57)	Monthly	20	35.1%
	Quarterly	6	10.5%
	Biannually	12	21.1%
	Annually	13	22.8%
	Never checked	6	10.5%

In Table 12, among the 250 respondents, the majority relies on regular freezers for long-term preservation, accounting for 50.8% of facilities. This choice shows a general acceptability to the use of a less ideal storage temperature particularly because regular freezers operate at optimum -20^{o}C. This choice could also be due to the use of what is available rather than what is preferred lending a voice to the absence of critical infrastructure needed to drive biobanking, which in ideal situations require better storage facility such as -80^{o}C and liquid nitrogen. -80°C freezers were the next most used storage method at 35.2%, this can also be adduced to availability as the Nigerian Centre for Disease Control distributed a sizable number these ultra-cold freezers to facilities across the country during the response especially centres identified as coordinating sample collection for the strain identification during the various phases of the response. This shows a knowledge and recognition of the need for better storage more than the prevalent -20^{o}C regular freezers. This is also reflected in the JEE

evaluation where the NCDC scored the highest change in the laboratory and diagnostic thematic areas (Fasominu et al., 2022). Similarly, liquid nitrogen tanks, known for providing most ideal cold temperatures for samples had the lowest report at 2.8% of all respondents. This continues to agree as seen in the literature review that inadequate infrastructure is a gap that needs to be filled for an enhanced biobanking system in Nigeria as this value is abysmally low. This inadequacy can also be attributed to insufficient funding or perhaps lack of an understanding of the importance of sample preservation to facilitate long-term usage and repeatability of study results. A fraction (4.4%) even higher than that of liquid nitrogen reported none availability of all storage options in this study. Only about 10% of the respondents do not have access to a standard system of specimen management as seen in Table 12. While this may show compliance in the use of standardized specimen management system (89.6%) which is good for biobanking, the minority value of non-compliance is still a cause for concern as this shows that about a tenth of donor samples or pathogen passing through the diagnostic system are exposed to misplacement and mishandling, which can significantly skew results wrongly.

Laboratory Information Management System (LIMS) is deployed by 52.1% of the 188 respondents in this category. LIMS are often preferred for sample management in biobanking as it affords users a comprehensive tracking capacity and can easily be attached to donor details or medical records. Another 40.4% of the respondents use electronic database systems, which could also provide some degree of tracking but far less effective than LIMS. Barcoding systems was preferred by 7.5%, this is often linked to LIMS but this study did not disaggregate along that line. Barcoding system was introduced for sample tracking in most public facilities during the response to protect result mismatch and also reduce the sample handling time. Of the 57 respondents for quality control practices, 35.1% indicated a monthly specimens viability test. The values indicated is a reflection of practices in a low-cost setting. Very few researchers have cause to check for viability particularly where there is no intended future use of the samples. Some of the well-established biobanks are known to regularly check for viability from experience of dealing with them and probably because they understand and frequently use such samples for other studies such as genomics. Lagos Sate

Biobank, NIMR biobank and the NCDC biobank are perfect examples of such facilities with acceptable frequent sample viability check.

4.6.3 Ethical and Regulatory Compliance in Biorepositories and research centres

Table 13: Ethical and Regulatory Compliance in Biorepositories and research centres

Question	Response Option	Frequency (N)	Percentage (%)
29. Does your facility secure ethical approval for specimen collection and use in research?	Yes	220	88.0%
	No	30	12.0%
30. Does your facility have an established institutional ethics review board?	Yes	214	85.6%
	No	36	14.4%
31. How does your biobank ensure compliance with regulatory requirements related to specimen storage and data protection? (N= 93)	Regular internal audits	23	24.7%
	External certifications and accreditations	15	16.1%
	Training programs for staff	25	26.9%
	Implementation of standard operating procedures (SOPs)	18	19.4%
	Periodic reviews and updates of policies	12	12.9%

In Table 13, the highlight of this result is a great compliance (88.0%) with securing necessary ethical approval through various institutional ethical review boards or committees. A focused discussion shows an extension of this to animal use for research where ethical approval for humane use of animals for public good is also required and

some institution have ethical boards for this separate from human ethical research boards. That 12% of respondents do not secure ethical approvals for sample collection and use is alarming and needs to be addressed and corrected. This speaks to the insufficiency in governance, which skewed to certain regions in the country. A commendably high proportion (85.6%) indicated the presence of established institutional ethics review board (IRB) in their facility. This shows an understanding of the need for some governance tools to give oversight over specimen collection and use protocols. On the contrary, 14.4% showed lack of ethical boards. This suggest possible reliance on external ethics board such as the National Health Research Ethics Committee, which has capacity to grant ethical approval across the nation and is preferred by some researchers as it gives them approval across states or region. It also helps to navigate local ethics board where the researcher is not based in the facility of sample collection.

About 30% of the 93 respondents employ training programs to address compliance. This is quite low and aligns with submissions of most researchers that there is a huge gap in technical competency in the Nigerian biobanking field. A slightly lower number of respondents (24.7%) indicated regular internal audits as their common compliance mechanism. While this is commendable, a viable biobank will require a very high rate of internal audits to ensure continued adherence to protocols and procedures. Implementation of standard operating procedures (SOPs) (19.4%) also is also critically low as this is the first aspect of every process in sample collection and use. Adherence to SOPs is a must to ensure uniformity of processes which is why the SOP was developed. External certifications and accreditations (16.1%) is a good test of fit for biobank and an assurance of quality and dependable sample collection and usage. Its low value in this case can be attributable to lack of international exposure of most of the facilities in Nigeria.

4.6.4 Data Management and Access in Biorepositories and facility centres

Table 14: Data Management and Access in Biorepositories and facility centres

Question	Response Option	Frequency (N)	Percentage (%)
32. How are demographic and clinical data linked to stored specimens? (N= 179)	Use of a centralized database	54	30.2%
	Implementation of unique specimen identifiers	29	16.2%
	Integration with electronic health records (EHRs)	68	38.0%
	Manual entry and verification processes	8	4.5%
	Secure and encrypted data storage solutions	20	11.2%
33. What policies and procedures are in place to govern access to specimens and associated data? (N=209)	Access control policies	43	20.6%
	Ethics committee approvals	64	30.6%
	Data use agreements (DUAs)	55	26.3%
	Review and approval by a governance board	24	11.5%
	Confidentiality agreements for researchers	23	11.0%
34. How do you treat metadata derived from processing collected samples? (N=93)	Metadata is stored separately from raw data	14	15.1%
	Metadata is integrated into the main database	41	44.1%
	Restricted access to metadata	6	6.5
	Regular updates and audits of metadata	21	22.6%
	Use of metadata standards for consistency	11	11.8%

Biorepositories utilize various methods to link demographic and clinical data to specimens as displayed in Table 14. Integration with electronic health records is the most commonly used method among 179 respondents (38.0%). This is expected as a good number as sample collection research is done at hospitals at tertiary levels where due to traffic there is compelling need to go electronic to reduce time of operation by providing a seamless transmission of patients record to necessary quarters. Centralized database system was reported by 30.2% of respondents where this shows a preference for a more comprehensive data management system. This is often deployed by large establishments such as universities and public health system where population data is also collected. Secure and encrypted data storage solutions were indicated by 11.2%. This shows a deep gap in the implementation of data governance as it exposes participants in the study, patients and relatives to an invasion of their privacy in the event of a breach in the system. Securing data access is not only critical to biobanking, but also one of the trust tools donors needs before their samples can be collected and utilized for any biobanking purposes. A small but critical number of respondents (4.5%) reported manual entry and verification processes during sample collection. This is quite surprising as experience in the Nigerian surveillance field does not align with this position. However, the deployment of the Integrated Diseases Surveillance (IDSR) Tool by the WHO in Nigeria has gained much acceptance and many states have adopted this comprehensively. This tool also came with the distribution of devices using Open Data Kits and regularly funded with internet bandwidth to upload sample collection across Nigeria. The IDSR tool deploys the Surveillance Outbreak Management Response Analysis System (SORMAS), which is a comprehensive data management system deployed in the public health field in Nigeria. This can possibly account for the low response for manual entry against expectations.

The use of ethics committee approvals to address specimen and data access governance was most indicated at 30.6% of the 209 respondents. It was followed by data use agreements (DUAs) at 26.3%. The variance in the option is almost evenly spread. There is a call to action in this regard as Nigeria as an LMIC is very vulnerable to sample use without control by external researchers where governance around sample access is not consolidated as in this case. This shows a deep governance gap

that may be due to lack of awareness on the facilities. Inability to satisfy governance of samples and data usage also limits access to international grants. It is therefore important to create an awareness around this. While the National Health Research Committee of Nigeria presently have oversight on biobanks in Nigeria and the biobanking policy statement indicate the use of Material Transfer Agreement for any sample released from the biobank, it did not make provision for a Data Transfer Agreement nor was it explicit about access control (National health research Ethics Committee of Nigeria, 2013). This shows the need for a more robust governance structure for the biobanking process to achieve the desired output. This aligns with the findings in some governance review conducted specifically in Nigeria and across Africa with Nigeria included (Staunton & de Vries, 2020; Staunton & Moodley, 2013; Yakubu et al., 2020).

Most of the respondents (44.1%) reported an integration of metadata into the main database. This is preferred possibly for ease of access and streamlining storage and also aligns with international best practices (Izzo et al., 2014; Shekhovtsov & Eder, 2022). This data shows 15.1% have their metadata separated from the main database (Table 14). About 22.6% preferred regular updates and audits of metadata to ensure data accuracy and relevance.

4.6.5 Research Collaboration and Capacity Building

Table 15: Research Collaboration and Capacity Building

Question	Response Option	Frequency (N)	Percentage (%)
35. What types of research studies or projects have utilized specimens from your biobank? (N=159)	Genetic research studies	51	32.1%
	Epidemiological studies	38	23.9%
	Clinical trials	31	19.5%
	Public health research	15	9.4%
	Translational research projects	24	31.2%

Question	Response Option	Frequency (N)	Percentage (%)
36. Are training programs available for biobank/biorepository staff? (N = 77)	Regular in-house training sessions	12	15.6%
	Online training modules	8	10.4%
	Workshops and seminars	21	27.3%
	Certification programs	7	9.1%
	Collaboration with external training providers	5	6.5%
37. What efforts are being made to build capacity and raise awareness about biobanking? (N=61)	Awareness campaigns and workshops	12	4.8%
	Partnerships with academic institutions	19	7.6%
	Outreach programs to healthcare professionals	11	18.0%
	Publications and presentations at conferences	23	37.7%
	Development of educational materials and resources	27	44.3%
38. Does your biobank collaborate with other institutions? (N=91)	National collaborations with other biobanks	35	38.5%
	International partnerships and networks	19	20.9%
	Joint research projects	12	13.2%
	Data and specimen sharing agreements	17	18.7%
	Participation in global biobanking initiatives	8	8.8%

As displayed in Table 14, which assessed the Utilization of Biobank Specimens, biobanks are indicated to be quite supportive of research activities with 32.1% of the 159 respondents using biobanked samples for genetic research studies. Application for epidemiological studies accesses at least one out samples (23.9%) as a standalone response and at 33.3% when considered along with access for public health research (9.4%) in this survey while clinical trials reported 19.5%. These easily aligns with the purposes of biobanking although along the line of population biobanks. It is instructive that sample access for translational research projects was 31.2%, unfortunately the scope of the survey did not include a disaggregation along specific research request, which would have shown what type of translational research were being conducted in Nigeria.

Reports from the 77 respondents showed a good distribution of training preferences. Similarly, only about 9% have accessed certification programs to guide their operations in sample collection, storage and handling. This definitely set the foundation for lack of adherence to governance mechanism such as SOPs and need other ethical and legislative issues earlier reportedly low. It further aligns with the established gaps in personnel competence and capacity.

Efforts to enhance capacity and raise awareness about biobanking were reported by 61 respondents, with a notable focus on developing educational materials and resources (44.3%) and publications and presentations at conferences (37.7%). These indications while showing a low level of education about biobanking also alludes to the admission for better training and exposure via conferences, which will increase the level of knowledge, competency and a more robust biobanking practice across Nigeria. Collaboration was indicated as valuable for a successful biobanking with 38.5% respondents out of 91 responses. This was evident during the pandemic as there was collaboration across the three biobanks situated in Lagos as well as some tertiary hospitals where samples were collated for sequencing to monitor the mutations in the virus. This system was also deployed during a recent cholera outbreak where samples were retrospectively tested to more appropriately determine the onset of the outbreak by a collaboration between Lagos State Biobank, a number of secondary hospitals and researchers from the Lagos State University College of Medicine (LASUCOM). The

choice of 20.9% respondents for reflects a desire to join the global stage which should be encouraged for the country to be able to build a robust biobanking processes for its over 200 million population.

4.6.6 Biorepository Efficiency and Performance Standards

Table 16: Biorepository Efficiency and Performance Standards

Question	Response Option	Frequency (N)	Percentage (%)
40. To what extent does your organization adhere to BBMRI-ERIC performance standards? (N =110)	Fully adherent	10	9.1%
	Mostly adherent	53	48.2%
	Partially adherent	43	39.1%
	Not adherent	4	3.6%
41. How would you rate the efficiency of sample processing and storage?	Very efficient	16	6.4%
	Efficient	88	35.2%
	Somewhat efficient	57	22.8%
	Inefficient	11	4.4%
	Very inefficient	2	0.8%
	Highly accessible and shared	13	5.2%
	Accessible and shared	57	22.8%
	Somewhat accessible and shared	62	24.8%
	Limited accessibility and sharing	16	6.4%
	Not accessible or shared	7	2.8%

Regarding BBMRI-ERIC performance standards as reported in Table 16, the data provides valuable insights into organizational practices regarding adherence to BBMRI-ERIC performance standards, the efficiency of sample processing and storage, and the

accessibility and sharing of samples. A significant majority (48.2) indicated “mostly adherent” to BBMRI-ERIC standards and about 39.1% described their adherence as "partial". Whilst this study did not investigate the specific BBMRI-ERIC adherence requirements to empirically determine the respondents choices, a 9.1% adherence which shows an abysmally low biobanking standards aligns with the field experience in Nigeria.

There is a 35.2% satisfactory response to sample collection. This more than any other parameter shows an absolute need for advocacy and structure placement for biobanking in Nigeria. The low level of satisfaction among the respondents in this part of the survey continues to underscore the absence of baseline infrastructure and governance to enable a robust biobanking practice in Nigeria with its teaming population and diverse ethnic groups (Udoh & Emmanuel, 2020). Expectedly, just about 6% indicated a very efficient sample collection level.

One out of every four samples (24.8%) stored are “somewhat accessible and shared”, one out of every five samples (22.8%) stored is accessible and shared and only out of every twenty samples (5.2%) is accessible and shared. This agrees with the general believe that samples are often accessed without due process. However, personal experience agrees more with infrequent accessibilities of these samples as the custodians are simply not enlightened enough that samples can be jointly collected for different research purposes provided this is stated in the informed consent and each research has an ethical approval granted by a competent review board. It is also a common practice to keep samples strictly for the use of close allies and not the general public. This is avoidable where competent personnels are employed to manage biobanks and well-structured governance mechanisms are put in place.

4.6.7 Biobank/ Biorepository Policy and Compliance Analysis

Table 17: Clarity of Biobank/Biorepository Policies

Response Option	Frequency (N)	Percentage (%)
No, not clear	10	4.0%
Not applicable	2	0.8%

Response Option	Frequency (N)	Percentage (%)
Yes, somewhat clear	123	49.2%
Yes, very clear	115	46.0%

Table 17 shows that a significant majority (95.2%) of respondents indicate that their biobank or biorepository has policies in place that are either somewhat clear (49.2%) or very clear (46.0%). This is a positive rating that could show some awareness. A more disaggregated survey could investigate the contents of the policy document as this has not been aligned with other responses pointing at a low level of policy document particularly where only the NHREC Policy (National health research Ethics Committee of Nigeria, 2013) document is known to exist. It is, however, understandable if the clarity is in respect of the NHREC Policy and Guidelines document, which is freely available on the web and has clarity but without robust governance framework.

Table 18: Compliance with International Ethical and Legal Standards

Response Option	Frequency (N)	Percentage (%)
Fully compliant	92	36.8%
Mostly compliant	114	45.6%
Not compliant	7	2.8%
Partially compliant	37	14.8%

Most respondents report that their policies are at least mostly compliant with international ethical and legal standards (82.4%) in Table 18. This is also seen in the report of (Staunton & de Vries, 2020), which stated the existence of specific and detailed provisions on genomic and biobank research in Nigeria. Specifically, 36.8% reported full compliance, and 45.6% indicated that they were mostly compliant. On the other hand, 2.8% admitted being non-compliant and 14.8% indicated partial compliance. It will be interesting to engage the respondents further to have a good understanding of how they graded their compliance.

Table 19: Improvements for Policy Clarity and Compliance

Improvement Suggestion	Frequency (N)	Percentage (%)
Development of new policies	31	12.4%
Enhanced training and education	179	71.6%
Revision of existing policies	40	16.0%

With 71.6% requesting enhanced training and education, Table 19 classically shows respondents suggestion to improve their policy clarity and compliance. This is wholly reflective of the sustained absence of necessarily knowledge to guide and operate an efficient biobanking system in Nigeria.

4.7 Infrastructure for Biobanking/Biorepositories: Report and Interpretation

4.7.1. Adequacy of Resources for Sample Collection, Transport, and Storage

Table 20: Resource Adequacy

Response Option	Frequency (N)	Percentage (%)
No, inadequate	55	22.0%
Not applicable	2	0.8%
Yes, fully adequate	51	20.4%
Yes, somewhat adequate	142	56.8%

The majority of respondents (77.2%) report that their resources for sample collection, transport, and storage are either somewhat adequate (56.8%) or fully adequate (20.4%) displayed in Table 20. However, 22.0% of respondents felt that these resources were inadequate, highlighting a significant portion of facilities facing challenges in maintaining the necessary infrastructure for effective biobanking. The 0.8% who indicated "Not applicable" may be due to these issues not being relevant to their specific operations, such as facilities not engaged in these activities or under development.

Table 21: Effectiveness of Maintaining Sample Integrity During Transport

Sample Integrity During Transport	Frequency (N)	Percentage (%)
Effectively	125	50.0%
Ineffectively	18	7.2%
Somewhat effectively	60	24.0%
Very effectively	47	18.8%

The results in Table 21 reveals that half of the respondents (50.0%) reported that maintaining sample integrity during transport effectively, 18.8% indicated that they do so very effectively. However, a considerable portion (24.0%) mentioned they maintain it somewhat effectively, and 7.2% reported doing so ineffectively. This variation in responses suggests that, while many biobanks are successfully maintaining sample integrity during transport, improvements in methods, equipment, and protocols could be beneficial to ensure higher reliability across all facilities. It is also worthy to note that the sample transport logistics chain deployed by NCDC during COVID-19 have been sustained and are present in some parts of the country especially the Southwest states, which includes Lagos State. This logistic system provides storage, security from tampering and viability when samples are sent to the National Reference Laboratory in Abuja during outbreak response.

Table 22: Logistical Challenges Faced in Biobanking/Biorepository Operations

Logistical Challenges	Frequency (N)	Percentage (%)
Other	29	11.6%
Personnel constraints	66	26.4%
Storage limitations	105	42.0%
Transportation issues	50	20.0%

The most significant logistical challenge reported by respondents is storage limitations (42.0%), followed by personnel constraints (26.4%) and transportation issues (20.0%) as reported in Table 22. Storage limitations suggest a lack of space or inadequate

storage facilities for specimens, which could hinder biobank operations as sample volumes increase. Personnel constraints highlight the need for adequate staffing or training to handle the growing demands of biobanking. Transportation issues reflect challenges in maintaining the integrity of samples during transit or logistical bottlenecks in sample collection and delivery. Additionally, 11.6% of respondents reported other challenges, indicating that there are various unique operational issues that may not have been captured by the predefined categories. Further exploration of these "other" challenges could provide deeper insights into specific hurdles faced by individual facilities.

4.8. Ethical Considerations in Biobanking/Biorepositories

4.8.1. Storage and Condition of Facilities

Table 23: Availability and Condition of Storage Facilities

Response Option	Frequency (N)	Percentage (%)
No, not available or in poor condition	30	12.0%
Not applicable	11	4.4%
Yes, readily available and in good condition	83	33.2%
Yes, somewhat available and in good condition	126	50.4%

The majority of biobanks report that storage facilities are either somewhat available and in good condition (50.4%) or readily available and in good condition (33.2%). However, 12.0% of respondents report that their storage facilities are either not available or in poor condition, highlighting a need for infrastructure improvements in some regions. A small percentage (4.4%) did not find the question applicable, possibly due to their stage in biobank development or non-active involvement as reported in Table 23.

4.8.2 Technological Infrastructure

Table 24: Technological Infrastructure for Data Management and Analysis

Response Option	Frequency (N)	Percentage (%)

Response Option	Frequency (N)	Percentage (%)
Advanced	95	38.0%
Basic	11	4.4%
Moderate	116	46.4%
Very advanced	28	11.2%

A substantial portion of respondents (38.0%) report having advanced technological infrastructure and 46.4% indicate it is moderate in Table 24. Only 11.2% describe their infrastructure as very advanced, while 4.4% rate it as basic. This suggests that while many biobanks have adequate technological infrastructure, there is potential for improvement in integrating more advanced systems for managing the increasing volume of data.

4.8.3 Improvements to Biobanking Infrastructure

Table 25: Improvements to Biobanking Infrastructure

Suggested Infrastructure Improvements:	Frequency (N)	Percentage (%)
Enhancing data management systems	73	29.2%
Investing in new technologies	77	30.8%
Other	6	2.4%
Upgrading storage facilities	94	37.6%

Table 25 displays the identified improvements to biobanking infrastructure**.** The most common suggestion for improving biobanks is upgrading storage facilities (37.6%), followed by investing in new technologies (30.8%) and enhancing data management systems (29.2%). These priorities reflect a clear need for both infrastructural and technological improvements to support growing demands for sample storage and data handling capabilities.

4.8.4 Informed Consent and Ethical Practices

Table 26: Percentage of Samples with Documented Informed Consent

Response Option	Frequency (N)	Percentage (%)
0-25%	31	12.4%
26-50%	69	27.6%
51-75%	91	36.4%
76-100%	59	23.6%

The majority of respondents (36.4%) report having 51-75% of their samples documented with informed consent, with 23.6% reporting 76-100% as displayed Table 26. However, 12.4% of respondents indicated that only 0-25% of their samples are covered by informed consent, raising potential ethical concerns related to transparency and participant rights. These findings underline the importance of ensuring full ethical compliance, especially with respect to informed consent protocols.

Table 27: Measures for Privacy and Data Security

Response Option	Frequency (N)	Percentage (%)
Data encryption	49	19.6%
Regular audits	36	14.4%
Strict access control	165	66.0%

To ensure privacy and data security, strict access control is the most widely adopted measure (66.0%), followed by data encryption (19.6%) and regular audits (14.4%). While access control is essential, the relatively low use of data encryption and audits suggests areas where data security measures could be strengthened to ensure comprehensive protection of sensitive biobank data presented in Table 27.

4.8.5 Ethical Review and Oversight

Table 28: Approaches to Ethical Considerations in Biorepositories and centres

Response Option	Frequency (N=127)	Percentage (%)
Ethics review boards	61	28.1%
Ethics review boards; Confidentiality agreements	11	5.1%
Ethics review boards; Informed consent protocols	17	7.8%
Ethics review boards; Informed consent protocols; Confidentiality agreements	38	17.5%
Informed consent protocols	60	27.7%
Informed consent protocols; Confidentiality agreements	20	9.2%
Informed consent protocols; Confidentiality agreements; Other	6	2.8%
Others	4	1.8%

As presented in Table 28, the data highlights the mechanisms employed to ensure the integrity of biological specimens by checking for viability, contamination, or degradation, emphasizing the role of ethical frameworks and procedural safeguards, 217 gave responses. About 28% of respondents indicated that ethic review boards are most preferred methods of approach in Nigerian biorepositories while 17.5% combine ethics review board, informed consent protocols and confidentiality agreements indicating a broader approach to ethical compliance.

As expected, informed consent protocols stood out as a key pillar as it was preferred by 27.7% of respondents in isolation and 41.5% in combination with other protocols. These results show an agreement on ethical practices governing specimen usage. A notable portion of responses (17.5%) reflects the integrated use of ethics review boards, informed consent protocols, and confidentiality agreements. This combination approach points to a robust ethical framework that prioritizes thorough oversight and compliance. Smaller proportions of respondents (5.1% and 2.8%) reported using combinations that include unspecified “other” measures, demonstrating some variability and adaptability in ethical practices.

Table 29: Enhancing Biobanking for Disease Outbreak Management

Suggested Improvements for Disease Outbreak Management:	Frequency (N)	Percentage (%)
Development of novel biobanking/biorepositories technologies	101	40.4%
Enhanced international collaboration	74	29.6%
Improved data sharing protocols	63	25.2%
Others	12	4.8%

In Table 29, respondents mainly preferred the development of novel biobanking/biorepositories technologies at 40.4%, which is a significant proportion of the respondents in order to enhance diseases outbreak management. This is followed by an enhanced international collaboration (29.6%), which could be a reflection of the need for technical competence. Improved data sharing protocols at a quarter in preference (25.2%) show an understanding that data sharing is critical to getting more information during outbreak management.

4.8.6 Challenges Faced by Biobanks in Nigeria

Table 30: Main Challenges in Specimen Collection, Storage, or Utilization

Response Option	Frequency (N)	Percentage (%)
Inadequate funding for maintenance and upgrade, limited research funding and grant, limited collaboration	8	18.2
Access to fund	2	4.6
Availability of storage space and software for priority pathogens	4	9.1
Electricity issues	5	11.4
Limited transport resources	2	4.6
Poor storage facility	12	27.3

Response Option	Frequency (N)	Percentage (%)
Personnel constraints	6	13.6
Lack of technical expertise	5	11.4

Table 30 shows that the highest challenge to biobank and biorepositories in Nigeria is about poor storage facility (27.3%). It is, however, important to state that the whole strength of biobanking lies in an ability to store samples while retaining their viability. Storage can be an issue in Nigeria due to the unstable power supply for cold-storage and the limited access to nitrogen cannisters or baths due to cost for nitrogen storage. While inadequate funding is also rated high as a challenge (18.2%) after poor storage facility, the combination of inadequate personnel and lack of technical expertise brings to concern the competence availability for biobanking operations in Nigeria. These findings align with established situation on the challenges faced by biobanking in Nigeria (Mendy et al., 2014). However, it is established that the Lagos State Government, Nigerian Institute of Biomedical Research, and the NCDC have established standard biobanks in 2018 (Lagos State Biobanks), 2019 for NIMR and 2022 for the NCDC Biobank with substantial financial support and training of personnel.

4.9 Hypothesis Testing

A model testing the associations between various factors that influence the performance of Biobanks, Biorepositories and Research Facilities (BBRF) in managing disease outbreaks, specifically focusing on key variables that shape the effectiveness of these systems.

Table 31: Key Variables in the statistical model

Variable	Description
Region	Geographic location of the facility.
Type of Facility	Classification of the healthcare facility (e.g., hospital, research center).

Variable	Description
Specialty	Area of medical expertise or focus of the facility.
Year of Establishment	The year when the facility was established.
BBRF Performance in Disease Outbreak Management	Efficiency of BBRF in addressing disease outbreaks (rating scale).
Challenges	Obstacles encountered in sample collection, resource constraints, laboratory delays, technical limitations, and logistical issues during outbreak management.
Healthcare Professionals (HCP) Perceived Benefit of BBRF	Perceived utility of BBRF by healthcare professionals (HCPs).
HCP Satisfaction with Integration of BBRF	Satisfaction of healthcare professionals (HCPs) with the integration of BBRF into existing systems.
HCP Perceived Confidence in BBRF	Confidence levels of healthcare professionals (HCPs) in BBRF for diagnostic and management tasks.
Regional Differences in BBRF Management	Variations in BBRF management approaches across regions.
Effectiveness of Current Diagnostic Testing	Assessment of diagnostic test efficiency during disease outbreaks.
HCP Perceived Effectiveness of Disease Management Strategies	Effectiveness of disease outbreak management strategies as perceived by healthcare professionals (HCPs).

This study investigated various factors that influenced the performance of Biobanks/Biorepositories/Research Facilities (BBRF) in managing disease outbreaks in Nigeria, specifically focusing on key variables that affect their effectiveness. Each of the variable served a distinctive part to understand how biobanks contribute to outbreak management in healthcare settings.

1. Region: This study revealed that geographical location of a facility significantly influences the effectiveness of outbreak management strategies in Nigeria. The study shows a skewed highlights that regions equipped with superior infrastructure, abundant resources, and robust support systems tend to achieve greater success in managing disease outbreaks.
2. Type of Facility: The classification of a facility, such as a hospital, research center, or other specialized institutions, plays a pivotal role in its capacity to address disease outbreaks. Facilities with advanced technologies and specialized resources often exhibit higher proficiency in outbreak management.
3. Specialty: The medical expertise or specialized focus of a facility directly shapes its approach to disease outbreak management. For example, facilities dedicated to infectious diseases generally have stronger protocols and greater capacity to handle outbreaks compared to general medical centers.
4. Year of Establishment: The establishment year of a facility correlates with its preparedness for managing disease outbreaks. Older facilities, with more time to develop and refine their protocols, tend to demonstrate superior performance due to their accumulated experience and enhanced infrastructure.
5. BBRF Performance in Disease Outbreak Management: This variable represents the core of the study—assessing how well biobanks perform in managing disease outbreaks. This performance is influenced by a variety of factors, including the type of facility, resources available, and regional differences in healthcare systems.
6. Challenges: This variable encapsulates the various obstacles faced during disease outbreak management, including delays in sample collection, resource limitations, and technical issues. These challenges directly affect the effectiveness of biobank operations and require targeted interventions to mitigate their impact.
7. Healthcare Professionals (HCP) Perceived Benefit of BBRF: The perceived utility of the biobank by healthcare professionals is a critical factor. If HCPs believe in

the value of biobanks for diagnostic and therapeutic purposes, they are more likely to integrate these resources effectively into their practices, improving outbreak management.

8. HCP Satisfaction with Integration of BBRF: The satisfaction of healthcare professionals with how well biobanks are integrated into existing healthcare systems influences their willingness to engage with and support biobank initiatives. Higher satisfaction levels correlate with smoother operations and more effective outbreak management.
9. HCP Perceived Confidence in BBRF: Confidence among healthcare professionals in biobanks' ability to support disease diagnosis and management is essential for effective outbreak response. Increased confidence leads to better utilization of biobank resources in critical situations.
10. Regional Differences in BBRF Management: This variable explores how variations in biobank management practices across different regions influence their overall effectiveness. Regional disparities, such as differences in infrastructure, training, and healthcare policy, can create significant challenges for disease outbreak management.
11. Effectiveness of Current Diagnostic Testing: The efficiency of diagnostic tests during outbreaks is crucial for identifying pathogens and tracking disease spread. This variable is linked to the success of biobank operations, as accurate and timely diagnostic information is essential for guiding treatment decisions and managing outbreaks.
12. HCP Perceived Effectiveness of Disease Management Strategies: This variable assesses how healthcare professionals view the overall effectiveness of the strategies used to manage disease outbreaks. The perceptions of healthcare professionals are influenced by the availability of diagnostic tools, the integration of biobanks, and the effectiveness of current management practices.

Table 32: Correlation Table: Key Variables in BBRF Performance and Disease Outbreak Management

Construct	1	2	3	4	5	6	7	8	9	10	11	12
1. Region	1.000											
2. Type of Facility	0.256***	1.000										
3. Specialty	0.276***	-0.132	1.000									
4. Year of Establishment	-0.001	0.102	0.036	1.000								
5. BBRF Performance in Disease Outbreak Management	-0.120	0.528***	-0.098	0.244***	1.000							
6. Challenges	-0.185*	-0.157	0.353***	0.047	0.321***	1.000						
7. HCP Perceived Benefit of BBRF	-0.098	0.024	0.018	0.170*	0.325***	0.232**	1.000					
8. HCP Satisfaction with Integration of BBRF	0.064	-0.190*	-0.299**	-0.235**	0.040	-0.346***	-0.345***	1.000				
9. HCP Perceived Confidence in BBRF	0.178**	0.110	-0.151	-0.076	0.273***	-0.124	-0.262**	0.341***	1.000			
10. Regional Differences in BBRF Management	0.008	-0.100	0.094	0.028	-0.521***	-0.298***	0.011	0.085	0.043	1.000		
11. Effectiveness of Current Diagnostic Testing	-0.026	0.086	-0.074	0.104*	0.666***	0.323***	-0.009	0.078	0.221***	-0.263**	1.000	
12. Perceived Effectiveness of Strategies	0.103	-0.018	0.039	0.033	0.270***	-0.269***	-0.499***	0.256***	0.312***	0.042	0.187**	1.000

***p < 0.05; **p < 0.01; ***p < 0.001**

This study explores the effectiveness of an integration of biobanks, biorepositories and research facilities storing samples (BBRF) in managing disease outbreaks in Nigeria in Table 31. The findings reveal several noteworthy relationships among variables that contribute to a deeper understanding of biobanking practices and their role in public health strategies.

1. **Region** shows significant positive correlations with healthcare professionals' perceived confidence (r = 0.18***) and the effectiveness of disease outbreak management strategies (r = 0.10). This suggests that regional dynamics,

such as resource allocation and health infrastructure, play a crucial role in shaping the perceived efficiency of BBRF in outbreak contexts.

2. **Type of Facility** positively correlates with BBRF performance in outbreak management (r = 0.53***), indicating that facility classification (e.g., research centers vs. general hospitals) impacts the efficacy of biobanking practices, possibly due to differences in technical expertise and resource availability.

3. **Specialty** has a weak but significant correlation with the challenges faced during disease outbreak management (r = 0.35***), underscoring that specialized facilities may experience distinct logistical or technical hurdles.

4. **Year of Establishment** correlates positively with perceived effectiveness of diagnostic testing (r = 0.10*). Older facilities may have more established protocols and experienced staff, enhancing diagnostic reliability during outbreaks.

5. **BBRF Performance in Disease Outbreak Management** is strongly associated with several factors, including HCP satisfaction with BBRF integration (r = 0.39***), perceived benefits (r = 0.63***), and effectiveness of current diagnostic testing (r = 0.67***). This association strongly implies that satisfaction, benefits sharing, and diagnostic precision together enhanced the performance of BBRF systems.

6. **Challenges** such as sample collection and resource limitations show significant association with BBRF performance (r = 0.32***), indicating their role in defining operational efficiency. Therefore, an attention to these challenges will significantly improve biobanking practices in Nigeria.

7. **HCP Perceived Benefits of BBRF** also shows a positive correlation with HCP confidence (r = 0.17*), signifying that perceived utility fosters trust among healthcare professionals in BBRF systems.

8. **HCP Satisfaction with BBRF Integration** relates inversely (strongly) with challenges (r = -0.35***), which shows that where there is seamless integration, there will be a reduction in perceived difficulties, thus creating an enabling and more supportive role for biobanking operations.

9. **Effectiveness of Current Diagnostic Testing** and **Perceived Effectiveness of Strategies** shows a positive association with BBRF performance (r = 0.67*** and r = 0.27***, respectively), strongly indicating

the vital role an elaborate diagnostic process and complete management strategies in outbreak responses.

These insights can guide targeted interventions to optimize biobanking practices and inform policies aimed at strengthening Nigeria's public health infrastructure.

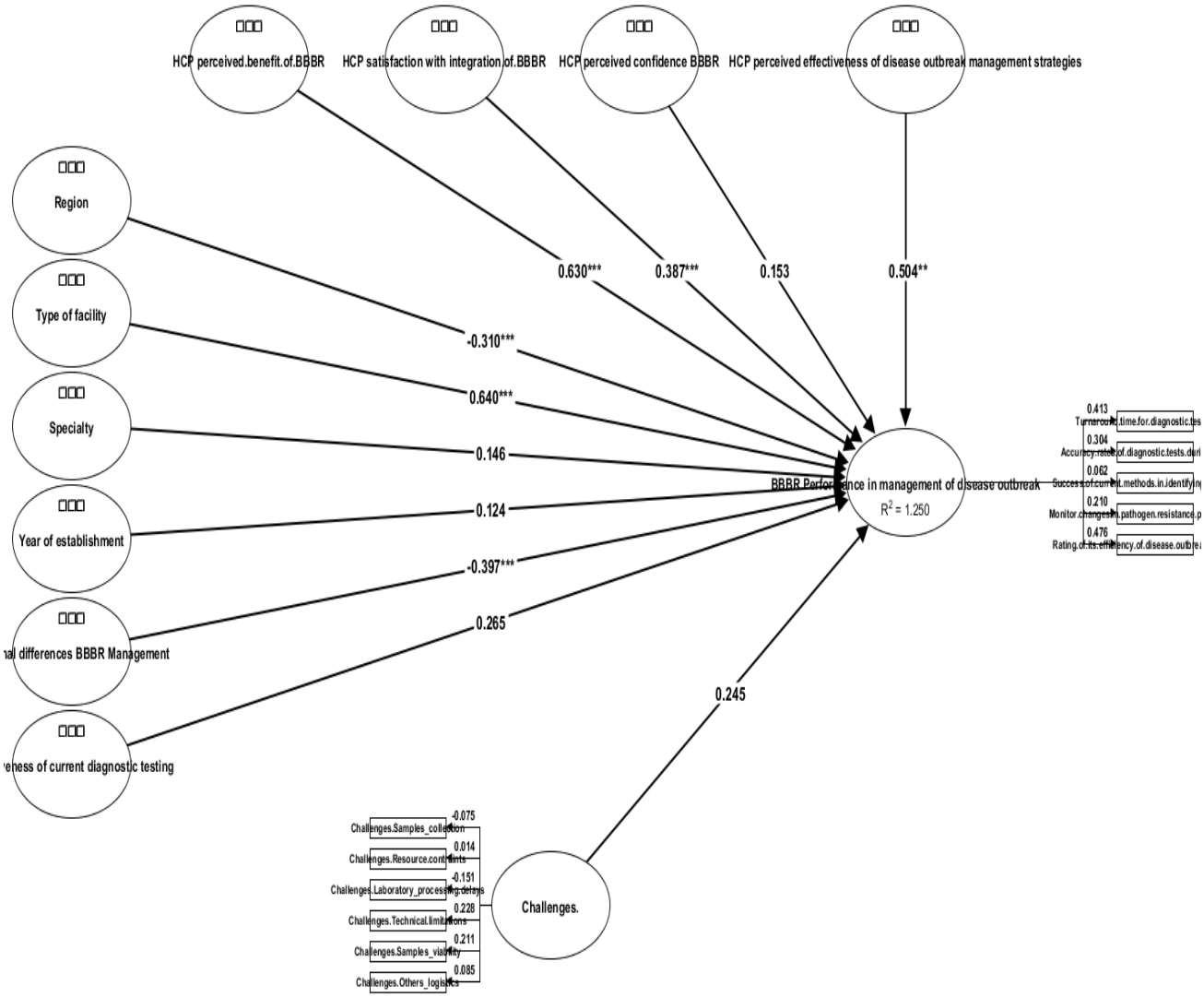

Figure 1: **Model of Performance of Biobanks in Managing Disease Outbreaks**

Model of Performance of Biobanks in Managing Disease Outbreaks

The model of biobank performance in managing disease outbreaks integrates various constructs, including the effectiveness of the biobank (BBRF), healthcare professional (HCP) satisfaction, perceived confidence, and external factors like regional differences, facility type, and challenges. This model assesses the influence of different factors on the effectiveness of biobanks in handling disease outbreaks, particularly in Nigerian cities like Lagos and Abuja.

4.9.1 Model Fit Analysis

The goodness-of-fit statistics of the model evaluate the extent to which the proposed framework corresponds with the gathered data. Essential metrics provide valuable information regarding the model's credibility:

SRMR (0.1652): Suggests a moderate fit; although lower values approaching zero are preferable, this indicates a reasonable correspondence with the data.

dULS (6.3057): This value indicates a significant opportunity for enhancing the model to more accurately reflect the underlying structure of the data.

dG (2.1048): Indicates a satisfactory fit, yet there is room for refinement to move closer to zero.

The findings indicate that the model identifies significant trends within the data; however, it necessitates adjustments to improve its overall alignment.

4.9.2 R-Squared, also known as the Coefficient of Determination

The R^2 value assesses the extent to which the independent variables account for variations in the dependent variable—BBRF Performance in Disease Outbreak Management:

The R^2 value of 1.25045 indicates a robust correlation between the factors of the model and the performance of the biobank. This value, surpassing 1, signifies considerable explanatory strength.

The adjusted R^2 value of 1.26203 enhances the model's predictive capability by taking into consideration the number of predictors and the size of the sample. The metrics underscore the crucial influence of independent variables in elucidating variations in performance.

4.9.3 Comprehensive Effects Examination

The comprehensive evaluation of total effects examines the various factors that impact BBRF Performance in Disease Outbreak Management, taking into account both direct and indirect contributions. The p-values, t-values, and confidence intervals are used to evaluate the significance of the relationships.

Table 33: Total Effects Inference for the Model of Biobank Performance in Disease Outbreak Management

Effect	B	SE	t-value	p-value	95.5% Confidence Interval

Effect	B	SE	t-value	p-value	95.5% Confidence Interval	
Region -> BBRF Performance in Disease Outbreak Management	-0.3101	0.0802	-3.87**	0.0001	-0.1763	-0.1062
Type of Facility -> BBRF Performance in Disease Outbreak Management	0.6404	0.1140	5.62**	0.0000	0.7996	0.9641
Specialty -> BBRF Performance in Disease Outbreak Management	0.1459	0.1328	1.20	0.1361	0.3856	0.4665
Year of Establishment -> BBRF Performance in Disease Outbreak Management	0.1241	0.0969	1.28	0.1003	0.3125	0.4284
Challenges -> BBRF Performance in Disease Outbreak Management	0.2454	0.2006	1.22	0.1107	0.4124	0.5233
HCP Perceived Benefit of BBRF -> BBRF Performance in Disease Outbreak Management	0.6301	0.1266	4.98**	0.0000	0.8395	0.9587
HCP Satisfaction with Integration of BBRF -> BBRF Performance in Disease Outbreak Management	0.3872	0.1108	3.50**	0.0002	0.5447	0.6283
HCP Perceived Confidence in BBRF -> BBRF Performance in Disease Outbreak Management	0.1534	0.1139	1.35	0.0892	0.3879	0.4719
Regional Differences in BBRF Management -> BBRF Performance in Disease Outbreak Management	-0.3967	0.0989	-4.01**	0.0000	-0.2345	-0.1972
Effectiveness of Current Diagnostic Testing -> BBRF Performance in Disease Outbreak Management	0.2646	0.1673	1.58	0.0570	0.5471	0.6367
HCP Perceived Effectiveness of Disease Outbreak Management Strategies -> BBRF Performance in Disease Outbreak	0.5038	0.1551	3.25**	0.0006	0.7876	0.9214

Effect	B	SE	t-value	p-value	95.5% Confidence Interval	
Management						

- Region -> BBRF Performance: The negative relationship between Region and BBRF performance (β = -0.3101, p = 0.0001) indicates that facilities in certain regions may face challenges that reduce their effectiveness in managing disease outbreaks.
- Type of Facility -> BBRF Performance: A positive and significant effect (β = 0.6404, p = 0.0000) suggests that facilities with specialized capabilities perform significantly better in managing disease outbreaks.
- Specialty and Year of Establishment have weaker effects on performance (with p-values > 0.05), indicating that these factors are not as crucial as other variables like HCP benefit perception and facility type.
- Challenges: While challenges such as resource constraints and laboratory delays impact performance, their effects are not as strong (p = 0.1107), suggesting that while important, they are secondary to structural and professional factors.
- HCP Perceived Benefit of BBRF and HCP Satisfaction with Integration are strongly related to improved performance (β = 0.6301 and β = 0.3872, both significant), emphasizing that HCP engagement and positive perception are critical for biobank success.
- Regional Differences in BBRF Management pointedly affected performance negatively (β = -0.3967, p = 0.0000), showing that that varying management practices among regions is an obstacle to biobank effectiveness.
- Effectiveness of Current Diagnostic Testing and HCP Perceived Effectiveness of Management Strategies has a positive effect in relationship to BBRF performance.

The model clearly states that there are multiple factors driving biobank suggests that biobank efficacy in managing disease outbreaks. As per benefit perception, satisfaction and confidence, facility type and HCP engagement possess highest

significant influence on biobank effectiveness. Regional variations and difficulties have impact roles which is less in effects than the infrastructural and competence factors. Biobanking effectiveness will be strengthened when logistical and resource challenges are removed with a consistent good management practices spread across all regions. On a final note, capacity for precise diagnostic testing along with outbreak management strategies are seen as effective and could improve the capacity to function and effects of biobanks as perceived by healthcare professionals.

4.10 Discussion

This study's results made possible a detailed examination of the existing environment, challenges, and opportunities in biobank and biorepository (BBRF) operations, especially regarding disease outbreak control in Nigeria. Many significant themes came up from the data covering regional differences, resource insufficiency, operational challenges, and the integration of biobanks into public health systems.

4.10.1 Disparities in Regions and Facilities

The regional skewness of participants, with the South-West area comprising over half of the sample (55.2%), indicates the concentration of biobank resources, infrastructure and possibly health care infrastructure and personnel in Lagos State. This can be attributed to Lagos's designation as the commercial nerve centre, its population and the location of significant biorepositories, such as the Lagos State Biobank, the Nigerian Institute of Medical Research Biobank, and the NCDC Biobank. The unequal allocation of facilities and resources among various regions indicates structural biases that may affect the efficacy of national outbreak response where biobanks have significant roles to play. The findings therefore reiterate the necessity for extensive infrastructure investment in underprivileged areas, as geographical disparities were substantially associated with the perceived efficacy of BBRF in disease treatment.

4.10.2 Utilisation of Biobanks and Their Impact on Outbreak Management

Overall result shows that biobanks are regarded as essential instruments in tackling disease outbreaks, with 62.4% of respondents acknowledging their central contribution to expedited reaction times. A strong confidence in biobank dependability (64% "Very Confident") strengthens their efficacy in improved

diagnostic accuracy and outbreak control. However, challenges such as insufficient financing (27.3%) and poor storage facilities (27.3%) were identified as significant hindrances, limiting the optimal utilisation of the biobanks. It is apparent that these deficiencies need to be rectified to improve the expansion and efficacy of biobanks in enhancing public health initiatives.

4.10.3 Operational Efficiency and Resource Limitations

Although the majority of respondents indicated a satisfactory level of resources for sample collection and storage, a sizable minority (22%) considered their resources insufficient. The deficiency is heightened by hands-on difficulties particularly in sample preservation and sample integrity during transportation, as just 18.8% evaluated their procedures as "Very Effective." Also, storage limitations were the predominant logistical challenge indicated (42%), underscoring the pressing necessity for infrastructure enhancements, especially in ultra-low-temperature storage solutions such as -80°C freezers.

4.10.4 Technological and Ethical Frameworks

The survey indicates varying degrees of technological progress in biobank operations, with 46.4% reporting intermediate infrastructure and merely 11.2% suggesting very sophisticated systems. This highlights the necessity for investment in advanced data management technologies, such as Laboratory Information Management Systems (LIMS), utilised by 52.1% of facilities. Ethical compliance was robust, with 88% obtaining ethical approvals and 85.6% possessing institutional ethics review boards. However, deficiencies in informed consent methods, evidenced by 12.4% of samples lacking documentation, underscore the need for enhancement in participant openness and rights.

4.10.5 Training and Collaboration

Capacity building is fundamental for enhancing biobank operations. Workshops and seminars were the predominant training techniques; nevertheless, the minimal participation in certification programs (9.1%) and partnerships with external training providers (6.5%) indicate underexploited avenues for professional advancement. Likewise, although national collaborations were prevalent (38.5%), involvement in global biobanking projects (8.8%) was restricted, suggesting potential for improved international integration and information exchange.

4.10.6 Recommendation

1. Infrastructure Development: Mitigate regional disparities by investing in biobank infrastructure in underprivileged areas, guaranteeing equal allocation of resources nationwide.
2. Technological Advancements: Broaden the implementation of sophisticated data management systems such as LIMS and advocate for the adoption of secure data-sharing protocols to improve operational efficiency.
3. Capacity Building: Establish organised training programs, encompassing certificates, and promote partnerships with global biobanking networks to enhance local proficiency.
4. Policy and Ethical Oversight: Augment informed consent protocols and refine ethical review procedures to guarantee adherence to international norms.
5. Collaboration and Advocacy: Foster alliances among biobanks, academic institutions, and public health authorities to incorporate biobank methodologies into comprehensive disease surveillance and management systems.

4.10.7 Conclusion

The report highlights the essential function of biobanks in managing disease outbreaks, while pinpointing areas for enhancement in infrastructure, operational efficiency, and capacity development. Rectifying these deficiencies necessitates a coordinated strategy that utilises local expertise, promotes international collaboration, and coincides with national public health objectives. By executing the strategic recommendations presented, Nigeria can bolster the resilience and efficacy of its biobank systems, establishing them as essential resources in addressing future health emergencies.

5 References

Abayomi, A., Balogun, M. R., Bankole, M., Banke-Thomas, A., Mutiu, B., Olawepo, J., Senjobi, M., Odukoya, O., Aladetuyi, L., Ejekam, C., Folarin, A., Emmanuel, M., Amodu, F., Ologun, A., Olusanya, A., Bakare, M., Alabi, A., Abdus-Salam, I., Erinosho, E., … Ogunsola, F. (2021). From Ebola to COVID-19: emergency preparedness and response plans and actions in Lagos, Nigeria. In *Globalization and Health* (Vol. 17, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12992-021-00728-x

Abimiku, A. G., Croxton, T., Ozumba, P. J., Agala, N., Balogun, O., Jonathan, E., Onyemata, E., Ndifon, K., Nadoma, S., Anazodo, T., Peters, S., & Beiswanger, C. M. (2019). Blueprint for building a biorepository in a resource-limited setting that follows international best practices. *African Journal of Laboratory Medicine*, *8*(1). https://doi.org/10.4102/ajlm.v8i1.722

Akinyemi, R. O., Akinwande, K., Diala, S., Adeleye, O., Ajose, A., Issa, K., Owusu, D., Boamah, I., Yahaya, I. S., Jimoh, A. O., Imoh, L., Fakunle, G., Akpalu, A., Sarfo, F., Wahab, K., Sanya, E., Owolabi, L., Obiako, R., Osaigbovo, G., … Owolabi, M. O. (2018). Biobanking in a Challenging African Environment: Unique Experience from the SIREN Project. *Biopreservation and Biobanking*, *16*(3), 217–232. https://doi.org/10.1089/bio.2017.0113

Akinyemi, R. O., Salami, A., Akinyemi, J., Ojagbemi, A., Olopade, F., Coker, M., Farombi, T., Nweke, M., Arulogun, O., Jegede, A., Owolabi, M., Kalaria, R. N., & Ogunniyi, A. (2019). Brain banking in low and middle-income countries: Raison D'être for the Ibadan Brain Ageing, Dementia And Neurodegeneration (IBADAN) Brain Bank Project. *Brain Research Bulletin*, *145*, 136–141. https://doi.org/10.1016/J.BRAINRESBULL.2018.08.014

Andy Field. (2013). *DISCOVERING STATISTICS USING IBM SPSS STATISTICS* (Michael Carmichael, Ed.; Fourth). SAGE.

Annaratone, L., De Palma, G., Bonizzi, G., Sapino, A., Botti, G., Berrino, E., Mannelli, C., Arcella, P., Di Martino, S., Steffan, A., Daidone, M. G., Canzonieri, V., Parodi, B., Paradiso, A. V., Barberis, M., & Marchiò, C. (2021). Basic principles of biobanking: from biological samples to precision medicine for patients. In *Virchows Archiv* (Vol. 479, Issue 2, pp. 233–246). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00428-021-03151-0

Argudo-Portal, V., & Domènech, M. (2020). The reconfiguration of biobanks in Europe under the BBMRI-ERIC framework: Towards global sharing nodes? *Life Sciences, Society and Policy*, *16*(1). https://doi.org/10.1186/s40504-020-00105-3

Asslaber, M., & Zatloukal, K. (2007). Biobanks: Transnational, European and global networks. *Briefings in Functional Genomics and Proteomics*, *6*(3), 193–201. https://doi.org/10.1093/bfgp/elm023

Barbian, L., & Reznick, J. S. (n.d.). *Remains of War: Walt Whitman, Civil War Soldiers, and the Legacy of Medical Collections*.

Betsou, F., Parida, S. K., & Guillerm, M. (2011). Infectious diseases biobanking as a catalyst towards personalized medicine: Mycobacterium tuberculosis paradigm. *Tuberculosis*, *91*(6), 524–532. https://doi.org/10.1016/J.TUBE.2011.07.006

Brancato, V., Esposito, G., Coppola, L., Cavaliere, C., Mirabelli, P., Scapicchio, C., Borgheresi, R., Neri, E., Salvatore, M., & Aiello, M. (2024). Standardizing digital biobanks: integrating imaging, genomic, and clinical data for precision medicine. In *Journal of Translational Medicine* (Vol. 22, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12967-024-04891-8

Branković, I., Malogajski, J., & Morré, S. A. (2014). Biobanking and translation of human genetics and genomics for infectious diseases. *Applied and Translational Genomics*, *3*(2), 30–35. https://doi.org/10.1016/j.atg.2014.04.001

Broger, T., Muyoyeta, M., Kerkhoff, A. D., Denkinger, C. M., & Moreau, E. (2020). Tuberculosis test results using fresh versus biobanked urine samples with FujiLAM. *The Lancet Infectious Diseases*, *20*(1), 22–23. https://doi.org/10.1016/S1473-3099(19)30684-X

Byrne, J. A., Carpenter, J. E., Carter, C., Phillips, K., Braye, S., Watson, P. H., & Rush, A. (2021). Building Research Support Capacity across Human Health Biobanks during the COVID-19 Pandemic. In *Biomarker Insights* (Vol. 16). SAGE Publications Ltd. https://doi.org/10.1177/11772719211024100

Cambon-Thomsen, A., Ducournau, P., Gourraud, P. A., & Pontille, D. (2003). Biobanks for genomics and genomics for biobanks. In *Comparative and Functional Genomics* (Vol. 4, Issue 6, pp. 628–634). https://doi.org/10.1002/cfg.333

Campbell, L. D., Astrin, J. J., DeSouza, Y., Giri, J., Patel, A. A., Rawley-Payne, M., Rush, A., & Sieffert, N. (2018). The 2018 Revision of the ISBER Best Practices: Summary of Changes and the Editorial Team's Development Process. In

Biopreservation and Biobanking (Vol. 16, Issue 1, pp. 3–6). Mary Ann Liebert Inc. https://doi.org/10.1089/bio.2018.0001

Chalmers, D., Nicol, D., Kaye, J., Bell, J., Campbell, A. V., Ho, C. W. L., Kato, K., Minari, J., Ho, C. H., Mitchell, C., Molnár-Gábor, F., Otlowski, M., Thiel, D., Fullerton, S. M., & Whitton, T. (2016). Has the biobank bubble burst? Withstanding the challenges for sustainable biobanking in the digital era Donna Dickenson, Sandra Soo-Jin Lee, and Michael Morrison. In *BMC Medical Ethics* (Vol. 17, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12910-016-0124-2

Colwill, M., Baillie, S., Pollok, R., & Poullis, A. (2024). Biobanks and biomarkers: Their current and future role in biomedical research. *World Journal of Methodology*, *14*(4). https://doi.org/10.5662/wjm.v14.i4.91387

Coppola, L., Cianflone, A., Grimaldi, A. M., Incoronato, M., Bevilacqua, P., Messina, F., Baselice, S., Soricelli, A., Mirabelli, P., & Salvatore, M. (2019). Biobanking in health care: Evolution and future directions. In *Journal of Translational Medicine* (Vol. 17, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12967-019-1922-3

Corral-Vázquez, C., Aguilar-Quesada, R., Catalina, P., Lucena-Aguilar, G., Ligero, G., Miranda, B., & Carrillo-Ávila, J. A. (2017). Cell lines authentication and mycoplasma detection as minimun quality control of cell lines in biobanking. *Cell and Tissue Banking*, *18*(2), 271–280. https://doi.org/10.1007/s10561-017-9617-6

Creswell, J. W. ., & Plano Clark, V. L. . (2018). *Designing and Conducting MIXED METHODS RESEARCH* (Third). SAGE.

Creswell John. W., & Cresswell David. J. (2018). *Research Design* (Fifth). SAGE Publications.

Croxton, T., Jonathan, E., Suleiman, K., Balogun, O., Ozumba, P. J., Aloyo, S. M., Nsubuga, G., Kamulegeya, R. E., Newton, L., Mukisa, J., Kader, M., Damaneite, V., Nadoma, S., Onyemata, E. J., Anzaku, A. A., Nasinghe, E., Troyer, J., Joubert, B. R., Beiswanger, C., … Abimiku, A. (2023). Building blocks for better biorepositories in Africa. *Genome Medicine*, *15*(1). https://doi.org/10.1186/s13073-023-01235-x

De Paoli, P. (2005). Biobanking in microbiology: From sample collection to epidemiology, diagnosis and research. In *FEMS Microbiology Reviews* (Vol. 29, Issue 5, pp. 897–910). https://doi.org/10.1016/j.femsre.2005.01.005

De Souza, Y. G., & Greenspan, J. S. (2013). Biobanking past, present and future: Responsibilities and benefits. In *AIDS* (Vol. 27, Issue 3, pp. 303–312). https://doi.org/10.1097/QAD.0b013e32835c1244

Eisenga, M. F., Gomes-Neto, A. W., Van Londen, M., Ziengs, A. L., Douwes, R. M., Stam, S. P., Osté, M. C. J., Knobbe, T. J., Hessels, N. R., Buunk, A. M., Annema, C., Siebelink, M. J., Racz, E., Spikman, J. M., Bodewes, F. A. J. A., Pol, R. A., Berger, S. P., Drost, G., Porte, R. J., … Bakker, S. J. L. (2018). Rationale and design of TransplantLines: A prospective cohort study and biobank of solid organ transplant recipients. *BMJ Open*, *8*(12). https://doi.org/10.1136/bmjopen-2018-024502

Elebesunu, E. E., Effiong, F. B., Asika, M. O., Fadele, P. K., Onyeogalu, F. A., Okafor, C. A., & Scott, G. Y. (2023). Combating the zoonotic trio of Ebola virus disease, Lassa fever, and COVID-19 in Nigeria: a retrospection of the challenges and lessons. *Annals of Medicine & Surgery*, *85*(8), 3955–3959. https://doi.org/10.1097/ms9.0000000000001038

Etikan, I. (2016). Comparison of Convenience Sampling and Purposive Sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1. https://doi.org/10.11648/j.ajtas.20160501.11

Fasominu, O., Okunromade, O., Oyebanji, O., Lee, C. T., Atanda, A., Mamadu, I., Okudo, I., Okereke, E., Ilori, E., & Ihekweazu, C. (2022). Reviewing Health Security Capacities in Nigeria Using the Updated WHO Joint External Evaluation and WHO Benchmarks Tool: Experience from a Country-Led Self-Assessment Exercise. *Health Security*, *20*(1), 74–86. https://doi.org/10.1089/hs.2021.0095

Gao, B., Shu, Z., Ren, S., & Gao, D. (2022). Biobanking: A foundation of life-science research and advancement. *Biosafety and Health*, *4*(5), 285–289. https://doi.org/10.1016/j.bsheal.2022.09.003

Grewal, R., Swanepoel, C., Snyders, C., Isaacs, S., & Abayomi, A. (2015). Biomarker discovery for diagnosis and treatment of tuberculosis: a role for biobanking? *Journal of Biorepository Science for Applied Medicine*, 47. https://doi.org/10.2147/bsam.s64571

He, S., & Han, J. (2021). Biorepositories (biobanks) of human body fluids and materials as archives for tracing early infections of COVID-19. In *Environmental Pollution* (Vol. 274). Elsevier Ltd. https://doi.org/10.1016/j.envpol.2021.116525

Henderson, M. K., Goldring, K., & Simeon-Dubach, D. (2019). Advancing professionalization of biobank business operations: Performance and utilization. *Biopreservation and Biobanking*, *17*(3), 213–218. https://doi.org/10.1089/bio.2019.0005

Hirtzlin, I., Dubreuil, C., Préaubert, N., Duchier, J., Jansen, B. J., Simon, J., Lobato de Faria, P., Perez-Lezaun, A., Visser, B., Williams, G. D., Cambon-Thomsen, A., Galloux, J. C., Sajantila, A., Sontot, A., Trommetter, M., Begemann, F., Mazzoni, C. M., Piazza, A., Bettencourt, E., … Chadwick, R. (2003). An empirical survey on biobanking of human genetic material and data in six EU countries. In *European Journal of Human Genetics* (Vol. 11, Issue 6, pp. 475–488). https://doi.org/10.1038/sj.ejhg.5201007

Igbe, M. A., & Adebamowo, C. A. (2012). Qualitative study of knowledge and attitudes to biobanking among lay persons in Nigeria. *BMC Medical Ethics*, *13*(1), 27. https://doi.org/10.1186/1472-6939-13-27

Ilesanmi, O. S., Afolabi, A. A., & Ilesanmi, O. (2021). *African Journal of Laboratory Medicine*. 2225–2002. https://doi.org/10.4102/ajlm

Irene, C., Elba, M., Jiménez, J. L., Mellado, M. J., & Muñoz-Fernández, M. Á. (2022). HIV HGM biobank as a research platform for paediatric infectious diseases and COVID-19 pandemic. *AIDS Research and Therapy*, *19*(1). https://doi.org/10.1186/s12981-022-00448-1

Izzo, M., Mortola, F., Arnulfo, G., Fato, M. M., & Varesio, L. (2014). A digital repository with an extensible data model for biobanking and genomic analysis management. *BMC Genomics*, *15*. https://doi.org/10.1186/1471-2164-15-S3-S3

Juozapaitė, D., Minkauskas, M., Laurinaitytė, I., Simutytė, M., Griškevičius, L., & Naumovas, D. (2023a). The COVID-19 pandemic reveals the wide-ranging role of biobanks. *Frontiers in Public Health*, *11*. https://doi.org/10.3389/fpubh.2023.1256601

Juozapaitė, D., Minkauskas, M., Laurinaitytė, I., Simutytė, M., Griškevičius, L., & Naumovas, D. (2023b). The COVID-19 pandemic reveals the wide-ranging role of biobanks. *Frontiers in Public Health*, *11*. https://doi.org/10.3389/fpubh.2023.1256601

Laurie, G., Mallia, P., Frenkel, D. A., Krajewska, A., Moniz, H., Nordal, S., Pitz, C., & Sandor, J. (2010). Managing access to biobanks: How can we reconcile individual privacy and public interests in genetic research? In *Medical Law International* (Vol.

10, Issue 4, pp. 315–337). SAGE Publications Inc. https://doi.org/10.1177/096853321001000404

Lazareva, T. E., Barbitoff, Y. A., Changalidis, A. I., Tkachenko, A. A., Maksiutenko, E. M., Nasykhova, Y. A., & Glotov, A. S. (2022). Biobanking as a Tool for Genomic Research: From Allele Frequencies to Cross-Ancestry Association Studies. In *Journal of Personalized Medicine* (Vol. 12, Issue 12). MDPI. https://doi.org/10.3390/jpm12122040

Maseme, M., Gardner, J., & Mahomed, S. (2024). Broad consent for biobank research in South Africa - Towards an enabling ethico-legal framework. *Global Bioethics*, *35*(1). https://doi.org/10.1080/11287462.2023.2288331

Mathew Miles, Michael Huberman, & Johnny Saldana. (2014). Qualitative-Data-Analysis. In *SAGE Publications* (Third). SAGE.

Mauffrey, C., Giannoudis, P., Civil, I., Gray, A. C., Roberts, C., Pape, H. C., Evans, C., Kool, B., Mauffrey, O. J., & Stengel, D. (2017). Pearls and pitfalls of open access: The immortal life of Henrietta Lacks. In *Injury* (Vol. 48, Issue 1, pp. 1–2). Elsevier Ltd. https://doi.org/10.1016/j.injury.2016.12.008

Mcleroy, K. R., Bibeau, D., Steckler, A., & Glanz, K. (1988). An Ecological Perspective on Health Promotion Programs. *Health Education & Behavior*, *15*(4), 351–377. https://doi.org/10.1177/109019818801500401

Mendy, M., Caboux, E., Sylla, B. S., Dillner, J., Chinquee, J., & Wild, C. (2014). Infrastructure and facilities for human biobanking in low-and middle-income countries: A situation analysis. *Pathobiology*, *81*, 252–260. https://doi.org/10.1159/000362093

Mentzer, A. J., Brenner, N., Allen, N., Littlejohns, T. J., Chong, A. Y., Cortes, A., Almond, R., Hill, M., Sheard, S., McVean, G., Aiello, A., Bangham, C., Borrow, R., Breuer, J., Brooks, T., Franceschi, S., Gkrania-Klotsas, E., Greenwood, B., Griffiths, P., … Waterboer, T. (2022). Identification of host–pathogen-disease relationships using a scalable multiplex serology platform in UK Biobank. *Nature Communications*, *13*(1). https://doi.org/10.1038/s41467-022-29307-3

Mikkelsen, R. B., Gjerris, M., Waldemar, G., & Sandøe, P. (2019). Broad consent for biobanks is best-provided it is also deep. *BMC Medical Ethics*, *20*(1). https://doi.org/10.1186/s12910-019-0414-6

Ogun. (2022). Efficacy of Hexetidine, Thymol and Hydrogen Peroxide-Containing Oral Antiseptics in Reducing Sars-Cov-2 Virus in the Oral Cavity: A Pilot Study. *West Africa Journal of Medicine*, *39*(1), 83–89. https://doi.org/10.55891/wajm.v39i1.98

Oleribe, O. O., Momoh, J., Uzochukwu, B. S. C., Mbofana, F., Adebiyi, A., Barbera, T., Williams, R., & Taylor-Robinson, S. D. (2019). Identifying key challenges facing healthcare systems in Africa and potential solutions. *International Journal of General Medicine*, *12*, 395–403. https://doi.org/10.2147/IJGM.S223882

Olumade, T. J., Adesanya, O. A., Fred-Akintunwa, I. J., Babalola, D. O., Oguzie, J. U., Ogunsanya, O. A., George, U. E., Akin-Ajani, O. D., & Osasona, D. G. (2020a). Infectious disease outbreak preparedness and response in Nigeria: history, limitations and recommendations for global health policy and practice. In *AIMS Public Health* (Vol. 7, Issue 4, pp. 736–757). American Institute of Mathematical Sciences. https://doi.org/10.3934/publichealth.2020057

Olumade, T. J., Adesanya, O. A., Fred-Akintunwa, I. J., Babalola, D. O., Oguzie, J. U., Ogunsanya, O. A., George, U. E., Akin-Ajani, O. D., & Osasona, D. G. (2020b). Infectious disease outbreak preparedness and response in Nigeria: history, limitations and recommendations for global health policy and practice. In *AIMS Public Health* (Vol. 7, Issue 4, pp. 736–757). American Institute of Mathematical Sciences. https://doi.org/10.3934/publichealth.2020057

Omoleke, S. A., Ajibola, O., Ajiboye, J. O., & Raji, R. O. (2018). Quagmire of epidemic disease outbreaks reporting in Nigeria. In *BMJ Global Health* (Vol. 3, Issue 1). BMJ Publishing Group. https://doi.org/10.1136/bmjgh-2017-000659

Paskal, W., Paskal, A. M., Dębski, T., Gryziak, M., & Jaworowski, J. (2018). Aspects of Modern Biobank Activity – Comprehensive Review. In *Pathology and Oncology Research* (Vol. 24, Issue 4, pp. 771–785). Springer Netherlands. https://doi.org/10.1007/s12253-018-0418-4

National health research Ethics Committee of Nigeria. (2013). *Policy Statement on Storage of Human Samples in Biobanks and Biorepositories in Nigeria (PS1.02013)* (1).

Resnik, D. B. (2018). *Privacy and Confidentiality* (pp. 149–163). https://doi.org/10.1007/978-3-319-68756-8_6

Rogier van der Stijl, A., & Schaaij-Visser Rick van Nuland, T. (n.d.). *Creating an Environment for Sustainable Biobanking in the Netherlands Perspectives and Challenges of Dutch Biobank Users*.

Rotimi, C., Abayomi, A., Abimiku, A., Adabayeri, V. M., Adebamowo, C., Adebiyi, E., Ademola, A. D., Adeyemo, A., Adu, D., Affolabi, D., Agongo, G., Ajayi, S., Akarolo-Anthony, S., Akinyemi, R., Akpalu, A., Alberts, M., Alonso Betancourt, O., Alzohairy, A. M., Ameni, G., … Zar, H. (2014). Research capacity. Enabling the genomic revolution in Africa. In *Science* (Vol. 344, Issue 6190, pp. 1346–1348). American Association for the Advancement of Science. https://doi.org/10.1126/science.1251546

Rush, A., Catchpoole, D. R., Ling, R., Searles, A., Watson, P. H., & Byrne, J. A. (2020). Improving Academic Biobank Value and Sustainability Through an Outputs Focus. *Value in Health*, *23*(8), 1072–1078. https://doi.org/10.1016/j.jval.2020.05.010

Sargsyan, K., Macheiner, T., Story, P., Strahlhofer-Augsten, M., Plattner, K., Riegler, S., Granitz, G., Bayer, M., & Huppertz, B. (2015). Sustainability in Biobanking: Model of Biobank Graz. *Biopreservation and Biobanking*, *13*(6), 410–420. https://doi.org/10.1089/bio.2015.0087

Sett, S., dos Santos Ribeiro, C., Prat, C., Haringhuizen, G., Avšič, T., Batten, C., Beato, M. S., Bourhy, H., Di Caro, A., Charrel, R., Coutard, B., Drexler, J. F., Drosten, C., Fooks, A. R., Klempa, B., Koopmans, M., Klimkait, T., Günther, S., Manuguerra, J. C., … Scholz, A. H. (2022). Access and benefit-sharing by the European Virus Archive in response to COVID-19. In *The Lancet Microbe* (Vol. 3, Issue 4, pp. e316–e323). Elsevier Ltd. https://doi.org/10.1016/S2666-5247(21)00211-1

Shekhovtsov, V. A., & Eder, J. (2022). Metadata Quality for Biobanks. *Applied Sciences (Switzerland)*, *12*(19). https://doi.org/10.3390/app12199578

Simeon-Dubach, D., & Henderson, M. K. (2020). Opportunities and Risks for Research Biobanks in the COVID-19 Era and beyond. In *Biopreservation and Biobanking* (Vol. 18, Issue 6, pp. 503–510). Mary Ann Liebert Inc. https://doi.org/10.1089/bio.2020.0079

Singh, A., Arulogun, O., Akinyemi, J., Nichols, M., Calys-Tagoe, B., Ojebuyi, B., Jenkins, C., Obiako, R., Akpalu, A., Sarfo, F., Wahab, K., Sunday, A., Owolabi, L. F., Adigun, M., Afolami, I., Olorunsogbon, O., Ogunronbi, M., Melikam, E. S., Laryea, R., … Akinyemi, R. (2022a). Biological sample donation and informed consent for neurobiobanking: Evidence from a community survey in Ghana and Nigeria. *PLoS ONE*, *17*(8 March). https://doi.org/10.1371/journal.pone.0267705

Singh, A., Arulogun, O., Akinyemi, J., Nichols, M., Calys-Tagoe, B., Ojebuyi, B., Jenkins, C., Obiako, R., Akpalu, A., Sarfo, F., Wahab, K., Sunday, A., Owolabi, L. F., Adigun, M., Afolami, I., Olorunsogbon, O., Ogunronbi, M., Melikam, E. S., Laryea, R., … Akinyemi, R. (2022b). Biological sample donation and informed consent for neurobiobanking: Evidence from a community survey in Ghana and Nigeria. *PLoS ONE*, *17*(8 March). https://doi.org/10.1371/JOURNAL.PONE.0267705

Sobel, M. E., Dreyfus, J. C., Dillehay McKillip, K., Kolarcik, C., Muller, W. A., Scott, M. J., Siegal, G. P., Wadosky, K., & O'Leary, T. J. (2020). Return of Individual Research Results: A Guide for Biomedical Researchers Utilizing Human Biospecimens. *American Journal of Pathology*, *190*(5), 918–933. https://doi.org/10.1016/j.ajpath.2020.01.014

Sohail, M., Izarraras-Gomez, A., & Vecchyo, D. O. Del. (2021). Populations, Traits, and Their Spatial Structure in Humans. *Genome Biology and Evolution*, *13*(12). https://doi.org/10.1093/gbe/evab272

Staunton, C., & de Vries, J. (2020). The governance of genomic biobank research in Africa: Reframing the regulatory tilt. *Journal of Law and the Biosciences*, *7*(1). https://doi.org/10.1093/jlb/lsz018

Staunton, C., & Moodley, K. (2013). Challenges in biobank governance in Sub-Saharan Africa. *BMC Medical Ethics*, *14*(1). https://doi.org/10.1186/1472-6939-14-35

Sudoi, A., De Vries, J., & Kamuya, D. (2021). A scoping review of considerations and practices for benefit sharing in biobanking. *BMC Medical Ethics*, *22*(1). https://doi.org/10.1186/s12910-021-00671-x

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. In *International journal of medical education* (Vol. 2, pp. 53–55). https://doi.org/10.5116/ijme.4dfb.8dfd

Tindana, P., & De Vries, J. (2016). Broad Consent for Genomic Research and Biobanking: Perspectives from Low- and Middle-Income Countries. *Annual Review of Genomics and Human Genetics*, *17*, 375–393. https://doi.org/10.1146/annurev-genom-083115-022456

Tupasela, A. (2017). Populations as brands in medical research: Placing genes on the global genetic atlas. In *BioSocieties* (Vol. 12, Issue 1, pp. 47–65). Palgrave Macmillan Ltd. https://doi.org/10.1057/s41292-016-0029-9

Turner, T. (2012). Development of the polio vaccine: A historical perspective of Tuskegee University's role in mass production and distribution of HeLa cells. *Journal of Health Care for the Poor and Underserved*, *23*(4 SUPPL.), 5–10. https://doi.org/10.1353/hpu.2012.0151

Udoh, I., & Emmanuel, I. (2020). Nigerian Languages and Identity Crises Nigerian Languages and Identity Crises 1. *Language and Semiotic Studies*, *6*(3). https://www.researchgate.net/publication/363884936

Umpeleva, T. V., Vakhrusheva, D. V., & Skornyakov, S. N. (2022). Biobank as a key component of supporting research in phthisiology and infectious diseases. *Cardiovascular Therapy and Prevention (Russian Federation)*, *20*(8), 158–163. https://doi.org/10.15829/1728-8800-2021-3045

Vandenberg, O., Durand, G., Hallin, M., Diefenbach, A., Gant, V., Murray, P., Kozlakidis, Z., & Van Belkum, A. (2020). *Consolidation of Clinical Microbiology Laboratories and Introduction of Transformative Technologies*. https://doi.org/10.1128/CMR

Vaught, J., Rogers, J., Carolin, T., & Compton, C. (2011). Biobankonomics: Developing a sustainable business model approach for the formation of a human tissue Biobank. *Journal of the National Cancer Institute - Monographs*, *42*, 24–31. https://doi.org/10.1093/jncimonographs/lgr009

Xia, S., Zhou, X. N., & Liu, J. (2017). Systems thinking in combating infectious diseases. *Infectious Diseases of Poverty*, *6*(1). https://doi.org/10.1186/s40249-017-0339-6

Xu, W., Liang, X., Chen, L., Hong, W., & Hu, X. (2024). Biobanks in chronic disease management: A comprehensive review of strategies, challenges, and future directions. In *Heliyon* (Vol. 10, Issue 11). Elsevier Ltd. https://doi.org/10.1016/j.heliyon.2024.e32063

Yakubu, A., Munung, N. S., & De Vries, J. (2020). *AMA Journal of Ethics ® MEDICINE AND SOCIETY How Should Biobanking Be Governed in Low-Resource Settings?* (Vol. 22, Issue 2). www.amajournalofethics.org

Yakubu, A., Tindana, P., Matimba, A., Littler, K., Munung, N. S., Madden, E., Staunton, C., & De Vries, J. (2018). Model framework for governance of genomic research and biobanking in Africa – a content description. *AAS Open Research*, *1*, 13. https://doi.org/10.12688/aasopenres.12844.1

Yuille, M., van ommen, G. J., Bréchot, C., Cambon-Thomsen, A., Dagher, G., Landegren, U., Litton, J. E., Pasterk, M., Peltonen, L., Taussig, M., Wichmann, H. E., & Zatloukal, K. (2008). Biobanking for Europe. In *Briefings in Bioinformatics* (Vol. 9, Issue 1, pp. 14–24). https://doi.org/10.1093/bib/bbm050

Zhu, Y. Y., Jackson, D., Hunter, B., Beattie, L., Turner, L., Hambly, B. D., Jeremy, R. W., Malecki, C., Robertson, E. N., Li, A., dos Remedios, C., Richmond, D., Semsarian, C., O'Sullivan, J. F., Bannon, P. G., & Lal, S. (2022). Models of cardiovascular surgery biobanking to facilitate translational research and precision medicine. In *ESC Heart Failure* (Vol. 9, Issue 1, pp. 21–30). John Wiley and Sons Inc. https://doi.org/10.1002/ehf2.13768

Zohouri, M., & Ghaderi, A. (2020). The significance of biobanking in the sustainability of biomedical research: A review. In *Iranian Biomedical Journal* (Vol. 24, Issue 4, pp. 206–213). Pasteur Institute of Iran. https://doi.org/10.29252/ibj.24.4.206

Annex – (project plan)

Annex – (Questionnaire)

A copy of the questionnaire deployed for the survey on Assessing the Role of Biorepositories in Outbreak Management in Nigeria

Assessing the Role of Biorepositories in Outbreak Management in Nigeria

Email:

WELCOME TO OUR SURVEY

Thank you for participating in this survey. Your insights are invaluable to our research on biobanking and diseases outbreak management in Nigeria. The following questions are designed to gather information about your experiences, practices, and their role in managing diseases outbreaks. Completing this survey will take approximately 2 to 5 minutes.

Purpose: To gather insights on biobanking practices and their impact on managing diseases outbreak.

Informed Consent Statement:

By proceeding with this questionnaire, you consent to participate in this study. Your participation is voluntary, and you have the right to withdraw at any time without consequence. Your responses will be kept confidential and will only be used for research purposes. If you have any questions or concerns about this study, please contact the researcher at (sakababatunde@gmail.com, babatunde.saka@stud.medunigraz.at).

Participant Information
Instructions: Please provide the following information about yourself. Your responses will remain confidential and will only be used for research purposes (note: Biorepositories are specialized facilities which collect, process, store, and distribute various types of biological specimens, including tissues, blood, stem cells, genetic materials (such as DNA and RNA), environmental samples, microbial cultures, and pathology specimens).

1. Region
    - South-West
    - South-South
    - South-East
    - North-Central
    - North-East
    - North-West
2. State

    - Abuja
    - Abia
    - Adamawa
    - Akwa Ibom
    - Anambra
    - Bauchi
    - Bayelsa
    - Benue
    - Borno
    - Cross River
    - Delta
    - Ebonyi
    - Edo
    - Ekiti
    - Enugu
    - Gombe
    - Imo
    - Jigawa
    - Kaduna
    - Kano
    - Katsina
    - Kebbi
    - Kogi
    - Kwara
    - Lagos
    - Nasarawa

- Niger
- Ogun
- Ondo
- Osun
- Oyo
- Plateau
- Rivers
- Sokoto
- Taraba
- Yobe
- Zamfara

3. Gender:

    - Male
    - Female
    - Prefer not to say
    - Other

4. Age in years (in figure e.g. 29)
5. Job designation: (e.g Medical Laboratory Scientist, Medical Doctor, Nurses, medical Laboratory Technician, Researcher, Molecular biologist, Medical/Research Assistant etc)
6. Years of experience in years (in figure e.g 2)
7. Does your facility currently have a biospecimen or biorepository storage facility? a. Yes [] b. No []
8. What type of facility do you operate? Academic research facility [], Healthcare facility [], Diagnostic facility [], Biobank/ biorepositories [], Private research facility []
9. What type of biorepositories or biobank(s) do you have in the facility: Population-Based Biobank/ biorepositories: Disease-Specific Biobank/ biorepository [ ], Tumor Biobank/ biorepository [ ], Stem Cell Biobank/ biorepository [ ], Environmental Biobank/ biorepository [ ], Rare Disease Biobank/ biorepository [ ], Cohort Biobank/ biorepository [ ], Infectious Diseases Biobank/ biorepository [ ]

10. Year of establishment of the facility: _____
11. Have you had any experience or involvement with operating a biobank/biorepository? a. Yes [] b. No []
12. Have you had any experience or involvement with infectious disease management? a. Yes [] b. No []

Section 2: Assessment of Disease Outbreak Management Efficiency in Nigeria

Instructions: Please answer the following questions regarding your perception of disease outbreak management efficiency in Nigeria.

1. How would you rate the efficiency of disease outbreak management in Nigeria?
   a. Very Inefficient
   b. Inefficient
   c. Neutral
   d. Efficient
   e. Very Efficient
2. Please give a reason for your answer _____
3. Have you observed any differences in the management of disease outbreaks in the state and regions?
   a. Yes
   b. No

3. If you answered "Yes" to the previous question, please specify the differences you observed:
4. How would you rate the effectiveness of current diagnostic testing methods in providing timely and accurate results during disease outbreaks? Very ineffective (1) [], Ineffective (2) [], Neutral (3) [], Effective (4) [], Very effective (5) []
5. What challenges do you face in ensuring accurate and timely diagnostic testing during outbreaks? Please indicate the extent to which each challenge contributes to difficulties in ensuring accurate and timely diagnostic testing during disease outbreaks.
   - Response: Please rate each item on a scale from 1 to 5, where:

1. 1 = Not a challenge
2. 2 = Minor challenge
3. 3 = Moderate challenge
4. 4 = Major challenge
5. 5 = Extremely challenging

Challenges	Rating
Sample collection issues	[ ]
Resource constraints	[ ]
Laboratory processing delays	[ ]
Technical limitations	[ ]
Sample viability	[ ]
Other (please specify): _____	[ ]

Timely and Accurate Diagnostic Testing

6. What is the average turnaround time for diagnostic tests during disease outbreaks? Within hours [ ], Within a day [ ], Within a few days [ ], Longer than a few days []
7. How do the accuracy rates of diagnostic tests during outbreaks compare to established reference standards? Much higher [], Higher [], Comparable [], Lower [], Much lower []
8. What factors contribute to delays or inaccuracies in diagnostic testing during outbreaks? Sample collection issues [], Sample handling issues [],

Resource constraints [ ], Laboratory processing delays [], Technical limitations [], Other (please specify): _____

9. How successful are current methods in identifying drug-resistant strains during disease outbreaks? Very successful [ ], Successful [ ], Somewhat successful [ ], Not successful [ ] Not applicable []
10. How do you monitor changes in pathogen resistance patterns over time? Regular surveillance programs [ ], Research studies [ ], Other (please specify): _____

Perception and experiences of healthcare professionals and researchers about biobank/repositories

13. To what extent do healthcare professionals using this your facility or other biobank facilities perceive the integration of biobank/ biorepositories into disease outbreak management strategies as beneficial? Not Beneficial at All [], Slightly Beneficial [], Neutral [], Moderately Beneficial [], Extremely Beneficial []
14. How satisfied are healthcare professionals using your facility or other biobank facilities with their experiences of integrating biobanks/ biorepositories into disease outbreak management strategies? Very Dissatisfied [], Dissatisfied [], Neutral [], Satisfied [], Very Satisfied []
15. To what extent do researchers believe that biobanks/ biorepositories enhance the effectiveness of disease outbreak management strategies? Not at All [], Slightly [], Neutral [], Moderately [], Significantly []
16. How confident are healthcare professionals using your facility or other biobank facilities and researchers in the reliability of data obtained from biobanks/ biorepositories for disease outbreak management? Not Confident at All [], Slightly Confident [], Neutral [], Moderately Confident [], Very Confident []

17. How optimistic are you about the potential impact of enhancing biobanking/ biorepositories practices on the efficiency of disease outbreak management in Nigeria? Not Optimistic at All [], Slightly Optimistic [], Neutral [], Moderately Optimistic [], Very Optimistic []

18. To what extent do you believe that improving biobanking/ biorepositories practices will lead to faster response times during disease outbreaks? Not at All [], Slightly [], Neutral [], Moderately [], Significantly []
19. How likely is it that enhancing biobanking/ biorepositories practices will improve the accuracy of diagnostic testing during disease outbreaks? Very Unlikely [], Unlikely [], Neutral [], Likely [], Very Likely []
20. How confident are you that enhancing biobanking/ biorepositories practices will contribute to better understanding and management of disease outbreaks in Nigeria? Not Confident at All [], Slightly Confident [], Neutral [], Moderately Confident [], Very Confident []

Performance of Biobanking/ biorepositories System

21. What is the primary focus or specialty area of your facility (select all that apply)? Population-Based [], Disease-Specific [], Tumor Centre [], Stem Cell [], Environmental [], Rare Disease [], Cohort [], Infectious Diseases []
22. What types of biological specimens does your facility collect (select all that apply)? Tissue samples [], blood [], urine [], cell lines [], Environmental Samples [], Plants []
23. What methods are used for specimen collection where applicable? Surgical procedures [], minimally invasive techniques [],
24. How are specimens processed upon collection to ensure their integrity and suitability for research? In situ [], separated into constituents [], formalin-fixed, paraffin-embedded (FFPE) [],
25. What storage facilities and conditions are available for long-term specimen preservation? -80^{o}C Freezers [], liquid nitrogen tanks [], Regular Freezers [], None of the above []
26. Are specimens tracked and managed using a standardized system? Yes [], No []
27. If yes, which of the following does your facility use? Barcoding [], electronic databases [], Laboratory Information Management System [],
28. How often are specimens checked for viability, contamination, or degradation? Monthly [], quarterly [], biannually, [], annually [], never checked []

29. Does your facility secure ethical approval for specimen collection and use in research? Yes [], No []
30. Does your facility have an established institutional ethics review board? Yes [], No []
31. How does your biobank/biorepositories ensure compliance with regulatory requirements related to specimen storage and data protection? a. Regular internal audits [] b. External certifications and accreditations [] c. Training programs for staff [] d. Implementation of standard operating procedures (SOPs) [] e. Periodic reviews and updates of policies []
32. How are demographic and clinical data linked to stored specimens, and how is this information managed? a. Use of a centralized database [ ] b. Implementation of unique specimen identifiers [ ]c. Integration with electronic health records (EHRs) [ ] d. Manual entry and verification processes [ ] e. Secure and encrypted data storage solutions [ ]
33. What policies and procedures are in place to govern access to specimens and associated data by researchers and collaborators? a. Access control policies [ ] b. Ethics committee approvals [ ] c. Data use agreements (DUAs) [ ] d. Review and approval by a governance board [ ] e. Confidentiality agreements for researchers [ ]
34. How do you treat metadata derived from processing collected samples? a. Metadata is stored separately from raw data [ ] b. Metadata is integrated into the main database [ ] c. Restricted access to metadata [ ] d. Regular updates and audits of metadata [ ] e. Use of metadata standards for consistency [ ]
35. What types of research studies or projects have utilized specimens from your biobank/biorepositories? a. Genetic research studies [ ] b. Epidemiological studies [ ] c. Clinical trials [ ] d. Public health research [ ] e. Translational research projects [ ]
36. Are training programs available for biobank/biorepositories/facility staff regarding specimen handling, data management, and ethical considerations? a. Regular in-house training sessions [ ] b. Online training modules [ ] c. Workshops and seminars [ ] d. Certification programs [ ] e. Collaboration with external training providers [ ]

37. What efforts are being made to build capacity and raise awareness about biobanking/biorepositories among researchers and healthcare professionals in Nigeria?a. Awareness campaigns and workshops [ ] b. Partnerships with academic institutions [ ] c. Outreach programs to healthcare professionals [ ] d. Publications and presentations at conferences [ ] e. Development of educational materials and resources [ ]
38. Does your biobank/biorepositories/facility collaborate with other biobank/biorepositories or research institutions within Nigeria or internationally? a. National collaborations with other biobanks [ ] b. International partnerships and networks [ ] c. Joint research projects [ ] d. Data and specimen sharing agreements [ ] e. Participation in global biobanking initiatives [ ]
39. How do you envision strengthening collaboration and networking among biobank/ biorepositories and research organizations in Nigeria? _____
40. To what extent does your organization adhere to BBMRI-ERIC performance standards? Fully adherent [], Mostly adherent [], Partially adherent [], Not adherent []
41. How would you rate the efficiency of sample processing and storage within your biobank/ biorepositories/facility system? Very efficient [], Efficient [], Somewhat efficient [], Inefficient [], Very inefficient []
42. How accessible and shared is the data within your biobanking/ biorepositories network? Highly accessible and shared [], Accessible and shared [], Somewhat accessible and shared [], Limited accessibility and sharing [], Not accessible or shared []

Policy on Biobank/ biorepositories

43. Does your organization have clear policies governing biobanking/biorepositories operations? Yes, very clear [], Yes, somewhat clear [], No, not clear [], Not applicable []
44. How well do these policies comply with international ethical and legal standards? Fully compliant [], Mostly compliant [], Partially compliant [], Not compliant []

45. What improvements could be made to enhance policy clarity and compliance? Enhanced training and education [], Revision of existing policies [], Development of new policies [], Other (please specify): _____

Logistical Support for Biobank/ biorepositories

46. Are the resources for sample collection, transport, and storage adequate for your needs? Yes, fully adequate [], Yes, somewhat adequate [], No, inadequate [], Not applicable []
47. How effectively do you maintain sample integrity during transport? Very effectively [], Effectively [], Somewhat effectively [], Ineffectively [], Very ineffectively []
48. What logistical challenges do you face in biobanking/ biorepositories operations? Transportation issues [], Storage limitations [], Personnel constraints [], Other (please specify): _____

Infrastructure for Biobanking / biorepositories

49. Are storage facilities readily available and in good condition? Yes, readily available and in good condition [], Yes, somewhat available and in good condition [], No, not available or in poor condition [], Not applicable []
50. How advanced is the technological infrastructure for data management and analysis in your biobanking/ biorepositories system? Very advanced [], Advanced [], Moderate [], Basic [], Very basic []
51. What upgrades or improvements would you suggest for biobanking/ biorepositories infrastructure? Upgrading storage facilities [], Enhancing data management systems [], Investing in new technologies [Other (please specify) []: _____

Ethical Considerations in Biobanking / biorepositories

52. What percentage of samples in your biobank/ biorepositories have documented informed consent? 0-25% [], 26-50% [], 51-75% [], 76-100% [], Unknown []

53. What measures are in place to ensure privacy and data security for biobank/ biorepositories ed samples? Strict access control [], Data encryption [], Regular audits [] Other (please specify): _____
54. How do you address ethical considerations in biobanking/ biorepositories operations? Ethics review boards [], Informed consent protocols [], Confidentiality agreements [], Other (please specify): _____
55. What specific improvements or innovations would you like to see in biobanking/ biorepositories practices to enhance disease outbreak management? Improved data sharing protocols [], Enhanced international collaboration [], Development of novel biobanking/ biorepositories technologies [], Other (please specify): _____
56. What are the main challenges faced by your biobank/ biorepositories /facility in Nigeria in terms of specimen collection, storage, or utilization? _____
57. What strategies or initiatives are being considered to enhance biobanking/ biorepositories practices and infrastructure in Nigeria? _____