AFIDEP
African Institute for Development Policy

AUDA-NEPAD
AFRICAN UNION DEVELOPMENT AGENCY

Leveraging Research Prioritisation and Emerging Technologies to Strengthen Healthcare Delivery in Africa

Monograph

African Union Development Agency (AUDA-NEPAD)
African Institute for Development Policy (AFIDEP)
African Union High-Level Panel on Emerging Technologies (APET)

2024

AFIDEP
African Institute for Development Policy

AUDA-NEPAD
AFRICAN UNION DEVELOPMENT AGENCY

Leveraging Research Prioritisation and Emerging Technologies to Strengthen Healthcare Delivery in Africa

Monograph

HealthTech
Promoting dialogue and action on health technologies in Africa

African Union Development Agency (AUDA-NEPAD)
African Institute for Development Policy (AFIDEP)
African Union High-Level Panel on Emerging Technologies (APET)

Leveraging Research Prioritisation and Emerging Technologies to Strengthen Healthcare Delivery in Africa

This monograph is a product of the African Union Development Agency (AUDA-NEPAD), the African Institute for Development Policy (AFIDEP), and the AU High-Level Panel on Emerging Technologies (APET). It is part of a larger effort by the three institutions to promote knowledge and learning, share ideas, provide open access to its research, and contribute to the development of evidence-based policies in African countries. The topics featured in the respective chapters of the monograph are considered to have a bearing on the missions of the three institutions and their strategic objectives, as aligned to the African Union Agenda 2063, and the vision of an integrated, prosperous, and peaceful Africa, driven by its citizens, representing a dynamic force in the international arena.

Citation: African Union Development Agency (AUDA-NEPAD), African Institute for Development Policy (AFIDEP), AU High-Level Panel on Emerging Technologies (APET), 2025. Leveraging Research Prioritisation and Emerging Technologies to Strengthen Healthcare Delivery in Africa.

Address:

1. **AUDA-NEPAD**
   AUDA-NEPAD Agency
   230 15th Road, Midrand
   South Africa
   Telephone: +27 11 256 3600
   info@nepad.org

2. **AFIDEP**

Malawi Office
Public Service Pension Fund
Building, 3rd floor, Presidential Way,
City Centre,
P.O. Box 31024, Lilongwe 3, Malawi
Tel: +265 995 495 143
Email: info@afidep.org

Kenya Office
6th Floor (Block A), Westcom Point
Building, Mahiga Mairu Avenue, off Waiyaki
Way,
P.O. Box 14688-00800, Westlands-Nairobi,
Kenya
Tel: +254 20 4343 116 | +254 716 002 059
Email: info@afidep.org

X handles
@NEPAD_Agency
@AFIDEP
#TheAfricaWeWant

Acknowledgements

Authors of Monograph

1. The African Union Development Agency (AUDA-NEPAD)
2. African Institute for Development Policy (AFIDEP)
3. African Union High Level Panel on Emerging Technologies (APET)
4. African experts, researchers and stakeholders

AU High-Level Panel on Emerging Technologies (APET)

Chairperson

Yaye Kène Gassama, Université Cheikh Anta Diop de Dakar, Senegal

Panel Members

Abdallah Daar, University of Toronto, Canada
Abubakar Sani Sambo, Usmanu Dan Fodio University, Sokoto, Nigeria
Berhanu M. Abegaz, University of Johannesburg, South Africa
Francine Ntoumi, Fondation Congolaise pour la Recherche Médicale, Congo-Brazzaville
Karim Maredia, Michigan State University (MSU), East Lansing, Michigan, USA
Rachel Chikwamba, Council for Scientific and Industrial Research (CSIR), South Africa
Roseanne Diab, University of KwaZulu Natal, South Africa
Shireen Assem, Agricultural Research Center (ARC), Egypt
William Wasswa, Mbarara University of Science and Technology, Uganda

Research and Drafting Team

Eliya Zulu, Rose Oronje, Aggrey Ambali, Justina Dugbazah, Barbara Glover, Msingathi Sipuka, Maria Stella Namyalo, Patricia Wamukota.

Reviewers

These experts reviewed and provided comments on the draft monograph:

Abdallah Daar, Abubakar Sani Sambo, Adaudo Anyiam-Osigwe, Aggrey Ambali, Barbara Glover, Berhanu M. Abegaz, Bhekani Mbuli, Catherine Ngwira, Charles Mugoya, Chifundo Kungade, Derick Ngaira, Emmanuel Kaunda, Eliya Zulu, Francine Ntoumi, Gloria Amegatcher, Joseph Berko, Justina Dugbazah, Karim Maredia, Maria Stella Namyalo, Patricia Wamukota, Rachel Chikwamba, Rose Oronje, Roseanne Diab, Shireen Assem, Sylvia Yissa, William Wasswa, Yaye Kene Gassama.

AUDA-NEPAD, AFIDEP, and APET wish to express thanks and appreciation to their staff members, and external experts who made contributions and comments on earlier versions of this monograph.

The African Union (AU)

The African Union (AU) is a continental body comprising all 55 countries on the African continent. The union was founded following the Sirte Declaration of the Heads of State and Governments of the Organisation of the African Unity (OAU) on 9 September 1999. It was established on 26 May 2001 in Addis Ababa, Ethiopia, and launched on 9 July 2002 in South Africa[1] to replace the Organisation of African Unity (OAU). The AU is based on a common vision of a united and strong Africa and on the need to build a partnership between governments and all segments of civil society, in particular, women, youth and the private sector, to strengthen solidarity and cohesion amongst the peoples of Africa. As a continental organisation, it focuses on promoting peace, security, and stability. Its development work is guided by the AU Agenda 2063, a 50-year plan sub-divided into 10-year development plans, to harness Africa's comparative advantage to deliver on the vision of "The Africa We Want". The Assembly of the African Union, a semi-annual meeting of the Heads of State and Government of the member states, makes the most important decisions of the union. The union's secretariat, the African Union Commission, is based in Addis Ababa, Ethiopia.

The African Union Development Agency (AUDA-NEPAD)

Created by the African Union, the African Union Development Agency (AUDA-NEPAD) is a strategic framework for pan-African socio-economic development. African leaders spearheaded the formation of AUDA-NEPAD to address critical challenges facing the continent, including poverty, development, and Africa's international marginalisation. The agency provides unique opportunities for African countries to take full control of their development agendas, to work more closely together and to cooperate more effectively with international partners. In Nouakchott, Mauritania, June 2018, a decision was taken to transform the NEPAD Planning and Coordination Agency into the African Union Development Agency-NEPAD (AUDA-NEPAD). The AUDA-NEPAD manages several programmes and projects in four investment portfolios: Natural Resources Governance, Youth and Skills Development, Regional Integration, Infrastructure and Trade, and Industrialisation, Science, Technology, and Innovation.

The African Institute for Development Policy (AFIDEP)

The African Institute for Development Policy (AFIDEP) is an African-led, regional non-profit research and policy institute established in 2010, to help bridge the gaps between research, policy and practice in African development efforts. AFIDEP supports evidence use in formulating and implementing development policies and programmes. To fulfil its mandate, the organisation focuses on two areas: providing practical evidence to help governments move from policy rhetoric to action, strengthening institutional and individual capacity to demand and use evidence; and promoting interactions between researchers and policymakers. Since its establishment in 2010, AFIDEP has been advancing how development actors think about evidence generation, translation, and use, by placing policymakers at the centre of these efforts.

African Union High-Level Panel on Emerging Technologies (APET)

The first Specialised Technical Committee on Education, Science, and Technology (STC-EST I) in 2016 requested the AU Commission and AUDA-NEPAD to advise Member States and the Regional Economic Communities (RECs) on technology prospecting, including regulatory and ethical requirements that need to be put in place for the continent to benefit from research prioritisation and emerging technologies. The Ministers further directed NEPAD to establish a system for obtaining expert contributions on technology development, acquisition, and deployment

[1]About the African Union https://au.int/en/overview

for socio-economic development. Subsequently, the AU established a ten-member African Union High-Level Panel on Emerging Technologies (APET), composed of eminent experts to advise the union, its various organs, and Member States on how Africa should harness innovation and emerging technologies for socio-economic development.

The then Chairperson of the African Union Commission (AUC), Her Excellency Dr Nkosazana Dlamini Zuma, appointed ten (10) eminent experts from various fields to serve on the panel in December 2016. The ten (10) eminent experts are drawn from diverse professional backgrounds, representing both gender and geographical demographics. They are critical in terms of providing evidence-based analyses and recommendations that should inform policy direction at the continental, regional and national levels on the utilisation of existing and emerging technologies.

The panel is chaired by Prof. Yaye Kène-Gassama Dia, Professor in Plant Biotechnology at the Université Cheikh Anta Diop de Dakar and Vice-Chair of the Board of the National Academy of Science and Technology of Senegal, and Chair of the Basic, Applied Sciences and Innovation Section. She is a former Minister of Science and Technology of Senegal and acted on behalf of the Senegal Government as chair of African Ministerial Council on Science and Technology (AMCOST II).

The High Level APET offers advice to the AU and its Member States on research prioritisation and how to harness emerging technologies for economic development. It also makes recommendations on the nature of regional institutional arrangements that are required to promote and sustain common regulatory approaches to the application and use of emerging technologies. It also proposes strategies and policy on research prioritisation and emerging technologies in Africa.

The Monograph disseminates the findings of a comprehensive research, experience, and best practices and lessons learned in the utilisation of emerging technologies in the health sector in AU Member States.

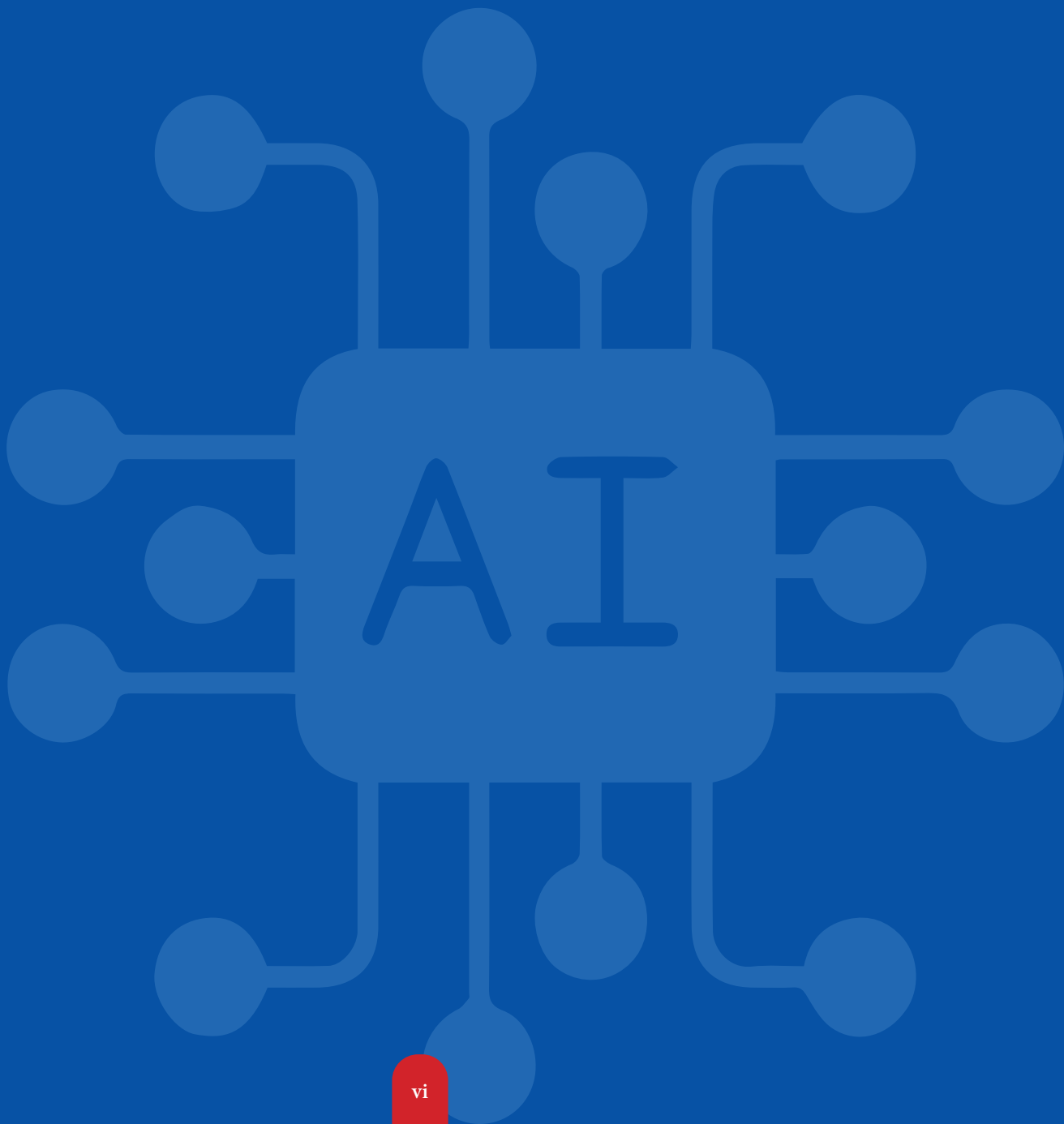


Table of Content

Abbreviations

AFIDEP	The African Institute for Development Policy
AI	Artificial Intelligence
APET	AU High-Level Panel on Emerging Technologies
AR	Augmented Reality
AU	African Union
AUC	African Union Commission
AUDA-NEPAD	African Union Development Agency-New Partnership for Africa's Development
CBD	Convention on Biological Diversity
COVID-19	Coronavirus Disease 2019
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CRISPR/Cas9	Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR-associated protein 9
DNA	Deoxyribonucleic Acid
EHRs	Electronic Health Records
ESHIA	Environmental, Social, and Health Impact Assessment
GBVC	Genetically-Based Vector Control
GMOs	Genetically Modified Organisms
H3Africa	Human, Heredity and Health in Africa
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome
IRS	Indoor Residual Spraying
IoMT	Internet of Medical Things
IoT	Internet of Things
MNCH	Maternal, Neonatal and Child Health
MRI	Magnetic Resonance Imaging
OIE	World Organisation for Animal Health (formerly Office International des Epizooties)
RECs	Regional Economic Communities
RNAi	Ribonucleic Acid (RNA) Interference
SEA	Strategic Environmental Assessment
UAVs	Unmanned Aerial Vehicles
UAS	Unmanned Aircraft Systems
VR	Virtual Reality
WHO	World Health Organization

Glossary

1. Emerging Technologies

Emerging Technologies refer to new and innovative technological developments in various fields that are currently being explored, developed, or implemented. These technologies often have the potential to significantly modify existing industries or improve the way individuals and organisations operate. Emerging technologies are characterised by their rapid evolution and impact, often leading to transformational changes across sectors and economies of countries.

2. Research Prioritisation

Research Prioritisation is the systematic process of identifying, evaluating, and ranking research topics or questions related to development sectors that are deemed most important or relevant to address specific needs or challenges of countries. This process helps to allocate resources such as technical expertise, time and funding effectively and efficiently in order to maximise the potential impact of research efforts. Research prioritisation is particularly important in sectors with limited resources, such as health, thereby helping to ensure that research efforts are focused on areas that will yield the greatest benefits for specific communities or countries generally.

Executive Summary

The progress and positive achievements made in healthcare delivery in Africa over recent years reflect efforts by governments and stakeholders in adopting a combination of innovative strategies, research prioritisation, emerging technologies, increased funding, and collaborative efforts to improve health outcomes across the continent. Several African countries have made significant strides toward universal health coverage (UHC) with initiatives for expanding access to essential health services, leading to improved health outcomes. Additionally, many African governments are allocating more resources to health services, driven by commitments to the Abuja Declaration which calls for countries to allocate at least 15% of the national budget to health,[2] and the more recent 2019 African Leadership Meeting (ALM) commitments on enhancing domestic financing for health in Africa.[3] The increased funding is crucial for enhancing healthcare service delivery and infrastructure development. Efforts to strengthen governance, training of healthcare professionals, and improved supply chain management have resulted in more resilient health services, capable of responding more effectively to public health challenges.

However, despite the significant progress made over the past few decades, the health sector in many African countries continues to face a myriad of constraints, which include a significant burden of communicable and non-communicable diseases, high maternal, neonatal and child mortality rates, and rising urbanisation and changing demographics.[4] An assessment of existing healthcare infrastructure reveals significant disparities in service delivery between urban and rural areas. Access to quality healthcare services is often hampered by factors such as inadequate infrastructure, insufficient healthcare workforce, and limited financial resources. Other challenges faced by healthcare providers and patients alike include resource shortages, long waiting periods for service and limited awareness of the available services resulting from a shortage of healthcare professionals.[5] These challenges impede the delivery of quality care and hold back public health advancements, as traditional healthcare models often struggle with efficiency and responsiveness, leading to poor health outcomes.

In recent years, there has been growing recognition by African governments and stakeholders that prioritising health research and emerging technologies can significantly enhance healthcare delivery and improve health outcomes.[6] To this end, African policy and decision-makers, technologists and health practitioners are increasingly exploring innovative solutions to address systemic challenges in the sector by creating an enabling policy environment. Health research prioritisation identifies areas that are most critical for countries, thereby enabling governments to focus their resources on these priorities. Emerging technologies, on the other hand, present a unique opportunity to enhance service delivery, improve patient outcomes, and expand access to care. They have the potential to facilitate remote consultations and more targeted care, thereby reducing the burden on overstretched health facilities and increasing access to care for under-served populations.[7]

Given these potential benefits, African countries have begun to invest relatively more in these areas, reflecting a broader commitment to improving health outcomes and operational efficiency. The healthcare landscape in Africa is undergoing a slow but noticeable transformative shift, driven by health research prioritisation and adoption of emerging technologies. However, despite the promise that these mechanisms and tools hold, several barriers hinder their widespread adoption. These barriers include policy and regulatory challenges and concerns over data privacy.

While challenges remain, many governments and stakeholders are optimistic about adopting research prioritisation and emerging technologies to build more resilient healthcare systems that can effectively meet the needs of their populations.[8] Adopting health research priorities and emerging technologies can enhance knowledge and invariably the quality of care and

[2]Abiola, T., & Chike, N. (2024) "Harnessing Artificial Intelligence for Enhanced Diagnostic Accuracy in African Healthcare" Journal of African Health Innovations, 12(1), 34-48

[3]https://www.nepad.org/publication/declaration-of-africa-leadership-meeting-investing-health-addis-ababa-commitments

[4]World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

[5]Amankwah-Amoah, J. (2023) Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. Sustainable Development, 27(5), 910-922

[6]Mohammadzadeh, N.; Gholamzadeh, M.; Saeedi, S.; Rezayi, S. The application of wearable smart sensors for monitoring the vital signs of patients in epidemics: A systematic literature review. J. Ambient Intell. Humaniz. Comput. 2020, 1–15. [Google Scholar] [CrossRef]

[7]Kamara, M., & Bangura, J. (2024). "Smart Wearable Devices for Real-Time Health Monitoring in Africa." African Journal of Biomedical Engineering, 7(2), 45-60.
[8]Abiola, T., & Chike, N. (2024). "Harnessing Artificial Intelligence for Enhanced Diagnostic Accuracy in African Healthcare." Journal of African Health Innovations, 12(1), 34-48.

improve health outcomes for millions of people across the African continent.

This monograph shares key health research priorities as well as emerging technologies that are poised to revolutionise healthcare systems across the continent.[9] It presents a comprehensive analysis of the current health landscape, and discusses the trends, challenges, transformative solutions, and potential impact of research prioritisation and emerging technologies. It discusses how emerging technologies can facilitate more efficient, accessible, and patient-centred healthcare delivery. The monograph presents case studies from various African countries that have successfully implemented research prioritisation and emerging technologies in health. The monograph further provides policy recommendations, emphasising the need for collaborative efforts among governments, private sector, communities and civil society.[10]

Some health research priorities were identified during the primary and secondary research undertaken for this monograph. These include research on genomic medicines, biospecimen and biobanking and data management, One Health, and maternal, neonatal and child health. The emerging technologies identified include artificial intelligence, drones, blockchain, Internet of Medical Things (IoMT) and genetically-based vector control. These emerged as critical for bridging the gap between healthcare providers and patients, especially in remote and underserved areas across the continent.[11] Genomics, for example, enables healthcare professionals to determine the genetic disposition of patients to particular diseases and provide targeted treatment. Additionally, research prioritisation enables governments to provide targeted investments in health research.

African countries are grappling with a shortage of healthcare professionals. Artificial intelligence (AI) and IoMT, for example, offer an innovative solution to extend expert care to rural communities and overcome the shortage of staff by facilitating virtual consultations, health monitoring, and disease management through mobile devices, and reducing travel time and costs for patients. IoMT encompasses interconnected devices and applications that enable real-time monitoring of patients' health status. Health priorities and interventions incorporating AI, machine learning and blockchain are enhancing diagnostic capabilities and predicting health trends, thereby allowing for more informed decision-making in public health.

In Africa, where data integrity is paramount in health priorities such as genomics, biospecimen and biobanking, blockchain technology has the potential to transform data management by ensuring security, interoperability, and transparency.[12] It enables secure sharing of patient records and clinical data while maintaining patient privacy. This enhances trust in health systems and facilitates seamless information exchange among stakeholders. Other technologies, such as machine learning algorithms, can analyse vast datasets to identify patterns, predict outbreaks, and improve decision-making processes. Similarly, AI applications in radiology and pathology as well as biospecimen and biobanking, are enhancing diagnostic accuracy, and leading to early disease detection. AI-driven tools and data analytics are also revolutionising diagnostics, treatment personalisation, and operational efficiency in healthcare in some countries.[13]

African countries that prioritise research and adoption of emerging technologies in health have gained useful insight on issues within the health sector, leading to increased investments, improved health outcomes and economic returns. Research prioritisation, technological advancements and innovative health interventions, e.g. community health worker training and targeted treatments, have significantly reduced health challenges such as high maternal, neonatal and child mortality. However, gaps remain in service delivery. African governments and stakeholders must continue to prioritise and invest in critical areas of health, to ensure a prosperous future for the continent.

African countries that prioritise research and adoption of emerging technologies in health have gained useful insight on issues within the health sector, leading to increased investments, improved health outcomes and economic returns. Research prioritisation, technological advancements and innovative health interventions

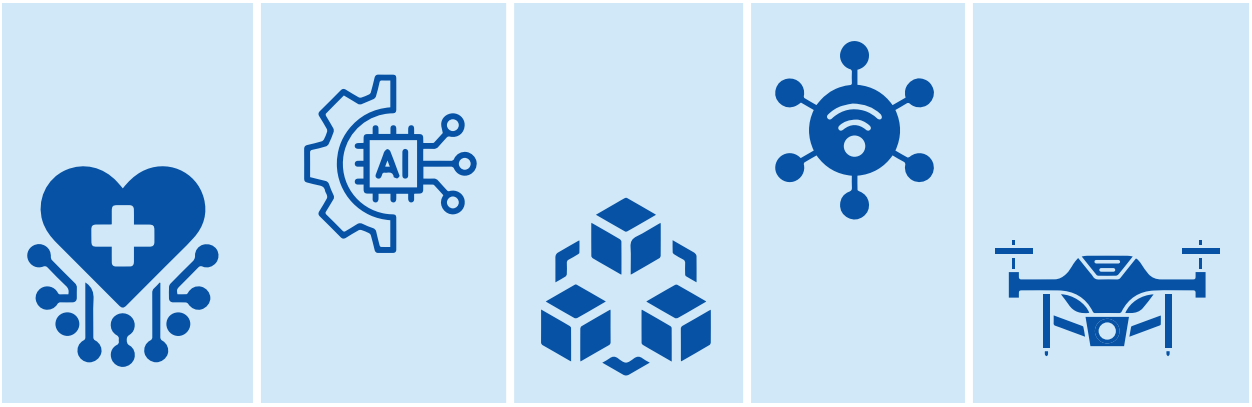
[9]Abimbola, S., & Nchinda, T. (2022). "Health systems strengthening in Africa: The role of digital health technologies." Global Health Action, 15(1), 2045692. https://doi.org/10.1080/16549716.2022.2045692

[10]Afolabi, S., & Kalu, O. (2024). "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review." African Journal of Telehealth, 10(2), 102-119

[11]Egbuta, C., & Oluwaseun, F. (2024). "Innovative Mobile Health Applications for Chronic Disease Management in Africa." International Journal of Mobile Health, 5(3), 205-220

[12]Amankwah-Amoah, J. (2023) Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. Sustainable Development, 27(5), 910-922

[13]Nduwayo, J. & Muko, S. (2023). "E-health Innovations in Africa: Enhancing Patient Engagement and Empowerment." Journal of Health Communication, 28(1), 12-26



Health research prioritisation and emerging technologies are paving the way for improved health outcomes. While there may be implementation obstacles, targeted interventions and collaborations can facilitate progress. This will ultimately contribute to achieving the continent's long-term health and economic development goals.

Key Scientific Health Research Priorities and Emerging Technologies and the Impact

This monograph discusses the following research priorities and emerging technologies and their impact in the health sector:

- **Artificial Intelligence (AI) and Machine Learning:** These technologies are being applied increasingly in the health sector to analyse vast datasets for predicting outbreaks, optimising resource allocation, and improving diagnostics. AI tools assist in interpreting medical data, such as X-rays, MRIs, and pathology reports, thereby facilitating quicker and more accurate diagnosis.[14]
- **Blockchain technology:** This technology enhances the security and interoperability of health records while ensuring patient data privacy. It secures patient records, ensuring that data is tamper-proof and accessible only to authorised personnel.[15] Trust in data management is essential within the health sector, where data privacy and security are major concerns. Blockchain also enhances the traceability of medications and vaccines, reducing the prevalence of counterfeit drugs and ensuring quality control.[16]
- **Internet of Medical Things:** This technology supports continuous monitoring, timely interventions, and personalised treatment plans, based on the data gathered from the devices
- **Drones:** They have broad application in public health, ranging from the delivery of medicines, and emergency transport of blood products in maternal healthcare. In Africa, drones are already saving lives by delivering blood packets to remote villages.
- **Genomic Medicine:** Genomics is the study of the complete set of genetic information (the genome) of an organism. Its impact in Africa has been significant and far-reaching. It has revolutionised the understanding of human genetic diversity, population history, and the genetic basis of health and disease on the African continent.[17]
- **Biospecimen, Biobanking and Data Governance:** Biobanks play a crucial role in supporting precision medicine initiatives, by providing researchers and healthcare professionals with the resources they need to tailor medical treatments and interventions to individual patients, based on their genetic makeup, lifestyle factors, and environmental influences.
- **Genetically-Based Vector Control:** These technologies offer several potential benefits for fighting infectious diseases in Africa, particularly those transmitted by mosquitoes, such as malaria, dengue fever, chikungunya and zika, and can contribute to reducing the populations of tsetse flies that cause sleeping sickness.
- **Gene Drive Technologies:** They offer new and potentially transformative methods for overcoming many challenges in controlling the transmission of vector-borne diseases. Research has been most vigorous in Anopheles mosquitoes, which are responsible for transmitting malaria in Africa, because this is arguably where new solutions are most urgently needed.
- **One Health:** The One Health concept is a collaborative approach to improving the health

[14]Egbuta, C., & Oluwaseun, F. (2024). "Innovative Mobile Health Applications for Chronic Disease Management in Africa." International Journal of Mobile Health, 5(3), 205-220

[15]Dada, D., & Afolabi, O. (2023). "The potential of blockchain technology in improving healthcare delivery in Africa." Journal of Health Informatics in Developing Countries, 16(1), 15. https://doi.org/10.12860/jhidc.2023.01

[16]Juma, P. A., & Nyauma, F. (2023). "The role of digital technologies in the management of non-communicable diseases in Africa." BMC Public Health, 23(1), 152. https://doi.org/10.1186/s12889-022-13821-4

[17]Obafemi, A. & Omotola, A. (2024). "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

of people, animals, and the environment. It is a multisectoral and transdisciplinary approach that recognises their interconnectedness and proposes a collaborative approach to improving the health of people, animals, and the environment. The African Union (AU) endorses the One Health concept to address shared health threats, such as zoonotic diseases.

- **Maternal, Neonatal and Child Health:** Emerging technologies can play a significant role in enhancing maternal, neonatal, and child health by expanding access to remote healthcare services, especially in rural and underserved areas. The effective integration and implementation of these emerging technologies, along with capacity building and infrastructure development, can significantly improve access, quality, and outcomes of maternal, neonatal, and child healthcare in Africa.

Benefits of Research Prioritisation and Emerging Technologies in Health

The benefits of research prioritisation and emerging technologies in health include the following:

- **Enhanced quality of care:** Research prioritisation in health leads to improvement in precision and efficiency, which can lead to more accurate diagnoses and personalised treatment plans.[18]
- **Data-driven public health strategies:** Enhanced data collection and analysis through technology can inform public health initiatives, enabling more effective responses to health crises and resource allocation.
- **Increased access to care:** Research priorities and emerging technologies are improving access to healthcare professionals and essential services, by bridging geographical gaps, particularly in remote and under-served areas.
- **Cost reduction:** Automation of administrative tasks and remote consultations aided by emerging technologies can reduce operational costs, making healthcare services more affordable.
- **Empowerment of patients:** Tools that promote self-management and awareness enable patients to take charge of their health, leading to better health outcomes.

Challenges in Research Prioritisation and Emerging Technologies

While the benefits of research prioritisation and emerging technologies are promising, several challenges may hinder their implementation. These include the following:

- Infrastructure limitations, such as limited access to reliable internet and electricity in many rural areas, could restrict the effectiveness of research priorities such as genomics and One Health, and emerging technologies such as telehealth and mHealth solutions.
- Inadequate training and lack of familiarity with research prioritisation and emerging technologies among healthcare professionals can impede integration into existing healthcare systems.
- Concerns regarding data security and patient confidentiality, resulting from increased use of digital health records and personal data collection.[19]
- Absence of clear regulatory frameworks surrounding the use of emerging technologies can stifle innovation and deter investments.[20]

Strategic and Policy Recommendations

- Governments, and policy and decisionmakers should develop robust policies and regulatory frameworks to govern research prioritisation and adoption of emerging technologies in healthcare, to ensure patient safety, data privacy and efficacy.
- Governments and private sector stakeholders should develop robust digital infrastructure to support health research and emerging technologies.[21]
- Healthcare professionals should be trained in research prioritisation and the utilisation of emerging technologies, to maximise their benefits and integration into healthcare systems.
- Healthcare providers should invest in training and capacity building to ensure effective utilisation of research skills within the health sector.
- Governments, technology companies, and healthcare providers should enhance collaboration to foster health research tailored to local needs.
- Stakeholders should foster partnerships to drive resource mobilisation.
- Governments and stakeholders should conduct public awareness campaigns to educate communities about available emerging technologies, thereby fostering social acceptance and adoption.
- Engaging local populations in the design and implementation of research prioritisation can ensure ownership and accuracy of data.

[18]Kibet, J., & Muriuki, J. (2024). "Utilizing Big Data Analytics to Enhance Public Health Decision-Making in Africa." Journal of Public Health Analytics, 8(1), 77-90

[19]Juma, P. A., & Nyauma, F. (2023) "The role of digital technologies in the management of non-communicable diseases in Africa." BMC Public Health, 23(1), 152. https://doi.org/10.1186/s12889-022-13821-4

[20]Obafemi, A. & Omotola, A. (2024). "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158.

[21]Nduwayo, J. & Muko, S. (2023). "E-health Innovations in Africa: Enhancing Patient Engagement and Empowerment." Journal of Health Communication, 28(1), 12-26

- Educational programmes that enhance stakeholder understanding should be implemented to ensure ethical and socio-cultural considerations in research prioritisation and emerging technologies.
- Governments and stakeholders should implement pilot projects to test and refine technological solutions in diverse settings before broader rollout, ensuring their effectiveness and sustainability across the continent.

Conclusion

This monograph serves as a vital resource for policy and decision-makers, healthcare providers, researchers, and innovators seeking to leverage research prioritisation and emerging technologies to address health challenges on the African continent. The monograph emphasises the importance of these mechanisms and strategies in bridging the gaps in healthcare delivery across the continent.[22] It highlights the fact that adopting research prioritisation and emerging technologies for health will enhance access, improve the quality of care, and increase efficiency in healthcare delivery.[23] In strategically harnessing these strategies and tools, the African continent can overcome longstanding challenges, improve health outcomes, and increase resilience of its healthcare systems. This can create a transformative impact, ultimately leading to healthier populations and more resilient healthcare systems across the continent.[24]

[22]African Union Development Agency (AUDA-NEPAD). (2021) "Emerging technologies and their potential for improving health in Africa". (APET Blog)

[23]World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: An Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals.

[24]Obafemi, A. & Omotola, A. (2024) "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

The state of health delivery on the continent remains a pressing concern. Many countries struggle with a limited number of hospitals and clinics, and a shortage of staff, leading to overcrowded facilities and long wait times for patients to access medical care.

Harnessing Research Priorities and Emerging Technologies for Effective Healthcare Delivery in Africa

1

Harnessing Research Priorities and Emerging Technologies for Effective Healthcare Delivery in Africa

1.1 Introduction

In recent years, Africa has made remarkable strides in adoption of research prioritisation and existing and emerging technologies to revolutionise healthcare service delivery. The COVID-19 pandemic underscored this necessity, prompting governments and organisations to undertake research prioritisation and innovate rapidly in response to emergency health needs. During the pandemic, rapid research was undertaken for priorities such as biospecimen, biobanking and data management. During the lockdown, the use of emerging technologies like artificial intelligence surged and became a vital means of communication for health education and service provision. Healthcare delivery models have since evolved across the continent, demonstrating the capacity of research prioritisation and emerging technologies to enhance the resilience of health systems in the face of adversity.

However, the utilisation of research prioritisation and the integration of emerging technologies is not without challenges. Issues such as infrastructural gaps, limited digital literacy, and regulatory hurdles can impede progress. Additionally, there is a pressing need to ensure that the deployment of emerging technologies does not exacerbate existing health disparities, but rather works towards an inclusive approach that benefits all segments of the African society.

This monograph explores the multifaceted contribution of research innovations and emerging technologies towards improving healthcare delivery in Africa. Firstly, the document offers a broad analysis of the application of these strategies and tools within the healthcare sector, highlighting some examples of implementation across the continent. The monograph also discusses the benefits as well as constraints encountered in the utilisation of health research prioritisation and emerging technologies within the African context. It also examines the ethical and socio-cultural issues that should be considered. Lastly, the monograph provides recommendations for policy- and decision-makers, health practitioners and other stakeholders, reiterating the need for adoption of emerging technologies and increased investments in health research, innovation, infrastructure, training and capacity strengthening, collaborations and community engagement. The purpose is to improve healthcare delivery and well-being of Africans.

1.2 Background

The African continent has the youngest population in the world, and it is estimated that by 2050, the total population on the continent will be 2.8 billion, with 163 million aged 60 years, up from 43 million in 2022.[25] This highlights the need for Africans to have adequate access to healthcare services to improve their well-being and workforce productivity.

Recent studies have demonstrated the positive relationship between improved health care and economic performance, and the importance of research prioritisation and emerging technologies in transforming healthcare delivery. Growing evidence has emerged on the linkages between healthcare, nutrition, and freshwater supply, and adequate investment in human capital development to promote sustainable development in African countries. There is evidence that provision of adequate healthcare at an early age reduces mortality and health outlays over the life cycle. Furthermore, research has demonstrated that appropriate health and nutritional interventions can have positive impact on the productivity of the workforce.

African governments have made significant efforts in recent years to improve health outcomes across the continent, reflecting a growing commitment to public health and the well-being of their populations. This has led to some progress and success in health outcomes over the past decade. For example, adult mortality rates have decreased, and while still far behind the rest of the world, life expectancy has been increasing due to reductions in extreme poverty and hunger. In addition, there has been an overall downward trend in infectious diseases. The World Health Organisation (WHO) estimates that the African region successfully reduced the number of malaria cases by 66%, HIV cases by 57% and achieved a reasonable decline in mortality rates for children under the age of 5 years by 2021.[26] Communicable and non-communicable diseases account for two-thirds and one-third of the total disease

[25]Amankwah-Amoah, J. (2023) Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. Sustainable Development, 27(5), 910-922

[26]World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

burden in Africa, respectively. Between 2020 and 2022, AIDS-related deaths decreased by thirty-six percent, and the number of new HIV infections also decreased by forty-three percent.[27] However, HIV continues to be an epidemic, especially in Africa's urban areas and is more prevalent in women.

Healthcare delivery in Africa is complex and multifaceted, and influenced by a range of factors, including the socio-economic landscape, infrastructure development, disease burden, and the capacity of the healthcare workforce.[28] Despite the efforts of governments to improve healthcare in their countries, the continent's health burden remains relatively high, compared to other regions. Relatively less resourced countries and those affected by conflict face the highest rates of communicable diseases and the highest disease burden. Minimal access to quality primary health services also contributes to the poor health outcomes. For example, a third of Africans live more than two hours away from health services, and there are severe shortages in hospital beds, medical equipment, and drugs.[29]

The state of health delivery on the continent remains a pressing concern. Many countries struggle with a limited number of hospitals and clinics, and a shortage of staff, leading to overcrowded facilities and long wait times for patients to access medical care.[30] This scarcity of resources is further exacerbated by the unequal distribution of services, with rural areas often being the most underserved.[31] In addition, recent economic successes in African countries, including rapid unplanned urbanisation, have brought lifestyle changes and a rise in both alcohol consumption and tobacco usage. This has strained the already weak health services. Therefore, the continent needs to adopt innovative ways in dealing with the disease burden.

The state of health delivery on the continent remains a pressing concern. Many countries struggle with a limited number of hospitals and clinics, and a shortage of staff, leading to overcrowded facilities and long wait times for patients to access medical care.

Improvement in healthcare and provision of future health security in Africa will depend on two main factors: increased research in priority areas such as genomics, biospecimen, biobanking and data management, maternal, neonatal ad child health, and one health; and adoption of emerging technologies such as artificial intelligence, drones, Internet of Medical Things, blockchain to improve diagnostics and treatments and ultimately health outcomes. In recent years, Africa has witnessed remarkable strides in the prioritisation of research by the various countries and utilisation of emerging technologies to revolutionise healthcare. The COVID-19 pandemic prompted governments and organisations to innovate rapidly to respond to emergency health needs.

Research prioritisation fosters the development of local scientific and technological capabilities, enhancing the creation of a robust research ecosystem in health. This has led to the emergence of homegrown innovations and solutions that are better suited to the unique challenges and contexts of African countries. The COVID-19 pandemic highlighted the importance of investing in research prioritisation to develop rapid, context-specific responses to emerging health threats. Strengthening the capacity of African countries to conduct health research and develop innovative solutions can improve their preparedness and resilience against future pandemics. However, although some African governments and policymakers are investing more resources in health research, others are yet to achieve this goal.

Many diseases that disproportionately affect African populations, such as malaria, neglected tropical diseases, and certain non-communicable diseases, have historically received limited attention and investment from the research prioritisation efforts of governments. Setting research priorities can help address these neglected diseases and develop tailored interventions. As most deaths in Africa are caused by communicable diseases, poor nutrition, or maternal and perinatal challenges, it is critical for countries to capitalise on existing research that offer unique solutions to address these poor health outcomes. This will contribute to economic growth and social development, by increasing access to healthcare, reducing healthcare costs, and enhancing human capital. Prioritising research can also create new job opportunities in the health sector,

[27]Juma, P. A., & Nyauma, F. (2023) "The role of digital technologies in the management of non-communicable diseases in Africa." BMC Public Health, 23(1), 152. https://doi.org/10.1186/s12889-022-13821-4

[28]Okafor, I., & Adisa, Y. (2024). "Artificial Intelligence in Predictive Analytics for Disease Outbreaks in Africa." Journal of Epidemiology and Digital Health, 15(2), 203-218

[29]World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

[30]Kamara, M., & Bangura, J. (2024) "Smart Wearable Devices for Real-Time Health Monitoring in Africa" African Journal of Biomedical Engineering, 7(2), 45-60

[31]Afolabi, S., & Kalu, O. (2024) "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review" African Journal of Telehealth, 10(2), 102-119

by fostering the growth of the pharmaceutical and biotechnology industries in Africa. Organisations, including Africa Centres for Disease Control and Prevention (CDC) and Clim-Health Africa, are already leading the way by working to increase the continent's capacity to manufacture multiple life-saving vaccines and building regional capacity for delivering training in climate impact on health for local public health practitioners. [32]

Africa's health challenges require a coordinated approach involving policymakers, business leaders, international institutional investors, philanthropists, local actors, and civil society. In addition, African-led initiatives will be critical in addressing challenges and shaping the region's health future.[33] For instance, at Omenako in Ghana, Zipline drones are used to deliver blood samples and drugs to other facilities in the country. Initiatives such as M-TIBA in Kenya, Imara Health in South Africa, and LifeMD in Nigeria are utilising telehealth technologies to provide healthcare services. M-TIBA connects patients in rural areas with doctors and healthcare providers using mobile phones. Imara Health uses video conferencing to connect HIV-positive women with healthcare providers. LifeMD combines video conferencing, phone calls, and messaging, to provide reproductive healthcare services to women trying to conceive.[34] Technologies such as Augmented Reality (virtual reality) smart technologies such as IoMT, and Blockchain have helped to bridge the gap in use of sophisticated equipment to deal with health problems.

Ghana's National E-Health Project, powered by the Lightwave Health Information Management System (LHIMS), improves healthcare delivery, by providing a comprehensive eHealth platform that offers electronic health records, telemedicine services, and robust health information management, positioning Ghana as a pioneer in Africa's digital health landscape. The Ethiopian Telemedicine Network (ETN), a chapter organisation of the African Telemedicine Network, was established to bring Ethiopian Telemedicine practitioners together so that they can build local digital health capacity. This in turn allows healthcare professionals to practice digital health anywhere in the country, removing existing territorial barriers. As telehealth continues to evolve, African governments should pursue these innovative approaches to enhance the health and well-being of their citizens throughout the continent.[35] Through such initiatives, Africa can build on its economic, green and health achievements to make the African Union's Agenda 2063 a reality.

1.3 Challenges Confronting African Healthcare Delivery

Africa faces a dual burden of communicable and non-communicable diseases. While significant progress has been made against diseases such as HIV and AIDS, malaria, and tuberculosis, non-communicable diseases (NCDs) such as diabetes, cancer, and cardiovascular diseases are on the rise.[36] The healthcare systems across the continent often struggle to effectively address both categories of diseases due to limited resources. Research prioritisation is therefore much needed in various areas such as disease management and health systemic issues[37] and an integrated approach to health service delivery that balances the management of communicable and non-communicable diseases. The research must be multifaceted, arising from historical, socio-economic, and political factors, and resulting in comprehensive strategies for improvement in healthcare delivery.

One of the most pressing issues in healthcare delivery in Africa is the lack of adequate infrastructure. Disparities in the distribution of healthcare facilities, including hospitals and clinics, exacerbate the challenges faced by many African countries.[38] Additionally these countries struggle with poorly equipped facilities and insufficient medical supplies. Many countries have poor primary healthcare, characterised by shortage of drugs and absence of health-promoting amenities, especially in rural areas. Hospitals and clinics often lack basic amenities, such as functioning laboratories, diagnostic equipment, and essential medicines. As a result, patients in need of care face significant barriers to accessing timely and effective treatment. In rural areas, where healthcare facilities are scarce, individuals may travel long distances to receive care, often at a great personal and financial cost.[39] This contributes to delays in diagnosis and treatment, resulting in poor health outcomes for many Africans living in rural areas.[40] Prioritising research can play a crucial role in addressing these challenges.

The healthcare sector in Africa is also characterised by inadequate human resources. There is a shortage of

[32]Afolabi, S., & Kalu, O. (2024) "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review" African Journal of Telehealth, 10(2), 102-119

[33]Juma, P. A., & Nyauma, F. (2023). "The role of digital technologies in the management of non-communicable diseases in Africa." BMC Public Health, 23(1), 152. https://doi.org/10.1186/s12889-022-13821-4

[34]Ndung'u, D., & Akol, A. (2024). "E-Health Initiatives: Bridging the Gap in Maternal Health Services in Africa." Journal of International Maternal Health, 6(1), 99-115.

[35]Afolabi, S., & Kalu, O. (2024) "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review" African Journal of Telehealth, 10(2), 102-119

[36]Obafemi, A. & Omotola, A. (2024) "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

[37]Afolabi, S., & Kalu, O. (2024). "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review." African Journal of Telehealth, 10(2), 102-119

[38]World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

[39]Kibet, J., & Muriuki, J. (2024) "Utilizing Big Data Analytics to Enhance Public Health Decision-Making in Africa." Journal of Public Health Analytics, 8(1), 77-90

[40]Obafemi, A. & Omotola, A. (2024) "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

trained healthcare professionals, and many countries experience high outflow of medical personnel to developed nations, drawn by better salaries and working conditions. This "brain drain" exacerbates the existing workforce shortages, resulting in a small number of healthcare workers forced to provide services to a large population.[41] The low number of healthcare professionals also impacts the quality of health services provided, as healthcare workers struggle to manage their overwhelming caseloads.

Healthcare systems in Africa are also generally underfunded and overburdened, as health spending remains inadequate to meet increasing demands. Many African countries spend less than 10% of their Gross Domestic Product on healthcare. This arises from governments often prioritising other sectors such as defence or infrastructure.[42] A significant portion of healthcare financing comes from out-of-pocket payments, which can deter individuals from seeking medical care. As a result, health inequalities widen, with the poorest populations bearing the greatest burden of disease and unmet health needs.[43] In many African communities, traditional health practices coexist with modern medicine, and cultural beliefs and practices can pose challenges to effective healthcare delivery. This contributes to hesitancy in seeking care from formal healthcare providers. Furthermore, low health literacy can hinder individuals' ability to make informed decisions on health, to understand treatment options, and adhere to medical advice.[44] Efforts to improve patient education and community engagement are necessary to bridge these gaps.

Despite challenges, healthcare delivery in Africa also presents opportunities for transformative change. A multifaceted approach is needed to address these issues, one that combines research prioritisation, investment in health infrastructure and services, and a commitment to strengthening governance and policy frameworks.[45] Collaboration and partnerships between governments, non-governmental organisations, and the private sector are also essential to drive positive change in healthcare in Africa. Stakeholders can create sustainable solutions that benefit all Africans by working together to address common challenges and sharing resources and expertise.

1.4 Opportunities for Improvement through Health Research and Emerging Technologies

Prioritising health research focuses on discovering and developing new tools, mechanisms and approaches to treat a wide range of medical conditions. This includes exploring novel mechanisms of action, improving existing treatments, and addressing unmet medical needs. Research prioritisation efforts aim to design and enhance medical devices, diagnostic tools, and healthcare technologies, to improve patient outcomes, enhance efficiency, and provide more accurate and reliable healthcare services. The process involves extensive research to understand the underlying mechanisms and causes of various diseases, including genetic, environmental, and lifestyle factors. Health research prioritisation can also focus on addressing broader public health concerns, such as infectious disease outbreaks, chronic disease management, and health disparities. This may involve developing vaccines, improving epidemiological surveillance, and designing effective public health interventions.

Research prioritisation often involves collaboration across disciplines, including medicine, biology, engineering, computer science, and social sciences. This interdisciplinary approach can lead to innovative solutions that address complex healthcare challenges. Research prioritisation is not only a feasible approach, but it is also vital to addressing existing gaps and building resilient healthcare systems on the continent.[46] By investing in research prioritisation, the health sector can drive scientific discoveries, develop new and

[41]World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

[42]Abimbola, S., & Nchinda, T. (2022). "Health systems strengthening in Africa: The role of digital health technologies." Global Health Action, 15(1), 2045692. https://doi.org/10.1080/16549716.2022.2045692

[43]Juma, P. A., & Nyauma, F. (2023). "The role of digital technologies in the management of non-communicable diseases in Africa." BMC Public Health, 23(1), 152. https://doi.org/10.1186/s12889-022-13821-4

[44]Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." Journal of Health Ethics, 3(1),

[45]Kamara, M., & Bangura, J. (2024) "Smart Wearable Devices for Real-Time Health Monitoring in Africa" African Journal of Biomedical Engineering, 7(2), 45-60

[46]Afolabi, S., & Kalu, O. (2024). "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review." African Journal of Telehealth, 10(2), 102-119

improved treatments, enhance healthcare delivery, and ultimately improve the overall health and well-being of the population.

Emerging technologies have great potential to transform healthcare systems in Africa and worldwide. They can revolutionise healthcare systems by enhancing diagnostic accuracy, treatment efficacy, and operational efficiency.[47] They can also enable early disease detection, personalised treatment plans, and data-driven decision-making.[48] Additionally, emerging technologies are building a sustainable foundation for affordable, accessible, and high-quality medicines, vaccines, medical devices, and system innovations, and enabling public sector efforts to address the most challenging health problems.[49]

Through the application of emerging technologies such as Artificial Intelligence (AI) and Internet of Medical Things (IoMT), powered tools such as machine learning algorithms, predictive analytics, and natural language processing, healthcare providers can optimise resource allocation, streamline healthcare processes and improve health outcomes. AI-powered chatbots and telemedicine are helping to address the shortage of healthcare professionals by automating routine tasks, enabling remote consultations and answering patient queries. By increasing access to healthcare services, emerging technologies can optimise the workload and reach of existing healthcare professionals.[50] Others such as virtual reality and online learning platforms can enhance medical education and training in Africa by providing continuous learning opportunities for healthcare professionals, even in areas with limited clinical resources. More innovations are expected to emerge as healthcare demand and investment in the sector increases.

Nevertheless, many of these novel technologies have not been fully integrated in health systems in most African countries.[51] Their effective implementation is constrained by inadequate e-health governance structures and weak institutional capacities for planning, implementation, supervision, monitoring and evaluation, and lack of sustainable funding. Furthermore, issues such as data privacy and security, regulatory frameworks, ethical considerations, data bias, infrastructure limitations, and workforce capacity pose significant obstacles to the widespread use of emerging technologies in healthcare settings across the continent.[52] The low digital literacy skills of a

significant portion of the population also hinders the adoption of emerging technologies in Africa. Limited access to smartphones, internet connectivity, and digital devices exacerbates this challenge, creating a significant barrier to the widespread adoption and utilisation of these technologies.

Case studies of successful adoption of emerging technologies exist in many African countries. Uganda, for example, uses mTrac in its public health system for data reporting, verification, and analysis, as well as communication among its work force. The SMS for Life programme, a public-private partnership between the pharmaceutical company Novartis and eight African countries, has reduced the shortage of malaria treatments and other essential drugs in primary health care facilities by using mobile phones to track and manage stock levels.[53] In Uganda, a local company, Matibabu, created the Matiscope, an IoMT device that fits onto the index finger and, in just a few minutes and without drawing blood, can detect the presence of malaria-causing parasites and send the result to a smartphone or computer application.[54]

Other technologies that are being adapted to the health sector include drones. In 2016, Rwanda, through a contract with Zipline, became the world's first country to incorporate the use of drones into its health care system to deliver blood for transfusions to remote regions. The California company, now also operating in Ghana and Nigeria, designed a drone capable of

[47]Amankwah-Amoah, J. (2023) Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. Sustainable Development, 27(5), 910-922

[48]Ige, O., & Wale, A. (2024) "Blockchain for Health Data Security: Opportunities and Challenges in African Nations." Journal of Health Systems Security, 11(1), 18-34

[49]Obafemi, A. & Omotola, A. (2024) "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

[50]Alhassan, M., & Otchere, E. (2023) "The impact of mobile health technologies on maternal health in Ghana." Journal of Global Health, 13(1), 56-64. https://doi.org/10.7189/jogh.13.01001

[51]Alam, M. Z., Hoque, M. R., Hu, W., & Barua, Z. (2020) Factors influencing the adoption of mHealth services in a developing country: A patient-centric study. International Journal of Information Management, 50, 128–143

[52]Abubakar, A., & Bmitone, T. (2023). "Telemedicine in Africa: Challenges and Future Directions." African Journal of Primary Health Care & Family Medicine, 15(2), a1015

[53]Obafemi, A. & Omotola, A. (2024) "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

[54]Kamara, M., & Bangura, J. (2024) "Smart Wearable Devices for Real-Time Health Monitoring in Africa" African Journal of Biomedical Engineering, 7(2), 45-60

flying 100 miles round-trip in all-weather conditions while carrying several pounds of supplies. In Nigeria, a company has utilised AI technology and machine learning in a user-friendly App called Ubenwa, which can analyse the cries of a baby and detect child-birth asphyxiation, a major cause of child mortality, without the presence of a health care provider.[55] In Uganda, a medical researcher, Agnes Kiragga, has developed a machine learning system that uses an HIV database to analyse retention rates of at-risk and infected female populations.

In Ethiopia, AI is being used to help medical professionals accurately diagnose cervical cancer and medical irregularities during checkups. IBM Research Africa is using AI to determine optimal methods for eradicating malaria in specific locations and using game theory and deep-learning data analytics to diagnose pathological diseases and birth asphyxia.[56] Emerging technologies go even further with medical records, using blockchain to safely share data and information between doctors. In a continent where most people own a mobile phone, providers such as Kenya's Safaricom and Nigeria's MTN are experimenting with micro-insurance products using mobile payments.[57] Mobile operators are also offering other sorts of mobile airtime credits that patients, who are ineligible for traditional credit cards, can use to pay for healthcare. However, without proper governance and policy frameworks in place, the potential benefits of health research prioritisation and emerging technologies in healthcare may not be fully realised, and there is a risk of exacerbating existing health disparities and inequalities.[58]

There are compelling reasons for African countries to prioritise health research and adoption of emerging technologies to address healthcare challenges.[59] Investment in these areas, combined with a commitment to integrate them into existing healthcare systems, is essential for building resilient and effective healthcare delivery frameworks that meet the needs of African populations.[60] By embracing research prioritisation and emerging technologies, African countries can pave the way for a healthier future and overcome the longstanding challenges facing healthcare services across the continent.

1.5 African Union Position on Emerging Technologies

The African Union Heads of State and Government Summit of July 2016 endorsed a recommendation by the African Ministers of Education, Science and Technology that the NEPAD Agency (now African Union Development Agency, AUDA-NEPAD), in collaboration with the African Union Commission (AUC), should guide Member States and Regional Economic Communities (RECs) regarding technology prospecting, including the necessary regulatory and ethical requirements for Africa to benefit from emerging technologies. The summit mandated the NEPAD Agency to establish a system that would facilitate expert input on technology development, acquisition, and deployment to drive socio-economic growth.

In October 2016, then Chairperson of the African Union Commission, H.E. Dr Nkosazana Dlamini Zuma, appointed a group of ten experts from diverse backgrounds to serve on the African Union High-Level Panel on Emerging Technologies (APET). The panel's primary objective was to harness existing and emerging technologies for Africa's economic advancement. The panel members, who represent a variety of professional fields, provide evidence-based analyses and recommendations to guide policy decisions made at continental, regional, and national levels on research priorities and utilisation of existing and emerging technologies. The panel also develops strategies, tools,

> The African Institute for Development Policy (AFIDEP) is collaborating with the AUDA-NEPAD to build evidence to advocate for policy reforms on prioritising research in health and application of emerging technologies in the healthcare systems in Africa.

[55]Amankwah-Amoah, J. (2023) Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. Sustainable Development, 27(5), 910-922

[56]Afolabi, S., & Kalu, O. (2024) "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review" African Journal of Telehealth, 10(2), 102-119

[57]Juma, P. A., & Nyauma, F. (2023). "The role of digital technologies in the management of non-communicable diseases in Africa." BMC Public Health, 23(1), 152. https://doi.org/10.1186/s12889-022-13821-4

[58]African Union Development Agency (AUDA-NEPAD). (2021) "Emerging technologies and their potential for improving health in Africa" (APET Blog)

[59]Ndembi, N. et al. (2023) African leadership is critical in responding to public health threats. Nat. Commun. 15, 877

[60]Alhassan, M., & Otchere, E. (2023) "The impact of mobile health technologies on maternal health in Ghana." Journal of Global Health, 13(1), 56-64. https://doi.org/10.7189/jogh.13.01001

policies, and institutional arrangements to promote and sustain common regulatory approaches for the application of emerging technologies in Africa.

The African Union Science, Technology and Innovation Strategy for Africa (STISA 2024) aims to harness innovation and emerging technologies to advance Africa's socio-economic development by increasing investment in research and development, incubating emerging technologies, building regulatory capacity, and strengthening inter-continental collaboration. The African Union seeks to transform healthcare delivery, among others, by embracing research prioritisation and emerging technologies across its Member States. The African Institute for Development Policy (AFIDEP) is collaborating with the AUDA-NEPAD to build evidence to advocate for policy reforms on prioritising research in health and application of emerging technologies in the healthcare systems in Africa.

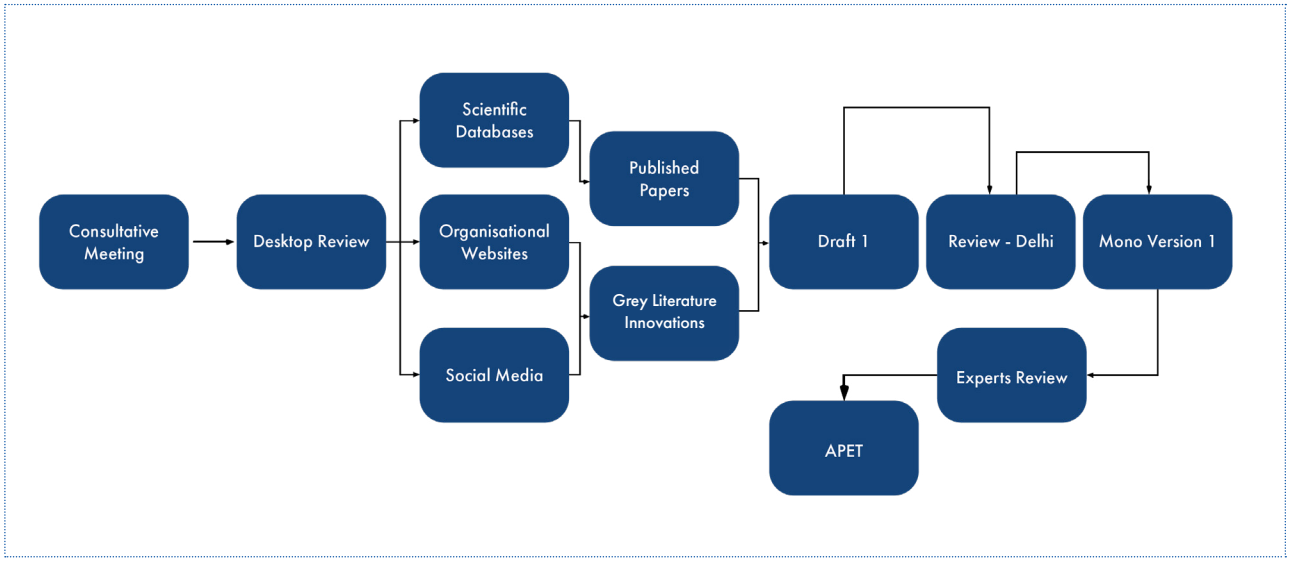
1.6 Purpose of the Monograph

This monograph focuses on emerging technologies for health in Africa and their application, while also highlighting areas of potential research. It is structured as a discussion of the core issues in systems thinking relating to emerging technologies in revolutionising healthcare systems in Africa. It is a multifaceted document, addressing local health challenges, informing policy, promoting ethical considerations, driving research, strengthening capacity and supporting sustainability. It highlights key challenges, interventions, and especially the opportunities that emerging technologies and research present for transforming healthcare delivery on the continent. This offers a detailed consideration of five research priorities and five emerging technologies, which include the application, challenges and benefits, and socio-cultural and ethical considerations for their adoption for healthcare delivery in Africa. These are: Artificial Intelligence (AI) and Machine Learning, Blockchain technology, Internet of Medical Things, Drones and Gene Drive Technologies, Genomic Medicine, Biospecimen, Biobanking and Data Governance, Genetically-Based Vector Control, One Health and Maternal, Neonatal and Child Health. The monograph also provides examples of research priorities and emerging technologies that have been applied within the healthcare sector. Lastly, each chapter provides policy recommendations to guide policy and decision-makers, healthcare professionals, researchers, and technologists in leveraging emerging technologies effectively to improve health outcomes for people.

1.7 Monograph Development Process and Methods

The authors conducted a comprehensive literature review on health and emerging technologies-related research in Africa. An appropriate sampling strategy consisting of a combination of random and purposeful sampling was used to ensure that representative and relevant data was collected. They also collected primary data using qualitative methods such as interviews, focus groups, surveys through stakeholder engagements, to complement the secondary data. Thematic analysis and content analysis techniques were selected, and a triangulation strategy was incorporated to enhance the validity, reliability, and credibility of the research findings for the monograph. Figure 1 below offers a summary of the methods and processes used in developing this monograph, which are discussed in depth in following sections.

Figure 1: Summary of methodology used to develop monograph



1.7.1 Scoping Exercise and Literature Review

As a first step, a comprehensive scoping was conducted of existing literature on healthcare, research and emerging technologies in Africa, to map the breadth and depth of available evidence. The researchers constructed specific research questions to guide the inquiry, addressing how research priorities and emerging technologies can be effectively harnessed in the health sector.

The review gathered information from technical reports, academic publications, reports, policy documents, research articles, books, technical reports, research documents, case studies, and regulatory documents, as well as statistical data from databases. Other sources reviewed include documents from ResearchGate and Google Scholar and other online sources, APET reports and publications on research prioritisation and emerging technologies.

1.7.2 Stakeholder Consultations

The researchers organised stakeholder dialogues or consultations with health professionals, researchers, African innovation and emerging technology experts, health policy and decision-makers and government officials, healthcare practitioners and administrators, community leaders and representatives, researchers and academics. The consultations aimed to gather diverse perspectives and insights into healthcare research priorities in Africa, challenges and potential solutions and best practices. The process involved a mix of individual interviews, focus group discussions, and workshops.

Through this process, the researchers identified critical issues, barriers, and enablers to effective healthcare delivery. This consultative approach allowed for a broad, multi-stakeholder exploration of the research prioritisation and emerging health technologies while also enabling an in-depth understanding of the contextual factors and lived experiences that shape healthcare delivery in Africa. It also ensured buy-in and ownership of the draft monograph.

The feedback from the dialogues was incorporated into the monograph which was presented to the AU High Level Panel of Emerging Technologies (APET) and a team of experts for discussion. The feedback from this meeting was incorporated into the document, and final revisions made. The resulting monograph provides a robust, evidence-based analysis to inform policy, practice, and future research.

1.7.3 Data Synthesis and Analysis

The data from the literature review and stakeholder consultations was analysed to identify key themes, patterns, and relationships that informed the structure and content of the monograph. Thematic analysis was applied for qualitative data, and statistical tools adopted for quantitative data to capture nuances and differences of research prioritisation and emerging technologies across various African contexts and populations.

The results were synthesised and the data from various sources integrated to present a comprehensive understanding of the healthcare landscape in Africa and how research prioritisation and emerging technologies can be leveraged in health Best practices and successful case studies were highlighted as models of implementation.

1.7.4 Drafting the Monograph

The monograph was drafted by a team of African experts. It is organised into clear sections such as executive summary, and introductory chapter, which is followed by in-depth discussion of five health research priorities and five emerging technologies. A rigorous peer review process was followed, involving subject matter experts, policymakers, and other relevant stakeholders to ensure that the content was scientifically sound. The monograph was also reviewed to ensure that it adhered to established editorial guidelines and formatting standards.

1.7.5 Review and Editing

Stakeholders and experts in the field reviewed the draft monograph, to ensure coherence and relevance to key stakeholders. Their feedback was incorporated in refining the draft. The document was drafted in simple language, employing a clear and straightforward writing style to ensure that it is reader-friendly and accessible to a diverse non-technical audience.

1.7.6 Dissemination of Monograph

To disseminate the monograph, the collaborating institutions and authors use a range of channels, including academic and policy publications, conferences, workshops, and webinars, online platforms and social media, government and organisational networks are leveraged to maximise the monograph's visibility and impact. Workshops, training sessions, or collaborative events are organised to facilitate the exchange of knowledge and experience around the

monograph's findings. Stakeholders are empowered to utilise the monograph's insights and apply them in their respective contexts. Mechanisms have been established to track the reach, uptake, and impact of the monograph's dissemination efforts to inform future initiatives.

1.8 Target Audience

This monograph is a useful resource for a large group of stakeholders interested in research prioritisation and emerging technologies for health in Africa. These include:

- Medical doctors, nurses, frontline healthcare workers, and public health officials interested in innovative approaches to healthcare delivery and medical researchers focused on health technologies and their applications in African contexts.
- National and regional health policy makers and government health officials responsible for setting strategic priorities and allocating resources for healthcare initiatives across the African continent, and looking to understand the impact of technology on healthcare systems; government representatives involved in health strategy development and implementation
- Leaders and administrators within national and regional healthcare systems, who are tasked with implementing new programmes, technologies, and evidence-based practices.
- Researchers, scientists, and technologists developing cutting-edge solutions in fields like digital health, telemedicine, AI-enabled diagnostics, and other emerging healthcare innovations.
- Nonprofit organisations, multilateral agencies, and philanthropic donors invested in improving healthcare access and outcomes in underserved African communities. Entities such as WHO, UNICEF, and others focusing on health systems strengthening, infectious disease control, and technology integration.
- Scholars in health sciences, technology, and social sciences studying the intersection of technology and health in developing countries. It will also be useful to graduate and postgraduate students researching health innovation and technology.
- Start-ups and established technology companies focusing on health tech solutions tailored for African markets; additionally, entrepreneurs seeking insights into opportunities for investment in health technologies will also find the monograph useful.
- Organisations working in health and development sectors interested in using technology to enhance service delivery or data management as well as international agencies seeking evidence-based approaches to support health initiatives in Africa.
- Individuals and firms looking to invest in health technology ventures or initiatives in the African market.
- Local leaders who influence health practices and technology adoption within communities and advocacy groups focusing on health equity and empowerment through technology.
- Professionals involved in training the next generation of healthcare workers and technicians in emerging technologies.
- Citizens interested in health advancement and technological impacts on their communities.

The monograph chapters are organised as follows:

Chapter 1

"Harnessing research priorities and emerging technologies for effective healthcare delivery in Africa" provides an overarching analysis of the status of healthcare in Africa and the role of health research priorities and emerging technologies in transforming the healthcare on the continent.

Chapter 2

"Application of artificial intelligence (AI) in healthcare systems in Africa" examines the state of artificial intelligence and tracks the development of current progress in healthcare resulting from the adoption of AI. It further discusses pertinent issues towards ensuring the responsible adoption of AI for positive health outcomes.

Chapter 3

"Utilisation of Internet of Medical Things (IoMT) for health" presents the current and future trends of the IoMTs, providing case studies, and covering benefits and challenges with some policy recommendations.

Chapter 4

"Harnessing blockchain technology for healthcare delivery in Africa" discusses the growing interest in exploring blockchain technology for data privacy and security in healthcare. The chapter further presents one of the primary benefits of blockchain technology in healthcare as its ability to provide a tamper-proof and decentralised system for storing and sharing medical records.

Chapter 5

"Application of drones in healthcare delivery systems in Africa" covers the impact of drones in reaching rural and remote areas in Africa with health services and calls for the adoption of drones for improving health outcomes in rural Africa.

Chapter 6

"Application of genomic medicine to advance healthcare in Africa" observes the contribution of biological health research priorities such as genomic research in Africa to medicine, presenting case studies for diseases like sickle cell. The chapter further discusses data management, operational, and logistic aspects of genomic research. This chapter asserts the view that genomic medicine is becoming an integral feature of contemporary management of healthcare and presents recommendations for research and adoption of the technology.

Chapter 6

"Biospecimen and biobanking in Africa" role and application of biological health research priorities such as biospecimen and biobanks in the healthcare system, the benefits and ethics of challenges and proposes policy recommendations through which these challenges can be navigated to ensure African leadership in biobanking research programmes in Africa.

Chapter 7

"Utilisation of Genetically-Based Vector Control (GBVC) technologies to control infectious diseases in Africa" presents an analysis of GVBC as a groundbreaking approach to combat diseases like malaria, dengue, zika and others by utilising genetic modification techniques to reduce the transmission. The chapter argues that the African continent, which bears the heaviest toll of vector-borne diseases, could greatly benefit from the GBVC technologies.

Chapter 8

"Exploration of gene drive technology for malaria elimination in Africa" provides an overview of the gene drive technology and its potential applications in malaria control and elimination in Africa. It addresses major developments so far accomplished, the current state of the technology, and approaches necessary to determine potential risks and benefits. Various opportunities for future research and development are highlighted.

Chapter 9

"Harnessing of emerging technologies to improve maternal, neonatal and child health (MNCH) in Africa" looks at the specifics of this very important public health issue to better understand them and plan more effective interventions through the application of emerging technologies to promote MNCH.

Chapter 10

"Harnessing One Health concept and applications in Africa" discusses One Health as a necessary emerging approach to deliver effective and efficient infectious disease surveillance, disease prevention and control, as well as public health emergency preparedness and response in Africa.

1.9 Conclusion

In recent years, the healthcare sector in Africa has undergone considerable technological advances, which have had a significant impact on patient care, clinical operations, and healthcare delivery.[61] However, many countries are confronted by challenges which include limited healthcare facilities, medical equipment, and trained healthcare personnel to meet the needs of their populations.[62] Healthcare systems often operate on limited budgets, leading to insufficient resources for essential services, equipment, and medications. Additionally, there is a significant shortage of healthcare professionals in many African countries, with healthcare workers often overburdened and under-skilled.[63] Disparities in access to healthcare services based on factors like location, socio-economic status, and gender contribute to health inequalities across the continent.

Addressing challenges within the health sector of African countries requires innovative solutions to strengthen healthcare systems, as there is need to improve access, quality, and equity in healthcare delivery.[64] As countries navigate the complexities of addressing challenges confronting healthcare systems, it is important to consider enhancing health research prioritisation and harnessing emerging technologies. Embracing a holistic approach that prioritises data governance, regulatory oversight, ethical considerations, and workforce development will pave the way for a sustainable and equitable use of health priorities and emerging technologies in African healthcare.[65] Adopting the policy recommendations outlined in this monograph will help governments and relevant stakeholders to create an enabling environment for driving improvements in patient care, operational efficiency, and health outcomes across the continent.

[61]World Health Organization Regional Office for Africa (2021) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

[62]Obafemi, A. & Omotola, A. (2024). "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." Health Systems and Policy Journal, 9(2), 142-158

[63]Kibet, J., & Muriuki, J. (2024) "Utilizing Big Data Analytics to Enhance Public Health Decision-Making in Africa." Journal of Public Health Analytics, 8(1), 77-90

[64]Ndembi, N. et al. (2023) African leadership is critical in responding to public health threats. Nat. Commun. 15, 877

[65]Kibet, J., & Muriuki, J. (2024). "Utilizing Big Data Analytics to Enhance Public Health Decision-Making in Africa." Journal of Public Health Analytics, 8(1), 77-90

Application of Artificial Intelligence in Healthcare Systems in Africa

2

Application of Artificial Intelligence in Healthcare Systems in Africa

2.1 Background

Artificial intelligence (AI) refers to the simulation of human intelligence processes by computer systems. These processes include learning (acquiring information and rules for using the information), reasoning (using rules to reach approximate or definite conclusions), and self-correction.[66] AI systems are designed to perform tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, language translation, and problem-solving. In recent years, AI has significantly advanced and become a reality in the daily lives of people globally, and in Africa.[67]

Application of AI in analysing and utilising healthcare data is directly impacting millions of people globally, including the African continent. Its potential is broad and far-reaching, from scanning radiological images for early detection of diseases to predicting outcomes from electronic health records.[68] By leveraging artificial intelligence, healthcare systems are becoming smarter, faster, and more efficient in providing care to millions of people worldwide. The technology can analyse vast amounts of clinical documentation quickly, helping medical professionals identify disease markers and trends that would otherwise be overlooked. In Africa, the emergence of AI in healthcare has been groundbreaking, reshaping the way health practitioners diagnose, treat and monitor patients. Medical professionals can make more informed decisions, based on more accurate information - saving time, reducing costs and improving medical records management overall.[69] This technology is drastically improving healthcare research and outcomes in Africa by producing more accurate diagnoses and enabling more personalised treatment.[70] AI in healthcare promises to be a game changer, leading the way towards a future where patients receive quality care and treatment faster and more accurately.[71]

However, there exists some challenges in harnessing the technology in Africa, which must be addressed. Some of the most pressing challenges include data privacy and security, patient safety and accuracy of diagnoses. Data privacy is paramount as AI systems collect large amounts of personal health information, which could be misused if not handled correctly. Other challenges are training algorithms to recognise patterns in medical data, integrating AI with existing IT systems, gaining physician acceptance and trust, and ensuring compliance with national, regional and continental regulations.[72]

For AI to be more actively applied in healthcare in Africa, it is important to increase awareness of the technology and to establish standardised guidelines and regulations. Additionally, ethical and regulatory issues must be addressed at national, regional and continental levels.[73] AI systems must also be trained to recognise patterns in medical data, understand the relationships between different diagnoses and treatments, and provide accurate recommendations that are tailored to each individual patient.[74] Furthermore, AI must be integrated with existing IT systems to ensure seamless operation.[75] Additionally, proper security measures must be put into place to protect sensitive patient data from being exploited for malicious purposes. Finally, the successful adoption of AI in healthcare requires acceptance and trust by medical providers.

2.2 Use of AI in the Healthcare Systems

The healthcare system in Africa is already applying AI in various ways, to improve patient care, enhance clinical decision-making, optimise healthcare delivery, and address challenges related to healthcare access and quality.[76] Some of the key applications of AI in healthcare include the following:

[66]African Union Development Agency (AUDA-NEPAD) (2023) AI for Africa: Artificial Intelligence for Africa's Socio-Economic Development

[67]Abayomi, A., & Mensah, J. (2021) "Artificial Intelligence Applications in African Healthcare: Opportunities and Challenges." African Journal of Health Policy, 14(2), 165-182

[68]African Union Development Agency (AUDA-NEPAD) (2023) AI for Africa: Artificial Intelligence for Africa's Socio-Economic Development

[69]Adegbite, O., & Ekundayo, T. (2023) "AI-Powered Telemedicine Solutions for Rural Health in Africa." Journal of Digital Health, 8(1)

[70]Makhuba, T., & Shokunbi, W. (2022) "The adoption of artificial intelligence in Kenyan healthcare: Opportunities, challenges, and recommendations." East African Medical Journal, 99(7), 671-678. https://doi.org/10.4314/eamj.v99i7.10

[71]Kamara, M., & Kanu, R. (2024) "Integrating AI into Primary Healthcare Systems in Africa." International Journal of Healthcare Delivery, 17(2), 155-172

[72]Chukwuneke, F. N., & Nwokolo, C. (2023) "The potential of AI-driven diagnostic tools in enhancing healthcare outcomes in Africa." African Journal of Health Informatics, 15(2), 123-132. https://doi.org/10.4314/ajhi.v15i2.9

[73]Ayo, C. K., & Otunla, O. (2022) Leveraging AI for Improved Health Systems in Sub-Saharan Africa. Health Policy and Technology,

[74]Iroha, E., & Nwogu, C. (2022) "Artificial intelligence for improving health service delivery in Sub-Saharan Africa: Barriers and solutions." Journal of Health Informatics in Africa, 9(1), 49-56. https://doi.org/10.12860/jhia.2022.04

[75]Okafor, I., & Bayo, A. (2022) "AI-Driven Healthcare Solutions: Transforming Patient Care in Africa" African Journal of Health Innovations, 13(1), 60-75

[76]Njeru, E. K., & Karanja, R. (2023) "Transforming healthcare in Africa through artificial intelligence: A review of recent innovations" African Journal of Health Science, 9(1), 13-22. https://doi.org/10.4314/ajhs.v9i1.2

- AI-powered diagnostic tools and algorithms, applied to analyse medical images, such as X-rays, Computed Tomography (CT) scans, and MRI scans, to detect and diagnose diseases like tuberculosis, cancer, and malaria.[77]
- AI-enabled telemedicine platforms and remote monitoring devices are used to provide virtual consultations, monitor patient health remotely, and deliver healthcare services to underserved and remote areas in Africa.
- AI algorithms are utilised to analyse genetic data, patient health records, and other relevant information to develop personalised treatment plans and predict individual responses to medications.
- AI-powered analytics tools are applied in analysing large volumes of healthcare data, such as electronic health records, medical imaging data, and public health data, to identify trends, patterns, and insights that can inform clinical decision-making, resource allocation, and public health interventions.[78]
- AI is used to accelerate the drug discovery process by analysing molecular structures, predicting drug interactions, and identifying potential drug candidates.
- AI-powered chatbots and virtual assistants are used to provide mental health support, counselling, and therapy to individuals in need.

Africa has a unique opportunity for leapfrogging in the application of AI in healthcare systems due to several factors as follows:

- **Widespread use of mobile phones:** Africa has one of the highest rates of mobile phone penetration globally. This provides a platform for innovative healthcare solutions, such as mobile health (mHealth) applications, telemedicine, and remote patient monitoring, which can leapfrog traditional healthcare infrastructure limitations and improve access to healthcare services.[79]
- **Increased digitisation of healthcare records:** With the increasing digitisation of healthcare records and the adoption of electronic health information systems, Africa could leapfrog traditional systems and implement modern, interoperable digital health infrastructure.
- **Partnerships and collaborations:** Through collaborations with private sector companies, research institutions, and non-profit organisations, African governments can leverage the strengths and expertise of different stakeholders to accelerate the adoption and scaling of AI-driven healthcare solutions, driving leapfrogging in healthcare innovation.
- **Supportive ecosystem:** Africa's growing ecosystem of innovators, entrepreneurs, and startups has the potential to leapfrog traditional approaches and disrupt the healthcare landscape by introducing cost-effective, scalable, and user-friendly technologies that address specific healthcare challenges faced by African populations.[80]
- **Conducive regulatory frameworks:** Some African countries are adopting regulatory frameworks and pilot programmes which allow innovators to test and validate AI-driven healthcare solutions in real-world settings, fostering a conducive environment for leapfrogging in healthcare innovation.[81]

2.3 Examples of Application of AI in Healthcare in Africa

- **Telemedicine and remote consultations:** AI-enabled telemedicine platforms, such as the ElBalto App in Egypt and Zimbabwe, are used to provide virtual consultations and remote services. Patients can consult healthcare providers via video calls, chatbots, or mobile apps, reducing the need to travel long distances to receive care.
- **Health data analysis and predictive analytics:** In Kenya and South Africa, AI technologies, such as AfyaRekod and Phillips EMRS, are used to analyse large volumes of health data, such as electronic health records and public health data to identify

[77]Shuaib, W., & Khamis, M. (2024) Artificial Intelligence as a Catalyst for Health System Strengthening in Africa: Perspectives from Stakeholders. Health Systems & Reform, 10(1), e22909 doi:10.1080/23288604.2023.22900

[78]Ugbeye, J., & Olatunji, S. (2023) "The impact of AI on healthcare delivery in West Africa: A systematic analysis" Journal of Health Services Research and Policy, 28(1), 4-12 https://doi.org/10.1177/1355819622111723

[79]Agbo, C. M., & Nduka, U. (2022) "The role of artificial intelligence in improving healthcare delivery in Nigeria: A systematic review." Nigerian Journal of Clinical Practice, 25(5), 645-654. https://doi.org/10.4103/njcp.njcp_287_21

[80]Kamara, M., & Kanu, R. (2024) "Integrating AI into Primary Healthcare Systems in Africa." International Journal of Healthcare Delivery, 17(2), 155-172

[81]Ogunleye, O. A., & Alabi, A. (2022) "Potential roles of artificial intelligence in combating infectious diseases in Africa" Journal of Medical Internet Research, 24(5), e26339. https://doi.org/10.2196/26339

trends, patterns, and insights from data to inform public health interventions.[82]

- **Precision medicine:** AI technologies, such as Babyl in Rwanda, are used to support precision medicine initiatives in analysing genetic data, medical images, and other patient information to tailor treatment plans to individual patients' unique characteristics.
- **3D Printing for Neonatal Medical Devices:** MedAdd in South Africa is utilising AI in 3D printing technology to create customised medical devices and equipment, such as prosthetics, to meet the unique needs of patients.[83]
- **Robotic surgery and minimally invasive procedures:** AI-driven robotic surgical systems are used in South Africa and Rwanda. They allow surgeons to perform complex procedures with greater accuracy, minimal invasiveness, and shorter recovery times. Other examples are innovations such as PapsAI in Uganda, and Urology in Tunisia.[84]
- **Early Detection of Disease:** In Kenya, AI technology is used to detect diabetic retinopathy (diabetes that affects the eyes) in patients at an early stage. This allows for timely interventions and treatments thus preventing blindness.
- **Monitoring chronic conditions:** South Africa has implemented mobile health apps that use AI algorithms to provide personalised healthcare services to patients. These apps assist in monitoring chronic conditions, offering remote consultations, and providing health education to individuals.

"When combined with AI, blockchain-based solutions facilitate secure data exchange between healthcare providers. They also improve the integrity of medical records, and enable seamless access to patient information."

2.4 Complementary Technologies to AI in the Healthcare

Several complementary technologies work alongside artificial intelligence (AI) to enhance healthcare systems and improve patient care. They include the following:

- **Internet of Medical Things (IoMT):** IoMT encompasses connected medical devices, sensors, and wearables that collect and transmit health data in real-time. They monitor vital signs, track adherence to medication, and provide remote patient monitoring, allowing healthcare providers to monitor patients' health status and intervene promptly when necessary.[85]
- **5G Technology and Blockchain:** Blockchain technology offers secure and transparent ways to store and share health data, ensuring data integrity, privacy, and interoperability. When combined with AI, blockchain-based solutions facilitate secure data exchange between healthcare providers. They also improve the integrity of medical records, and enable seamless access to patient information.
- **Augmented Reality (AR) and Virtual Reality (VR):** AR and VR technologies enable immersive visualisation and simulation experiences in healthcare, and can be applied to enhance medical training, surgical planning, and patient education.[86]
- **Robotics and Automation:** These technologies automate repetitive tasks, and can assist with surgical procedures, and enhance patient care. Automation solutions streamline administrative tasks, medication management, and laboratory workflows, improving efficiency and reducing human error.[87]
- **Genomics and Precision Medicine:** Genomics technologies, such as next-generation sequencing and genetic testing, provide insights into individuals' genetic makeup and susceptibility to diseases, and support personalised treatment plans tailored to patients' unique genetic profiles.[88]

[82]Okafor, I., & Bayo, A. (2022) "AI-Driven Healthcare Solutions: Transforming Patient Care in Africa" African Journal of Health Innovations, 13(1), 60-75

[83]Iroha, E., & Nwogu, C. (2022) "Artificial intelligence for improving health service delivery in Sub-Saharan Africa: Barriers and solutions." Journal of Health Informatics in Africa, 9(1), 49-56. https://doi.org/10.12860/jhia.2022.04

[84]Chukwuneke, F. N., & Nwokolo, C. (2023) "The potential of AI-driven diagnostic tools in enhancing healthcare outcomes in Africa." African Journal of Health Informatics, 15(2), 123-132. https://doi.org/10.4314/ajhi.v15i2.9

[85]Ayo, C. K., & Otunla, O. (2022) Leveraging AI for Improved Health Systems in Sub-Saharan Africa. Health Policy and Technology, 11(2), 100607. doi:10.1016/j.hlpt.2022.100607

[86]Makhuba, T., & Shokunbi, W. (2022) "The adoption of artificial intelligence in Kenyan healthcare: Opportunities, challenges, and recommendations." East African Medical Journal, 99(7), 671-678. https://doi.org/10.4314/eamj.v99i7.10

[87]Njeru, E. K., & Karanja, R. (2023) "Transforming healthcare in Africa through artificial intelligence: A review of recent innovations" African Journal of Health Science, 9(1), 13-22. https://doi.org/10.4314/ajhs.v9i1.2

[88]Ugbeye, J., & Olatunji, S. (2023) "The impact of AI on healthcare delivery in West Africa: A systematic analysis" Journal of Health Services Research and Policy, 28(1), 4-12 https://doi.org/10.1177/1355819622111723

- **Data Analytics and Business Intelligence:** Data analytics tools and business intelligence platforms help healthcare organisations to analyse large datasets, identify trends, and derive actionable insights to support strategic decision-making and improve operational efficiency.[89]

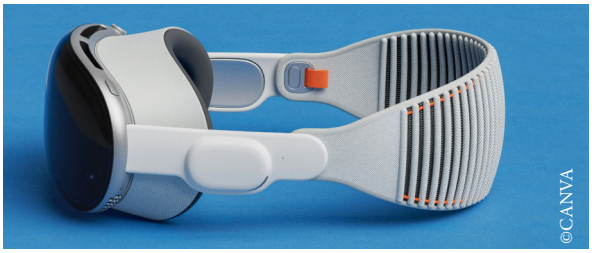
2.5 Human Resource Needs for AI Application in Healthcare Systems in Africa

The field of AI is rapidly evolving, and professionals in Africa working in healthcare need to continuously update their skills, stay informed about the latest developments, and adapt to changing trends and practices in the industry.[90] There are several skills gaps that need to be addressed in order to effectively apply AI in the healthcare system in Africa. These include the following:

- Shortage of professionals with expertise in artificial intelligence, machine learning, data science, and related fields in many African countries.
- Limited availability of healthcare professionals with data management skills to collect, clean, analyse, and interpret healthcare data. Professionals need to be proficient in data processing, data visualisation, and data governance to leverage the full potential of AI technologies in healthcare.[91]
- Few healthcare professionals with interdisciplinary skills, to bridge the gap between technical expertise and domain knowledge in healthcare. This is important as AI applications in healthcare often require collaboration between healthcare professionals, data scientists, computer scientists, and other experts.
- Inadequate understanding among some professionals about ethical principles for decision-making, regulatory compliance, and risk management, data privacy regulations, and healthcare policies, to ensure the responsible and ethical use of AI technologies.[92]
- Poor communication skills among some health professionals, which may hinder efforts to promote understanding, trust, and acceptance of AI technologies in healthcare.

2.6 Challenges in Harnessing AI Application in the Health System in Africa

While there are significant opportunities for harnessing AI applications in the health system in Africa, there are also several challenges that need to be addressed for the



continent to fully realise the technology's full potential. They include the following:

- **Limited infrastructure:** Many countries in Africa face challenges related to limited infrastructure, including reliable electricity, internet connectivity, and healthcare facilities.
- **Fragmented health data systems:** In many African countries, health data systems are fragmented, or have incomplete or inaccurate data. There is also limited interoperability between the different data systems.[93]
- **Shortage of skilled professionals:** There is a shortage of skilled professionals in Africa, such as data scientists, AI experts, and healthcare professionals with knowledge of AI applications.
- **Lack clear regulatory frameworks:** Many African countries lack clear regulatory frameworks for AI in healthcare, raising concerns about how data protection, and patient privacy is assured, and concerns about ethical use of AI technologies.[94]
- **Cultural beliefs and societal norms:** Cultural beliefs, societal norms, and perceptions about AI is influencing acceptance and adoption of AI technologies in healthcare in Africa.
- **Integration:** Integrating AI applications into existing healthcare systems and processes can be challenging due to interoperability issues, legacy systems, and siloed data systems.

2.7 Ethical and Socio-Cultural Considerations in the Application of AI in the Health System in Africa

Application of AI in the health system in Africa requires several social considerations, to ensure equitable, and culturally sensitive implementation. They include the following:

[89]Kivung, D. R., & Wamunyokoli, F. W. (2023) "AI ethics in healthcare: Perspectives from Africa." African Journal of Ethics in Health, 4(1), 15-29. https://doi.org/10.26525/ajeh.v4i1.4

[90]Shuaib, W., & Khamis, M. (2024) Artificial Intelligence as a Catalyst for Health System Strengthening in Africa: Perspectives from Stakeholders. Health Systems & Reform, 10(1), e22909 doi:10.1080/23288604.2023.22900

[91]Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." Journal of Health Ethics, 3(1),

[92]Shuaib, W., & Khamis, M. (2024) Artificial Intelligence as a Catalyst for Health System Strengthening in Africa: Perspectives from Stakeholders. Health Systems & Reform, 10(1), e22909 doi:10.1080/23288604.2023.22900

[93]Okafor, I., & Bayo, A. (2022) "AI-Driven Healthcare Solutions: Transforming Patient Care in Africa" African Journal of Health Innovations, 13(1), 60-75

[94]Iroha, E., & Nwogu, C. (2022) "Artificial intelligence for improving health service delivery in Sub-Saharan Africa: Barriers and solutions." Journal of Health Informatics in Africa, 9(1), 49-56. https://doi.org/10.12860/jhia.2022.04

- **Disparities in healthcare access:** In many African countries, there are disparities in access to healthcare, based on factors such as geography, socioeconomic status, and gender. It is essential to design AI solutions that address these disparities and ensure that all populations have equal access to AI-driven healthcare services.
- **Cultural sensitivities:** Cultural beliefs, practices, and norms play a significant role in decision-making around healthcare and treatment preferences in African societies. When applying AI technologies in healthcare settings, it is crucial to consider cultural sensitivities and to tailor AI solutions to align with local customs and beliefs.[95]
- **Patient protection and data security:** It is important to consider the protection of patient information and data security in the application of AI in healthcare. In AI-driven health systems, there is a need to establish robust data protection mechanisms, secure data storage practices, and transparent data sharing protocols to safeguard patient information.
- **Patients' informed consent:** Informed consent is a fundamental ethical principle in healthcare that ensures patients have the right to make informed decisions about their care. When using AI technologies in healthcare, it is essential to obtain informed consent from patients for data collection, analysis, and treatment recommendations.[96]
- **Accountability and governance:** Clear accountability mechanisms and governance structures are essential to ensure responsible and ethical use of AI in healthcare. Having guidelines, standards, and regulations as well as mechanisms for monitoring and evaluation will promote transparency and ethical conduct in the application of AI in the health system.

2.8 Public Policy Recommendations to Harness Application of AI in the Healthcare

To harness the full potential of AI in the healthcare system in Africa, several public policy recommendations can be considered, including the following:

- Develop a comprehensive regulatory framework that governs the use of AI technologies in healthcare, including guidelines for data privacy, security, transparency, and accountability.[97]
- Establish regulatory bodies or agencies to oversee the implementation of AI in healthcare.
- Invest in training programmes and capacity-building initiatives to enhance the knowledge and skills of healthcare professionals, data scientists, and AI developers in the application of AI technologies in healthcare.
- Improve data infrastructure and interoperability standards to facilitate the collection, sharing, and analysis of healthcare data for AI applications. Develop data governance frameworks that support data-driven decision-making in healthcare services.[98]
- Foster partnerships between the public sector, private industry, and civil society, to leverage resources, expertise, and technology in the development and deployment of AI solutions in healthcare.[99]
- Develop and promote ethical guidelines, principles, and standards for the responsible and ethical use of AI in healthcare. Raise awareness about the importance of ethical considerations and engage stakeholders in discussions on ethical issues related to AI in healthcare.
- Establish mechanisms for monitoring and evaluating the impact of AI technologies on health outcomes, patient care, and health system performance.[100] Conduct regular assessments of AI systems to ensure they meet quality standards.

> "Having guidelines, standards, and regulations as well as mechanisms for monitoring and evaluation will promote transparency and ethical conduct in the application of AI in the health system."

[95]Kivung, D. R., & Wamunyokoli, F. W. (2023) "AI ethics in healthcare: Perspectives from Africa." African Journal of Ethics in Health, 4(1), 15-29. https://doi.org/10.26525/ajeh.v4i1.4

[96]Makhuba, T., & Shokunbi, W. (2022) "The adoption of artificial intelligence in Kenyan healthcare: Opportunities, challenges, and recommendations." East African Medical Journal, 99(7), 671-678. https://doi.org/10.4314/eamj.v99i7.10

[97]Kivung, D. R., & Wamunyokoli, F. W. (2023) "AI ethics in healthcare: Perspectives from Africa." African Journal of Ethics in Health, 4(1), 15-29. https://doi.org/10.26525/ajeh.v4i1.4

[98]Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." Journal of Health Ethics, 3(1)

[99]Kamara, M., & Kanu, R. (2024) "Integrating AI into Primary Healthcare Systems in Africa." International Journal of Healthcare Delivery, 17(2), 155-172

[100]Njeru, E. K., & Karanja, R. (2023) "Transforming healthcare in Africa through artificial intelligence: A review of recent innovations" African Journal of Health Science, 9(1), 13-22. https://doi.org/10.4314/ajhs.v9i1.2

2.9 Priority Research Areas on AI in Healthcare in Africa

Priority research and development areas on AI in the healthcare systems in Africa include the following:

- AI tools in early detection and diagnosis of infectious diseases such as malaria, HIV/AIDS, tuberculosis, and emerging diseases like Ebola and COVID-19
- AI tools in the management and treatment of chronic diseases such as diabetes, hypertension, and cancer[101]
- Using AI in medical imaging (X-rays, CT scans, MRIs) to aid in the diagnosis of conditions such as pneumonia, cancers, and fractures
- AI-powered wearable devices for continuous health monitoring and early warning systems for various health conditions
- AI systems in the management of health records for better patient care, predictive analytics, and health trends identification
- AI in the discovery and development of new drugs, particularly for diseases prevalent in Africa
- AI-based early warning systems operating in tandem with traditional surveillance systems to provide an earlier trigger for investigation of potential outbreaks especially infectious disease outbreaks

2.10 Conclusion

The application of AI in healthcare in Africa is a dynamic landscape marked by both disparities and promising innovations. Integration of the technology into healthcare practices has demonstrated transformative potential, reshaping patient care, diagnostics, and healthcare accessibility.[102] The different stages of development in African countries underscore the importance of considering contextual factors in addressing diverse healthcare needs, and the need for scalable and culturally sensitive AI applications.

AI in the healthcare sector offers opportunities to expand access to services across all levels of care on the African continent. Advances in the technology have the potential to transform many aspects of healthcare, creating a future where health is more personalised, precise, predictive and portable. To achieve this potential, African countries need targeted strategies, laws, and policies to guide the application of AI and to protect users.[103] They also need AI solutions tailored to the local context, collaborations with international partners, investment in innovations, and local capacity building.

While the path to integrating artificial intelligence in healthcare in Africa is complex and multifaceted, the benefits it promises are significant. Strategic harnessing of AI can lead to improved health outcomes, increased efficiency, and ultimately, a more equitable healthcare landscape for all,[104] impacting patients' lives and enhancing the performance of healthcare systems.[105] Through collaborative efforts, prioritising ethical considerations, and tailoring solutions to the unique needs of diverse healthcare ecosystems, Africa can contribute to a more equitable and globally connected future for AI in healthcare. Concerted efforts to harness the potential of AI will lead to the betterment of healthcare, ensuring that technological advancements benefit all Africans.

[101]Shuaib, W., & Khamis, M. (2024) Artificial Intelligence as a Catalyst for Health System Strengthening in Africa: Perspectives from Stakeholders. Health Systems & Reform, 10(1), e22909 doi:10.1080/23288604.2023.22900

[102]Kivung, D. R., & Wamunyokoli, F. W. (2023) "AI ethics in healthcare: Perspectives from Africa." African Journal of Ethics in Health, 4(1), 15-29. https://doi.org/10.26525/ajeh.v4i1.4

[103]Shuaib, W., & Khamis, M. (2024) Artificial Intelligence as a Catalyst for Health System Strengthening in Africa: Perspectives from Stakeholders. Health Systems & Reform,

[104]Chukwuneke, F. N., & Nwokolo, C. (2023) "The potential of AI-driven diagnostic tools in enhancing healthcare outcomes in Africa." African Journal of Health Informatics, 15(2), 123-132. https://doi.org/10.4314/ajhi.v15i2.9

[105]African Union High Level Panel on emerging Technologies (2018) Blockchain: Technology Report on Powering the African Vision: Blockchain Technology for Africa's Transformative Governance

Harnessing Blockchain Technology for Healthcare Delivery in Africa

3

Harnessing Blockchain Technology for Healthcare Delivery in Africa

3.1 Background

Blockchain is a decentralised digital ledger that saves individual records as unique data elements, known as blocks, which can be identified and traced across multiple computers. The key features of blockchain include data integrity, security, immutability and transparency, which are enhanced through advanced cryptographic techniques. Each element is linked to the previous one in a chronological chain, hence the name "blockchain".[106] This technology allows for the secure and transparent recording of data, making it ideal for applications where trust and transparency are crucial, such as the healthcare sector where patient data is stored, transferred and managed to be traceable and to remain unadulterated.

Blockchain technology ensures the integrity and security of the management of health data by making it difficult for any single entity to alter the information without the consensus of the chain network.[107] The decentralised nature of the technology has the potential to revolutionise the health industry in Africa, by supporting ethical data management and optimising emerging technologies for socio-economic development.[108]

Early adoption of blockchain technology will address the following challenges in the African healthcare system:

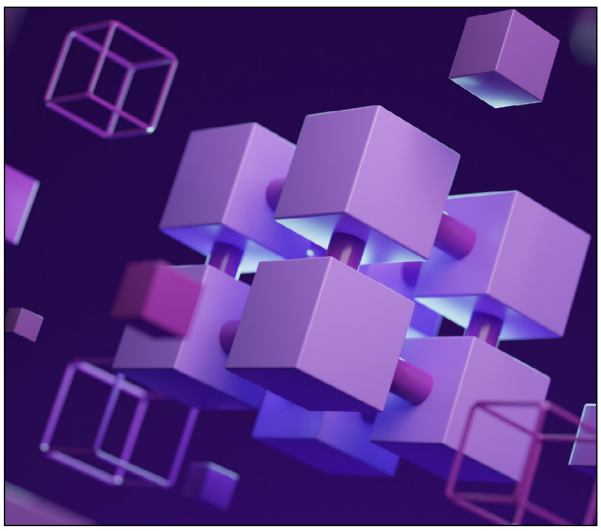
- Fragmented Data Systems: Having multiple, non-integrated record-keeping systems make it difficult to access and share patient information across facilities.
- Counterfeit Pharmaceuticals: Africa has one of the highest rates of counterfeit drugs, which not only pose health risks but also undermine trust in healthcare systems.
- Limited Quality Health Data: Data duplication and alterations often lead to breach of data ethics and affect the overall quality of data produced and the reports generated from it.

African countries that have employed blockchain technology have harnessed many opportunities through its application. The technology has been successfully used to resolve difficulties in handling patients' private data and sharing medical information between institutions securely. This has catalysed the general adoption of digitisation in the healthcare sectors.[109] This demonstrates the unprecedented demands for blockchain technology and the benefits that its early adoption would have on improving healthcare in Africa.

3.2 Application of Blockchain Technology in Healthcare Delivery

Blockchain technology has been applied in various ways to address challenges in the healthcare system in Africa, including the following:

- Improving the management of patient health records by ensuring secure and interoperable data sharing across healthcare providers.[110]
- Tracking the entire supply chain of drugs from manufacturer to patient, thus ensuring transparency and reducing the risk of counterfeit medicines entering the market.



[106]Alhassan, I., & Obaid, A. (2024) Blockchain-Enabled Health Data Management: Innovations for Africa's Healthcare Challenges. International Journal of Medical Informatics, 173, 105085. doi:10.1016/j.ijmedinf.2024.105085

[107]Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." Journal of Health Ethics, 3(1)

[108]Seriki, S. M., & Adegoke, A. A. (2024) Blockchain Technology for Health Data Security in African Countries: Challenges and Perspectives. Journal of Global Health Reports, 8, e2024004. doi:10.29392/001c.19665

[109]Seriki, S. M., & Adegoke, A. A. (2024) Blockchain Technology for Health Data Security in African Countries: Challenges and Perspectives. Journal of Global Health Reports, 8, e2024004. doi:10.29392/001c.19665

[110]Mlambo, T., & Zongwe, S. T. (2022) Blockchain Applications in Health Systems: The African Context. BMC Health Services Research, 22, doi:10.1186/s12913-021-07440-9

- Supporting telemedicine platforms, by securely storing patient data and facilitating payment transactions in a transparent and traceable manner.[111]
- Streamlining health insurance processes by automating claims processing, reducing administrative costs, and minimising fraud.
- Enhancing disease surveillance efforts by securely collecting and sharing epidemiological data in real-time.
- Facilitating the donation and distribution of medical supplies and equipment and ensuring transparency in donation tracking and delivery to healthcare facilities, particularly during emergencies or humanitarian crises.[112]

3.3 Examples of Blockchain Technology Application in Healthcare in Africa

In applying blockchain technology, it is crucial to analyse its strengths and weaknesses in real time contexts.[113] The following case studies highlight the adoption of blockchain technologies in practice in the African healthcare systems.

- **Patient Data Management in Tanzania** - AIDTech and PharmAccess Foundation: The AIDTech and PharmAccess Foundation collaboration in Tanzania aims to enhance maternal healthcare services through secure, blockchain-based data management.[114] Stakeholders involved in its implementation include local healthcare providers, and pregnant women enrolled in the programme. The project has led to enhanced medical access and care, increased data security, and improved health outcomes for mothers and infants. Some of the challenges faced include initial resistance to blockchain technology by healthcare workers, and lack of digital infrastructure in remote areas.
- **Drug Traceability in Uganda** – MediConnect: MediConnect works in Uganda to enhance the traceability of drugs and medical supplies using blockchain technology, to reduce counterfeit medications and improve overall healthcare delivery efficiency.[115] The platform uses blockchain to securely track and verify each step of the pharmaceutical supply chain, from manufacture to patient delivery. It assigns a unique digital identifier to each batch of medications. Every transaction is recorded on the blockchain, providing an immutable and transparent record. The project has resulted in a significant decrease in the circulation of counterfeit drugs, enhancing patient safety. Real-time tracking of drugs reduces losses and thefts, ensuring medications reach the intended recipients. Using blockchain also allows for easier auditing and compliance monitoring by health authorities, streamlining regulatory processes. Some of the challenges the project has experienced include difficulties in integrating the blockchain system with existing supply chain management tools, and supply chain staff who have limited familiarity with blockchain technology.

The project has led to enhanced medical access and care, increased data security, and improved health outcomes for mothers and infants. Some of the challenges faced include initial resistance to blockchain technology by healthcare workers, and lack of digital infrastructure in remote areas.

3.4 Complementary Technologies to Blockchain Technology in the Healthcare

Blockchain technology can significantly enhance the efficiency, security, and transparency of healthcare systems when combined with complementary technologies.[116] These include the following:

- **Internet of Things (IoT) devices**, such as wearable health monitors, smart medical devices, and sensors, can collect real-time patient data, which can be securely recorded on a blockchain.
- **Artificial Intelligence (AI) and Machine Learning (ML)** algorithms can analyse large datasets stored on blockchain to identify patterns, predict outcomes, and improve clinical decision-making.

[111]Tschider, C. A., & Rachael, D. (2023) "Blockchain technology and its impact on health security in Africa: A critical analysis." International Journal of Healthcare Technology and Management, 15(2), 109-123. https://doi.org/10.1504/IJHTM.2023.123456

[112]Ogundipe, A., & Tugbiyele, I. (2023) The Use of Blockchain in Preventing Health Fraud in African Healthcare Systems. Journal of Health Economics and Outcomes Research, 11(1), 32-40. doi:10.1177/20500683221029316

[113]Fatima, F., & Ojo, O. (2022) Blockchain Technology and Public Health in Africa: A Systematic Review. Journal of Global Health, 12, 04007. doi:10.7189/jogh.12.04007

[114]Osei-Tutu, E., & Nkrumah, E. (2023) "How blockchain can reshape healthcare in Africa: Innovations and challenges." Health Policy and Technology, 12(1), 1-11. https://doi.org/10.1016/j.hlpt.2022.100661

[115]African Union High Level Panel on emerging Technologies (2018) Blockchain: Technology Report on Powering the African Vision: Blockchain Technology for Africa's Transformative Governance

[116]Choi, Y. J., & Kamal, N. A. (2020) Using Blockchain to Improve Health Systems in Sub-Saharan Africa: A Review of Applications and Barriers. Blockchain in Health Journal,

- **Big data analytics tools** can process and analyse vast amounts of healthcare data stored on a blockchain to derive meaningful insights.
- **Cloud platforms** can provide scalable and secure storage solutions for blockchain-based healthcare applications.
- **Interoperability standards and protocols**, such as HL7 (Health Level Seven) and FHIR (Fast Healthcare Interoperability Resources), facilitate seamless data exchange between different healthcare systems and blockchain networks. This interoperability enhances care coordination and patient outcomes.[117]
- **Mobile applications and telemedicine** platforms can integrate with blockchain to enable secure patient-provider communication, remote consultations, and medication adherence monitoring.
- **Biometric authentication technologies**, such as fingerprint scanning and facial recognition, can enhance identity verification and access control for blockchain-based healthcare applications.
- **Progressive Innovation:** Combining AI with blockchain to create more intelligent data analysis tools that can automatically detect patterns and make recommendations for patient care management.[118]
- **Real Time Data Collection & Server Updates:** Integration of IoT devices with blockchain for real-time monitoring of patient vitals, securely updating patient records on the blockchain, and ensuring data integrity across remote monitoring devices.[119]

3.5 Human Resource Needs for Application of Blockchain Technology in Healthcare Services

The range of human resources skills required for implementing blockchain technology in public health in Africa include the following:

- **Skilled blockchain developers:** To design, develop, and maintain blockchain solutions tailored to healthcare applications. They should have expertise in blockchain platforms (e.g., Ethereum, Hyperledger) and smart contract development, as well as knowledge of healthcare data standards and privacy regulations.[120]
- **Data scientists:** To analyse large datasets stored on blockchain for insights that can improve clinical decision-making, population health management, and public health interventions.[121]
- **Cybersecurity specialists:** To design and implement robust security measures for blockchain-based healthcare solutions.
- **Professionals with knowledge of healthcare regulations and policies:** To navigate regulatory frameworks governing the use of blockchain in healthcare.
- **Experienced project managers:** To oversee the planning, implementation, and evaluation of blockchain projects in healthcare. To coordinate cross-functional teams, manage project timelines and budgets, and ensure that project goals align with organisational objectives and stakeholder expectations.
- **Educators and trainers:** To develop and deliver training programmes on blockchain technology for healthcare professionals. To build awareness, enhance skills, and foster a culture of innovation and continuous learning within healthcare organisations.[122]

> Mobile applications and telemedicine platforms can integrate with blockchain to enable secure patient-provider communication, remote consultations, and medication adherence monitoring.

[117]Gachanja, D., & Mukhwana, M. (2022) "Blockchain technology: A revolutionary approach to enhancing healthcare in Africa" Journal of Medical Internet Research, 24(5)

[118]Osei-Tutu, E., & Nkrumah, E. (2023) "How blockchain can reshape healthcare in Africa: Innovations and challenges." Health Policy and Technology, 12(1)

[119]Oduor, J., & Ogutu, J. (2022) "Enhancing trust in healthcare delivery through blockchain technology in sub-Saharan Africa." Journal of Global Health Reports, 6, e2022017. https://doi.org/10.29392/001c.21705

[120]Iyiola, O., & ntuale, P. (2024) Blockchain Solutions for Supply Chain Management in African Healthcare Systems: Current Perspectives and Future Directions. Journal of Supply Chain Management in Health, 8(1), 61-78. doi:10.1007/s40852-024-00320-3

[121]Fabi, M. S., & Anis, V. (2023) Decentralized Health Records: The Promise of Blockchain in Africa's Healthcare Delivery. Journal of Health Management, 25(1), 45-57. doi:10.1177/09720634221105545

[122]African Union High Level Panel on emerging Technologies (2018) Blockchain: Technology Report on Powering the African Vision: Blockchain Technology for Africa's Transformative Governance

- **Professionals specialising in ethics, law, and healthcare policy:** To provide guidance on ethical considerations, legal implications, and patient consent requirements related to blockchain-based healthcare applications.[123]

3.6 Ethical and Socio-Cultural Considerations in the Application of Blockchain Technology in Health

The application of blockchain technology in the health system in Africa requires careful consideration of socio-cultural factors to ensure acceptance, effectiveness, and sustainability. Some of the ethical and socio-cultural considerations include the following:

- **Scepticism towards new technologies:** In many African communities, there may be scepticism or lack of trust towards new technologies, including blockchain. Building awareness, maintaining transparency, and demonstrating tangible benefits of blockchain solutions is essential to gain acceptance.
- **Concerns over health information:** Socio-cultural norms around data ownership and control vary across Africa. Communities may have strong preferences for personal data privacy and control over health information.[124]
- **Digital health literacy:** Levels of health literacy and awareness about digital technologies vary widely across Africa. Ensuring that blockchain applications are user-friendly, culturally relevant, and accessible in local languages can enhance adoption among healthcare providers and patients.
- **Community engagement:** Involving local communities in the design, implementation, and governance of blockchain initiatives fosters trust, inclusivity, and sustainability. Engaging community leaders, healthcare workers, and patients in decision-making processes can address socio-cultural concerns and ensure that solutions meet local needs.
- **Cultural diversity:** In many African societies, traditional healing practices coexist with modern healthcare systems. Integrating blockchain technology into healthcare should respect and accommodate cultural diversity, including the role of traditional healers and community health workers, to ensure holistic and patient-centred care.[125]
- **Gender roles and norms:** Gender roles and norms influence health-seeking behaviours and access to healthcare services. Blockchain initiatives should consider gender-sensitive approaches to ensure equitable access and benefit-sharing, addressing potential disparities in healthcare access and outcomes.
- **Regulatory and policy requirements:** Socio-cultural factors also intersect with regulatory and policy environments. Developing inclusive regulatory frameworks that accommodate blockchain innovations while protecting patient rights and promoting equity is essential for sustainable implementation.

3.7 Challenges in Adopting Blockchain in African Healthcare Systems

- Integrating blockchain with existing healthcare IT systems can be challenging due to compatibility issues with existing systems and the technical limitations of legacy systems.
- Some blockchain models, particularly those based on proof-of-work, require significant energy to handle large volumes of data typical in healthcare settings without compromising performance. This raises concerns on their sustainability due to limited power infrastructure and energy supply in Africa.[126]
- While blockchain offers enhanced security, the immutable nature of blockchain can complicate compliance with data protection laws that include rights to amendment or deletion of personal data.

3.8 Priority Research Areas in the Development and Application of Blockchain Technologies in Public Health

Priority areas in research to advance the application of blockchain technology in health in Africa include the following:

- Investigations into interoperability standards and protocols that facilitate seamless integration of blockchain with existing healthcare IT systems.
- Optimising blockchain architectures, consensus algorithms, and network protocols to enhance scalability and performance in healthcare applications, ensuring efficient data management and transaction processing.[127]

[123]Oduor, J., & Ogutu, J. (2022) "Enhancing trust in healthcare delivery through blockchain technology in sub-Saharan Africa." Journal of Global Health Reports, 6, e2022017. https://doi.org/10.29392/001c.21705

[124]Fabi, M. S., & Anis, V. (2023) Decentralized Health Records: The Promise of Blockchain in Africa's Healthcare Delivery. Journal of Health Management, 25(1), 45-57. doi:10.1177/09720634221105545

[125]Mlambo, T., & Zongwe, S. T. (2022) Blockchain Applications in Health Systems: The African Context. BMC Health Services Research, 22, doi:10.1186/s12913-021-07440-9

[126]Osei-Tutu, E., & Nkrumah, E. (2023) "How blockchain can reshape healthcare in Africa: Innovations and challenges." Health Policy and Technology, 12(1), 1-11. https://doi.org/10.1016/j.hlpt.2022.100661

[127]Tschider, C. A., & Rachael, D. (2023) "Blockchain technology and its impact on health security in Africa: A critical analysis." International Journal of Healthcare Technology and Management, 15(2), 109-123. https://doi.org/10.1504/IJHTM.2023.123456

- Investigations into the use of blockchain technology for enhancing public health surveillance, disease tracking, and epidemiological data management in Africa.
- Studies on the use of smart contracts in automating and enforcing healthcare operations, such as insurance claims processing, healthcare supply chain management, and regulatory compliance.
- Studies on blockchain applications in healthcare financing, including transparent and secure payment systems, micro-insurance platforms, and crowdfunding for healthcare initiatives.
- Developing regulatory frameworks and policy guidelines that support the responsible adoption and governance of blockchain technology in African healthcare systems.[128]
- Exploring blockchain's potential in improving transparency, data integrity, and participant consent management in medical research and clinical trials.

3.9 Policy Recommendations to Promote Use of Blockchain Technology in Healthcare in Africa

To facilitate the application of blockchain technology in health systems, African countries should consider implementing the following actions:

- Establish clear and supportive regulatory frameworks that provide legal certainty and guidelines on the use of blockchain in healthcare. Work with regulatory bodies to craft guidelines specific to blockchain in healthcare, covering aspects from data security to ethical considerations of patient data handling.
- Encourage the development and adoption of interoperability standards and protocols that facilitate seamless integration of blockchain with existing healthcare IT systems. Advocate for the standardisation of blockchain protocols within healthcare to ensure compatibility and interoperability across various systems and borders.
- Allocate resources and investments to improve digital infrastructure, including internet connectivity, cloud computing capabilities, and cybersecurity measures.[129]
- Provide education and training to build technical expertise and awareness of blockchain technology among healthcare professionals, researchers, policymakers, and IT professionals.
- Facilitate collaboration and partnerships between government agencies, healthcare providers, technology developers, academic institutions, and private sector stakeholders.
- Incorporate ethical guidelines, patient rights protections, and data privacy principles into blockchain healthcare initiatives.[130]
- Evaluate the technology impact on healthcare outcomes, patient satisfaction, cost-effectiveness, and system efficiency to inform policy decisions, scale successful models, and address implementation challenges.
- Foster regional collaboration and knowledge sharing among African countries to leverage economies of scale, share best practices, and address common challenges in adopting blockchain technology in healthcare.[131]
- Ensure that blockchain implementations comply with international health data regulations and ethical standards to maintain trust and legality.[132]
- Establish regular audits of blockchain systems to ensure they meet ethical standards and regulatory compliance, adapting to new legal landscapes as they evolve.

3.10 Conclusion

Harnessing blockchain technology in healthcare presents a transformative opportunity for Africa, a continent facing unique challenges in health service delivery, data management, and infrastructure.[133] Blockchain technology can address critical issues such as medical record security, supply chain transparency, and interoperability across health systems.[134] Through the creation of immutable patient records, blockchain can facilitate seamless sharing of health information among providers while protecting patient privacy. The technology can secure the transfer of patient's medical records between hospitals, strengthen healthcare data defences and manage the medicine supply chain, reducing the illegal trading of medical products, counterfeit drugs, and corruption.

The use of blockchain increases accountability and transparency of recorded health information and creates a common source of truth, identity, authentication, and verification. By leveraging blockchain's inherent qualities, such as decentralisation, transparency, and security, African healthcare systems can enhance data integrity, improve patient access to information, and foster trust among stakeholders.[135] As the continent invests in digital health innovations, embracing blockchain could be a pivotal step toward overcoming existing barriers and achieving equitable and reliable healthcare solutions.

[128]Fabi, M. S., & Anis, V. (2023) Decentralized Health Records: The Promise of Blockchain in Africa's Healthcare Delivery. Journal of Health Management, 25(1), 45-57.

[129]Choi, Y. J., & Kamal, N. A. (2020) Using Blockchain to Improve Health Systems in Sub-Saharan Africa: A Review of Applications and Barriers. Blockchain in Health Journal, 2

[130]Abouelaziz, W., & Ibraheem, A. (2024) Blockchain Technology in Healthcare: Opportunities and Challenges in Africa. Journal of Healthcare Informatics Research, 8(1), 15-30

[131]African Union High Level Panel on emerging Technologies (2018) Blockchain: Technology Report on Powering the African Vision: Blockchain Technology for Africa's Transformative Governance

[132]Patel, R., & Mutua, D. (2021). Advancing Healthcare Delivery in Africa through Blockchain Technology. African Journal of Health Information, 8(1), 34-42.

[133]African Union High Level Panel on emerging Technologies (2018) Blockchain: Technology Report on Powering the African Vision: Blockchain Technology for Africa's Transformative Governance

[134]Boudjemaa, R., & Murwa, W. (2024) Blockchain Adoption in African Healthcare: Barriers and Drivers to Implementation. Health Policy and Technology, 13(1), 100050. doi:10.1016/j.hlpt.2023.100050

[135]Alhassan, I., & Ofori, A. (2020) IoMT: A New Paradigm for Healthcare Delivery in Rural Africa. Journal of Global Health Reports, 4

Application of Internet of Medical Things in Healthcare Services in Africa

4

Application of Internet of Medical Things in Healthcare Services in Africa

4.1 Background

The Internet of Things technology (IoT) is a fast-growing area of computing, applicable to almost all human endeavours. IoMT refers to a network of interconnected medical devices and systems, such as wearable fitness trackers, remote patient monitoring devices, medical sensors, and other medical equipment, which collect and transmit patient data to healthcare providers and other stakeholders in real-time.

IoMT can help to improve healthcare delivery, efficiency, and patient outcomes in Africa by supporting continuous monitoring, timely interventions, and personalised treatment plans, based on the data gathered from these devices.[136] This chapter provides an overview of current technologies in healthcare and how IoMT devices are improving health service delivery. It outlines how IoMT technologies can help improve healthcare outcomes on the African continent. The chapter also discusses the potential issues that IoMT healthcare generates, such as barriers to adoption from healthcare professionals and patients alike, confidence and acceptability, privacy and security, interoperability, standardisation and remuneration, data storage, and presents policy recommendations for relevant stakeholders.

4.2 Application of IoMT in Healthcare

IoMT has vast applications in healthcare, such as enhancing patient care, improving diagnosis, and streamlining clinical operations. Some key applications include the following:

- **Continuous monitoring of patients:** IoMT enables continuous monitoring of patients outside traditional clinical settings, such as in the home. Wearable devices like smartwatches, glucose monitors, and heart rate monitors collect real-time data on vital signs, physical activity, and other health metrics.
- **Assisting patients manage chronic conditions:** IoMT devices enable patients with chronic conditions, such as diabetes, hypertension, and heart disease, to manage and track their health more effectively. For example, connected glucometers can automatically log blood sugar levels and share the data with healthcare providers, ensuring timely adjustments to treatment.
- **Supporting diagnosis and personalised treatment:** IoMT devices can help diagnose conditions by collecting and analysing a wide range of health data. Smart imaging devices, for example, can capture high-resolution images and use AI to detect abnormalities. IoMT can also support personalised treatment plans by providing precise data on a patient's response to medication and therapy.[137]
- **Tracking medical supplies:** In hospitals, IoMT technology can track medical equipment and supplies, ensuring they are available when needed and reducing downtime. Adding Radio Frequency Identification (RFID) tags and sensors to equipment can provide real-time location information, maintenance status, and usage history. This improves operational efficiency and reduces costs.

IoMT devices can help diagnose conditions by collecting and analysing a wide range of health data. Smart imaging devices, for example, can capture high-resolution images and use AI to detect abnormalities.

[136]Mussa, I. M., & Zawadi, A. (2023) Adopting IoMT for Enhanced Maternal and Child Health in East Africa: A Comprehensive Overview. African Journal of Health Informatics, 7(2), 126-139. doi:10.4314/ajhi.v7i2.6

[137]Chibanda, D., & Chibanga, P. (2024) IoMT for Managing Chronic Diseases in Sub-Saharan Africa: Innovative Approaches and Research Directions. BMC Health Services Research, 24, 150. doi:10.1186/s12913-023-08021-9

- **Use in emergencies:** IoMT devices can provide critical health information to first responders during emergencies. Wearable devices or implanted sensors can transmit data about a patient's health status and medical history, allowing paramedics to make informed decisions and provide appropriate care enroute to the hospital.[138]
- **Advancing medical research:** The vast amount of data generated by IoMT devices can be analysed to identify trends, improve treatment protocols, and advance medical research. Big data analytics and machine learning can uncover insights from patient data, leading to better clinical outcomes and new discoveries in disease management.

4.3 Examples of use of Internet of Medical Things in Healthcare System in Africa

The following examples illustrate the increasing application of IoMT in healthcare in Africa:

- **Supporting CHPs' work:** D-tree leverages IoMT in Zanzibar through mHealth applications to support community health workers in diagnosing and managing childhood illnesses. These apps provide decision support, help to improve treatment adherence, and facilitate data collection for monitoring and evaluation.[139]
- **Saving for healthcare:** Mobile health wallet enable families and individuals to save and spend funds on healthcare services, thus improving access to healthcare financing, especially for low-income individuals.
- **Community health monitoring and data collection:** IoMT-enabled mobile applications like CommCare are used for community health monitoring and data collection. Community health workers use smartphones or tablets to record patient data, track immunisations, and monitor public health indicators, improving data accuracy and timeliness.[140]
- **Supporting early diagnosis:** The MamaOpe Smart Jacket designed in Uganda is a wearable device to aid in the early diagnosis of pneumonia in children. Equipped with sensors, the jacket monitors respiratory patterns and sounds, transmitting data via Bluetooth to a mobile app. Healthcare workers receive alerts for potential pneumonia cases, enabling early intervention and reducing mortality rates.[141]
- **Improving maternal health outcomes:** Various mHealth solutions are deployed across Africa to improve maternal health outcomes by enabling remote monitoring of pregnant women, facilitating timely interventions and reducing maternal and infant mortality rates. These solutions often include mobile apps that integrate with IoMT devices such as blood pressure monitors and foetal heart rate monitors.
- **Supporting logistics:** In Nigeria, solar-powered IoT devices are used to monitor the cold chain for vaccines. These devices track temperature and humidity conditions in vaccine storage facilities and send alerts if conditions deviate from recommended ranges.

4.4 Complementary Technologies to Internet of Medical Things in the Healthcare System

The following technologies complement IoMT devices to improve their application:

- **AI and Machine Learning:** Artificial Intelligence (AI) and Machine Learning (ML) algorithms, which analyse large datasets generated by IoMT devices to derive insights, make predictions, and improve clinical decision-making.
- **Big data analytics:** These technologies process and interpret vast amounts of data from IoMT devices, electronic health records (EHRs), and other sources. [142]
- **Blockchain:** Blockchain ensures secure and transparent data sharing and transactions among healthcare stakeholders.
- **Virtual Reality:** Augmented Reality (AR) and Virtual Reality (VR) technologies offer immersive experiences that support medical training, surgical planning, and patient education. They enable healthcare professionals to visualise complex medical data from IoMT devices in 3D, improving understanding and decision-making.
- **Robotics:** Robotics assist in surgical procedures, rehabilitation therapy, and repetitive tasks in healthcare settings. Combined with IoMT, robotic devices can monitor patient progress, adjust treatment regimens, and enhance the efficiency of healthcare delivery.[143]

[138]Akachi, Y., & Mofolorunsho, R. (2023) Exploring IoMT Applications for Universal Health Coverage in African Countries: Insights and Innovations. Journal of Health Management, 25(4), 455-466. doi:10.1177/09720634231145678

[139]Chibanda, D., & Chibanga, P. (2024) IoMT for Managing Chronic Diseases in Sub-Saharan Africa: Innovative Approaches and Research Directions. BMC Health Services Research, 24, 150. doi:10.1186/s12913-023-08021-9

[140]Nene, K., & Chime, N. (2022) The Future of IoMT and Healthcare in Africa: Challenges, Opportunities, and Innovations. Journal of Health Informatics in Africa, 9(4), 89-100. doi:10.18585/ijih.2022.16799

[141]Chibanda, D., & Chibanga, P. (2024) IoMT for Managing Chronic Diseases in Sub-Saharan Africa: Innovative Approaches and Research Directions. BMC Health Services Research, 24, 150. doi:10.1186/s12913-023-08021-9

[142]Nene, K., & Chime, N. (2022) The Future of IoMT and Healthcare in Africa: Challenges, Opportunities, and Innovations. Journal of Health Informatics in Africa, 9(4), 89-100. doi:10.18585/ijih.2022.16799

[143]Otunla, A., & Muda, R. F. (2024) IoMT Applications in Health Monitoring: A Case Study from West Africa. BMC Public Health, 24, 29.

- **Biometrics:** Biometric technologies such as fingerprint scanning and facial recognition enhance patient identification and authentication. They ensure secure access to medical records and IoMT devices, reducing errors and improving patient safety.
- **5G technology:** With its high-speed, low-latency capabilities, 5G technology is revolutionising healthcare by enabling faster, more reliable communication and data transfer. It supports advanced telemedicine services, allowing real-time consultations and remote monitoring with minimal lag.[144] 5G technology enhances the capabilities of IoMT devices, ensuring continuous, high-quality data streams from wearables and sensors for accurate, immediate analysis.

4.5 Human Resource Needs for Applying Internet of Medical Things in Public Health

The application of IoMT technologies in Africa is affected by several factors, including:

- **Shortage of healthcare professionals:** The successful application of IoMT requires professionals skilled in information technology, data analysis, and biomedical engineering. However, many African countries face a shortage of healthcare and data professionals, which can impede the effective utilisation of IoMT technologies. It is important to have interdisciplinary training programmes to bridge the gap between healthcare knowledge and technical expertise.[145]
- **Shortage of training programmes:** There is still a significant need for more comprehensive training programmes focused on IoMT and related technologies. Some universities and technical institutes in Africa are beginning to offer programmes and courses in health informatics, biomedical engineering, and related fields to build a skilled workforce.[146]
- **Partnerships:** Partnerships with tech companies such as IBM, Google, and Microsoft can advance the application of IoMT technologies by training healthcare workers and IT professionals in their use.
- **Communication skills:** Training is also required in ensuring clear and effective communication between technical and clinical teams to facilitate collaboration and problem-solving.

4.6 Ethical and Socio-Cultural Considerations in the Application of Internet of Medical Things in the Health System in Africa

To successfully apply IoMT technology in health systems in Africa, it is important to consider socio-cultural factors, including the following:

- **Local beliefs about health and illness:** Many communities in Africa rely on traditional medicine and healers. Understanding local beliefs about health and illness is important for designing IoMT solutions that are culturally sensitive and appropriate.
- **Involvement of local community:** Engaging local communities and leaders in the planning and implementation of IoMT projects helps build trust and ensures that solutions meet community needs. [147]
- **Digital literacy:** Improving digital literacy and raising awareness about IoMT technologies can help overcome resistance and enhance user adoption.
- **Local languages:** Ensuring that IoMT interfaces, instructions, and educational materials are available in local languages can improve accessibility and usability.
- **Culturally appropriate communication:** Using culturally appropriate communication strategies to convey information about IoMT can enhance understanding and acceptance.
- **Gender disparities:** Addressing gender disparities in access to healthcare and technology

[144]Umeokafor, U. M., & Okwor, A. (2023) Artificial Intelligence and IoMT: A New Horizon for Healthcare Delivery in Africa. Journal of Healthcare Engineering, 2023, 6781234. doi:10.1155/2023/6781234

[145]Gana, I. A., & Mba, A. (2024) Impact of Internet of Medical Things on Healthcare Outcomes in Africa: A Systematic Review. Journal of Global Health Reports, 9, e2024015. doi:10.29392/001c.19702

[146]Kamata, K. M., & Okeke, C. (2023) "Adoption of IoMT technologies in Africa: A framework for understanding "International Journal of Healthcare Technology and Management, 24(3), 181-196. https://doi.org/10.1504/IJHTM.2023.123456

[147]Tjokro, I. D., & Verhoeven, H. (2024) The Transformative Role of IoMT in African Health Systems: Insights from Recent Developments. International Journal of Healthcare Technology and Management, 23(1), 41-58. doi:10.1504/IJHTM.2024.10038362

is important to ensure that IoMT benefits are equitably distributed.[148] Designing IoMT solutions that specifically address women's health issues, such as maternal and child health, can improve health outcomes and acceptance.

4.7 Priority Research Areas in the Development and application of Internet of Medical Things in Public Healthcare Systems in Africa

The following are some of the areas research should focus on, to advance IoMT technology and its application in Africa:

- Studies on developing reliable power sources and solutions to improve internet connectivity, particularly in rural and underserved areas, to ensure uninterrupted operation of IoMT devices.
- Designing cost-effective IoMT devices tailored to the needs and economic conditions of African healthcare systems.
- Studies on seamless integration of IoMT devices and platforms with existing health information systems and electronic health records.
- Studying the ethical implications of IoMT use, including issues related to informed consent, patient autonomy, and data ownership.

> Many communities in Africa rely on traditional medicine and healers. Understanding local beliefs about health and illness is important for designing IoMT solutions that are culturally sensitive and appropriate.

- Standardising data formats and protocols to facilitate interoperability between different IoMT devices and healthcare information systems.[149]
- Studies on the clinical effectiveness of IoMT devices in improving healthcare outcomes, patient management, and treatment adherence.

4.8 Policy Recommendations to Promote Availability and Utilisation of Internet of Medical Things in the Healthcare System in Africa

To promote the availability and utilisation of the Internet of Medical Things (IoMT) in the healthcare system in Africa, policymakers can consider the following recommendations:

- Invest in improving internet and telecommunications infrastructure, particularly in rural and underserved areas, to ensure reliable connectivity for IoMT devices.[150]
- Develop and harmonise regulatory frameworks across African countries to streamline the approval and deployment of IoMT devices. This will ensure the devices' safety, quality, and interoperability.
- Invest in educational and training programmes to build the technical skills of healthcare professionals in using, maintaining and managing IoMT devices.[151]
- Promote research and development in IoMT technologies through partnerships with academic institutions, and collaboration with the private sector.[152]
- Encourage local innovation and the development of IoMT solutions tailored to the specific needs and contexts of African healthcare systems.
- Develop ethical guidelines for the use of IoMT in healthcare, to address issues such as data ownership, consent, and equitable access.
- Develop tools and mechanisms for monitoring and evaluating the impact of IoMT technologies on healthcare delivery, patient outcomes, and health system efficiency.

[148]Akachi, Y., & Mofolorunsho, R. (2023) Exploring IoMT Applications for Universal Health Coverage in African Countries: Insights and Innovations. Journal of Health Management, 25(4), 455-466. doi:10.1177/09720634231145678

[149]Eldin, K., & Saeed, F. (2023) Internet of Medical Things in Africa: Barriers to Adoption and Future Prospects. Journal of Health Informatics in Africa, 9(1), 32-44. doi:10.1191/17538157.2023.0034

[150]Adepoju, A. A., & Karim, R. (2024) Leveraging IoMT for Improved Disease Management in Africa: A Systematic Review. Journal of Medical Systems, 48, 15. doi:10.1007/s10916-024-01345-6

[151]Gbadamosi, O. I., & Akinboro, A. (2022) Future Directions for IoMT in Africa's Healthcare Ecosystem: Challenges and Opportunities. Journal of Medical Systems, 46, 109. doi:10.1007/s10916-022-01840-9

[152]Otunla, A., & Muda, R. F. (2024) IoMT Applications in Health Monitoring: A Case Study from West Africa. BMC Public Health, 24, 29.

4.9 Conclusion

Harnessing the use of IoMT in healthcare delivery presents a remarkable opportunity for Africa to advance health outcomes, enhance the efficiency of service delivery, and empower patients. African countries can position themselves to capitalise on the benefits of IoMT by addressing the existing challenges and fostering an ecosystem of innovation, ultimately leading to a more robust and equitable healthcare system that meets the needs of their populations.[153] A strategic, inclusive approach will be crucial in realising the full potential of IoMT in transforming healthcare delivery in Africa.

As the adoption of technology-supported health services continues, an increasing number of traditional health service delivery practices will be complemented or replaced by IoMT. However, despite its potential benefits, there is still need for more research on the IoMT technologies, the health system, and the users of IoMT technology. Future research should address how IoMT devices can be designed with standardised protocols and interoperability with international and cross-state health systems.[154]

More research is also needed on the efficiency of blockchain storage compared with centralised cloud-based storage solutions in the context of IoMT-supported healthcare delivery in Africa.

[153]Onuoha, U. C., & Enyiajulu, H. (2023) Exploring the Role of IoMT in Preventive Healthcare: Evidence from Africa. Journal of Community Health, 48(6), 1093-1102. doi:10.1007/s10900-023-01381-7

[154]Chukwuma, A. O., & Eze, N. A. (2022) Drones as a Tool for Healthcare Delivery in Africa: The Case of Medical Supply Distribution in Remote Areas. African Journal of Health Informatics, 6(1), 15-25. doi:10.4314/ajhi.v6i1.3

Use of Drones in Healthcare Delivery Systems in Africa

5

Use of Drones in Healthcare Delivery Systems in Africa

5.1 Background

Drones are conventionally referred to as unmanned aerial vehicles (UAVs) and unmanned aircraft systems (UAS). Historically, UAVs were previously mostly used by the military as a platform for weapons and for gathering information for military intelligence.[155] A drone is made up of a propulsion system, an air frame and navigation system, which consist of an extensive range of supporting equipment and aircraft layout settings that facilitates several application programmes.

In recent time, they have been employed in an extensive range of activities outside military roles, from surveillance, traffic and weather monitoring, search and rescue, firefighting, photography or videography, to agriculture and delivery services, as well as for personal and commercial purposes. However, its breakthrough in healthcare systems has been slow compared to other sectors, where drones have been used extensively.[156]

This technology has the capability to drive medical care and propel advancement in the health industry. They have broad application in medicine, ranging from the delivery of medicines, and emergency transport of blood products in maternal healthcare. In Africa, drones are already saving lives by delivering blood packets to remote villages. They were first used for medical delivery in Rwanda and Ghana by Zipline, an American company that designs, manufactures, and operates delivery drones. They are used to deliver life-saving blood, blood specimens, and medical supplies between medical facilities and hospitals.[157] They are used more in rural areas due to the lack of infrastructure for land transport. Many researchers have since then used Zipline as the primary reference for drone delivery in medical services.

The use of drones to transport blood products in the event of a clinical emergency has been compared with ambulances and shown to significantly shorten transport time.[158] Drones have been found to improve healthcare delivery through faster response times, reductions in transport costs, enhanced access to medical products and services in remote or underserved environments. However, some issues have been raised about this use of technology, including fears about invasion of privacy and concerns about safety. This chapter looks at the current and future applications of drones in health services in Africa, to create awareness on their importance.

5.2 Civilian Application of Drones in Africa

Drones have been successfully tested and implemented in various civilian applications across Africa. Some of the examples include the following:

- **Medical supplies logistics:** Drones have been used to transport medical supplies, vaccines, and diagnostic samples to remote and underserved areas in countries such as Rwanda, Malawi, and Ghana.[159]
- **Agriculture:** Drones are being used for crop monitoring, pest control, and mapping. For example, in Kenya and Nigeria, drones are used to monitor crop health, assess soil conditions, and optimise irrigation practices to improve agricultural productivity and food security.
- **Search and Rescue:** Drones have been used for search and rescue operations, damage assessment, and delivery of relief supplies in countries such as Mozambique, Uganda, and Somalia, where natural disasters like floods, earthquakes and droughts have occurred.[160]
- **Infrastructure inspection:** In South Africa and Nigeria, drones are used to inspect bridges, roads, pipelines, and power lines to identify maintenance needs, assess structural integrity, and improve infrastructure resilience.
- **Wildlife monitoring:** Drones are used for wildlife monitoring, anti-poaching efforts, and habitat conservation in national parks and protected areas across Africa. Conservation organisations in countries such as Kenya, Tanzania, Burkina

[155]Gama, A. R., & Mhlanga, C. (2024) Drones in Public Health: A Comprehensive Review of Applications and Impact in Africa. Journal of Global Health Reports, 8, e2024011

[156]African Union High Level Panel on Emerging Technologies (2018) Drones on the Horizon - Transforming Africa's Agriculture

[157]Okeke, T. A., & Iwuoha, A. (2024) A Framework for Implementing Drone-Based Healthcare Delivery Systems in Nigeria: Challenges and Solutions. International Journal of Health Services, 54(2), 264-276. doi:10.1177/00207314211067025

[158]Abiona, A. F., & Olayiwola, J. (2023) The Role of Drones in Enhancing Healthcare Delivery in Rural Africa: Challenges and Opportunities. Journal of Health Management, 25(1), 80-92. doi:10.1177/09720634231129546

[159]Kachwanya, R., & Kihoro, J. M. (2023) Drone Technology and Healthcare Access: Overcoming Barriers in Remote Areas of Africa. Journal of Health Informatics in Africa, 8(1), 12-19. doi:10.18585/ijih.2023.16501

[160]Okeke, T. A., & Iwuoha, A. (2024) A Framework for Implementing Drone-Based Healthcare Delivery Systems in Nigeria: Challenges and Solutions. International Journal of Health Services, 54(2), 264-276. doi:10.1177/00207314211067025

Faso, and Botswana use drones to track wildlife populations, detect illegal activities, and protect endangered species.[161]

There are many opportunities for Africa to leapfrog the application of drones in healthcare, including the following:

- Drones can be leveraged to provide rapid response and emergency medical services in remote and hard-to-reach areas.
- Drones offer a cost-effective and reliable solution for delivering medical supplies, vaccines, and medications to underserved communities in remote areas.
- When equipped with telemedicine technology, drones can facilitate remote consultations, diagnosis, and treatment for patients in remote areas with limited access to healthcare facilities.[162]
- Drones equipped with sensors, cameras, and data analytics capabilities can be utilised for collection of health data, disease surveillance, and monitoring of public health indicators.
- Drones can be used for capacity building and training programmes, to enhance healthcare workforce skills, knowledge, and competencies in drone technology applications.[163]
- Collaboration among government agencies, healthcare providers, technology companies, academic institutions, and community organisations offers the opportunity for fostering innovation, knowledge sharing, and sustainable deployment of drone technology in healthcare systems.

> Drones have been employed in an extensive range of activities outside military roles, from surveillance, traffic and weather monitoring, search and rescue, firefighting, photography or videography, to agriculture and delivery services, as well as for personal and commercial purposes.

5.3 Examples of Use of Drones in Healthcare Delivery

- **Supporting delivery of medical supplies:** Since 2016, the government in Rwanda, in partnership with Zipline, has been using drones to deliver medical supplies, such as blood and vaccines, to remote areas with limited access to healthcare facilities. The drones deliver blood products to remote hospitals and health centres across the country, overcoming infrastructural challenges and ensuring timely delivery of critical medical supplies to underserved communities.[164] In Madagascar, the Ministry of Public Health partners with Vayu, a drone delivery company, to transport vaccines, medical supplies and essential medicines more efficiently, especially to communities located far from health facilities.
- **Supporting Biospecimen Services:** In Malawi, drones support biospecimen services by transporting medical samples, such as blood samples for laboratory testing between remote clinics and central healthcare facilities. UNICEF Malawi and partners have piloted the use of drones to transport dried blood samples from infants in remote areas to central laboratories for HIV testing. In speeding up the transport of blood samples, drones help ensure timely diagnosis and initiation of treatment for infants born to HIV-positive mothers.[165]
- **Health surveillance:** South Africa uses drones for health surveillance in remote and hard-to-reach areas. Drones equipped with cameras and sensors monitor public health indicators, such as disease outbreaks or environmental health hazards, enabling authorities to respond proactively to health emergencies.
- **Emergency response:** Drones have been used in emergency response situations in Malawi and Mozambique, such as natural disasters, disease outbreaks, and humanitarian crises, to assess damage, locate survivors, and deliver emergency medical supplies.
- **Dissemination of health information:** In Nigeria, Cote d'Ivoire and Mauritania, drones are used

[161]Kachwanya, R., & Kihoro, J. M. (2023) Drone Technology and Healthcare Access: Overcoming Barriers in Remote Areas of Africa. Journal of Health Informatics in Africa, 8(1), 12-19. doi:10.18585/ijih.2023.16501

[162]Rukundo, L., & Tindimuhorwa, P. (2022) Drone Logistics and Health Delivery: Innovations in Uganda's Healthcare System. Journal of Transport & Health, 27, 101103. doi:10.1016/j.jth.2022.101103

[163]African Union High Level Panel on Emerging Technologies. (2018) Drones on the Horizon - Transforming Africa's Agriculture

[164]Bamidele, O. J., & Abokede, E. (2023) Drone Technology for Health Logistics: Bridging Supply Chain Gaps in Rural Africa. Journal of Logistics Management, 12(3), 46-58. doi:10.14321/jml.2023.14321

[165]Okeke, T. A., & Iwuoha, A. (2024) A Framework for Implementing Drone-Based Healthcare Delivery Systems in Nigeria: Challenges and Solutions. International Journal of Health Services, 54(2), 264-276. doi:10.1177/00207314211067025

to disseminate health education messages, support awareness campaigns, and public health information to communities in resource-poor settings.[166]

- **Hospital logistics:** In Rwanda and Kenya, drones support hospital logistics, inventory management, and supply chain operations in high-income health systems. Hospitals use drones for inventory tracking, equipment maintenance, and medical waste disposal, streamlining healthcare operations, reducing costs, and improving overall hospital efficiency.[167]

5.4 Complementary Technologies to Drones in the Healthcare System

Several technologies complement drones to enhance healthcare systems and improve patient care. They include the following:

- **Telemedicine technologies:** Telemedicine and telehealth technologies enable remote consultations, virtual visits, and telemonitoring of patients, complementing drones in delivering healthcare services to remote or underserved areas.
- **IoMT:** IoMT devices, such as wearable health trackers, smart medical devices, and remote monitoring sensors, collect and transmit patient data in real-time. When integrated with drones, IoMT devices enable continuous monitoring of a patient's health parameters, support medical interventions, and enhance healthcare delivery by providing actionable insights for personalised care.[168]
- **AI:** When combined with drones, AI-powered systems can enhance medical imaging analysis, automate diagnostics, and improve patient outcomes through personalised treatment recommendations.
- **Blockchain:** Blockchain technology ensures secure and transparent storage of healthcare data, such as patient records, medical histories, and supply chain information. When integrated with drones, the technology enables healthcare providers to maintain data integrity, protect patient privacy, and track the delivery of medical supplies and services, thus enhancing accountability and trust in healthcare transactions.[169]
- **Robotics:** Robotics and automation technologies support healthcare operations, such as surgical procedures, medication dispensing, and patient care tasks. When coupled with drones, robotic systems can assist in medical procedures, automate medication delivery, and enhance logistical operations in healthcare settings, thereby improving efficiency and reducing human error.[170]
- **Virtual reality:** AR and VR technologies create immersive and interactive experiences for medical training, surgical simulations, patient education, and rehabilitation therapy. When integrated with drones, AR and VR applications enable remote training sessions, virtual consultations, and telepresence experiences, enhancing healthcare education and engagement for both patients and healthcare professionals.

5.5 Human Resource Needs for Drones Application in Healthcare Systems

While Africa has made progress in developing capacity and skills for drone technology in various sectors, there are still challenges and gaps that need to be addressed to fully leverage drones in healthcare applications.[171] Skilled professionals with expertise in drone technology, aerial imaging, sensor integration, drone customisation, maintenance, troubleshooting, and data analysis are crucial for optimising drone performance and ensuring accurate and reliable data collection in healthcare settings.[172] The following are some of the skills and capacity issues that should be considered to fully leverage the use of drone technology in healthcare in Africa:

- **Skills in drone technology:** Training and education programmes on drone piloting, maintenance, data analysis, and application in healthcare can help to build a skilled workforce capable of operating drones in healthcare settings.
- **Drone regulation:** Human resource skills in regulatory compliance, airspace management, and adherence to safety guidelines are essential for obtaining necessary permissions, licenses, and approvals for drone operations in the health sector.[173]

[166]Adeyemo, S. A., & Ogunsanya, A. (2022) Using Drones for Medical Supply Delivery in Nigeria: A Case Study of the Health Sector. BMC Health Services Research, 22, 682. doi:10.1186/s12913-022-08127-0

[167]Anozie, J., & Okanlawon, M. (2023) Evaluating the Efficacy of Drone Delivery Systems for Vaccines in Africa: A Review of Current Practices. Vaccine, 41(10), 2144-2151. doi:10.1016/j.vaccine.2023.02.021

[168]Kachwanya, R., & Kihoro, J. M. (2023) Drone Technology and Healthcare Access: Overcoming Barriers in Remote Areas of Africa. Journal of Health Informatics in Africa

[169]Hayford, K., & Mensah, E. (2023) Exploring the Use of Drones for Maternal Health in Rural Ghana: An Evaluation of Implementation Strategies. Journal of Telemedicine and Telecare, 29(2), 84-92

[170]Chukwuma, A. O., & Eze, N. A. (2022) Drones as a Tool for Healthcare Delivery in Africa: The Case of Medical Supply Distribution in Remote Areas. African Journal of Health Informatics, 6(1), 15-25. doi:10.4314/ajhi.v6i1.3

[171]Gama, A. R., & Mhlanga, C. (2024) Drones in Public Health: A Comprehensive Review of Applications and Impact in Africa. Journal of Global Health Reports, 8, e2024011. doi:10.29392/001c.19567

[172]Ghosh, S., & Nkosi, Z. (2022) Innovative Delivery Solutions: The Future of Drone Technology in African Healthcare. Telecommunications Policy, 46(7), 102231. doi:10.1016/j.telpol.2022.102231

[173]Hayford, K., & Mensah, E. (2023) Exploring the Use of Drones for Maternal Health in Rural Ghana: An Evaluation of Implementation Strategies. Journal of Telemedicine and Telecare, 29(2), 84-92. doi:10.1177/1357633X22113413

- **Communication:** Effective communication skills for collaboration among multidisciplinary teams comprising healthcare professionals, drone operators, data scientists, public health experts, and regulatory authorities are essential for successful drone application in the health system.[174]

5.6 Challenges in the Application of Drones in Healthcare in Africa

While drones have shown great promise in transforming healthcare delivery in Africa, there are several challenges that need to be addressed for their effective and sustainable application in the health system. They include the following:

- Limited, unclear or inconsistent regulatory frameworks, licensing requirements, and airspace restrictions create barriers to drone use in healthcare delivery, leading to uncertainties and delays in their deployment and operation.
- Inadequate infrastructure, including poor communication systems, lack of or weak internet connectivity in remote and rural areas restrict the use of drones for timely and effective medical supply delivery.[175]
- The initial investment, operational costs, and maintenance of drone technology may be prohibitive for healthcare systems in Africa, especially in resource-constrained settings.
- Limited technical capacity, training, and skills among healthcare professionals, drone operators, and maintenance staff can hinder the effective use of drones in healthcare systems.
- Concerns around data security, privacy, and confidentiality of health information collected and transmitted by drones pose challenges to their adoption in healthcare systems.
- Inadequate engagement with communities, failure to address cultural norms, and low trust in drone technology can hinder the acceptance and adoption of drones in healthcare services.
- Security concerns, such as safety issues and insecurity in some countries across the continent, affect trust in the technology.[176]
- Concerns about loss of jobs from the utilisation of the technology, which include concerns from operators of conventional/traditional modes of transportation, health workers etc.
- Perceptions of the general public, health workers, community members and other stakeholders about drones and other technologies, and how they work to complement health services.[177]
- Technological constraints and challenges, in terms of weather sensitivity issues, transport/payload capacity, battery strength or lifespan etc.

5.7 Ethical and Socio-Cultural Considerations in the Application of Drones in Healthcare

While drones have the potential to significantly enhance healthcare delivery in Africa, there are some ethical and socio-cultural considerations which require careful attention. Some of these considerations are as follows:

- **Respect for cultural attitudes to technology in healthcare:** Understanding and respecting cultural attitudes towards emerging technologies and healthcare delivery is important. Social acceptance of drone technology is crucial. Different communities may have varying perceptions of drones, which could stem from cultural beliefs, past experiences with technology, or mistrust. It is important to engage communities in discussions about the use of drones to address concerns and increase acceptance.[178] The utilisation of drones

Different communities may have varying perceptions of drones, which could stem from cultural beliefs, past experiences with technology, or mistrust.

[174]Okeke, T. A., & Iwuoha, A. (2024) A Framework for Implementing Drone-Based Healthcare Delivery Systems in Nigeria: Challenges and Solutions. International Journal of Health Services, 54(2), 264-276. doi:10.1177/00207314211067025

[175]Gama, A. R., & Mhlanga, C. (2024) Drones in Public Health: A Comprehensive Review of Applications and Impact in Africa. Journal of Global Health Reports, 8, e2024011. doi:10.29392/001c.19567

[176]Chukwuma, A. O., & Eze, N. A. (2022) Drones as a Tool for Healthcare Delivery in Africa: The Case of Medical Supply Distribution in Remote Areas. African Journal of Health Informatics, 6(1), 15-25. doi:10.4314/ajhi.v6i1.3

[177]African Union High Level Panel on Emerging Technologies (2018) Drones on the Horizon - Transforming Africa's Agriculture

[178]Abiona, A. F., & Olayiwola, J. (2023) The Role of Drones in Enhancing Healthcare Delivery in Rural Africa: Challenges and Opportunities. Journal of Health Management, 25(1), 80-92. doi:10.1177/09720634231129546

needs to align with community values and practices, to avoid resistance and ensure effective healthcare delivery.[179]

- **Ethics:** Codes and values of medical practice and actions that may emphasise the belief that technology should be used when its use does not increase risks to humans. Similarly, when utilising drones for healthcare tasks such as delivery of medical supplies or specimen transport, ethical concerns around informed consent arise, and communities and stakeholders need to be informed about how drones will be used, what data will be collected, and the implications for privacy.[180]
- **Complementary service:** Drones may supplement or even replace traditional healthcare delivery methods. Understanding the social implications of this shift is important, as it might affect local customs, practices, and healthcare providers. It is important to ensure that drone use does not undermine traditional healthcare systems.
- **Safety and trust:** There may be concerns that drone technology may be a safety risk, and perceptions that security may be compromised through the use of drones.[181] Generally, people need to trust that a recommended emerging technology can work for them. Using drones in healthcare delivery requires public trust.

Addressing these considerations can significantly enhance the use of drones in healthcare systems, and positively improve health outcomes, as well as ensure effective healthcare systems that respect the rights and needs of all communities.

5.8 Public Policy Recommendations to Harness Application of Drones in the Healthcare in Africa

The application of drones in the healthcare system in Africa requires a supportive policy environment that addresses regulatory, operational, and ethical considerations. To promote the responsible use of drones in healthcare in Africa, policy makers should consider implementing the following actions:

- Develop clear and comprehensive regulatory frameworks for the use of drones in healthcare, including licensing requirements, operational guidelines, safety standards, and regulations on data privacy.[182]
- Invest in capacity building initiatives to train healthcare professionals, drone operators, and support staff on the safe and effective use of drones in healthcare settings.[183]
- Improve infrastructure and logistical support for drone operations in healthcare, including establishing dedicated drone ports, maintenance facilities, and charging stations.
- Foster partnerships between government agencies, healthcare providers, technology companies, academic institutions, and civil society organisations to leverage expertise, resources, and knowledge in the deployment of drones in healthcare.
- Introduce incentives, such as tax incentives, subsidies, or grants, to encourage investment in drone technology for healthcare applications.[184]
- Involve local communities, beneficiaries of healthcare services, and stakeholders in the planning, implementation, and evaluation of drone-enabled healthcare services.
- Establish quality assurance as well as monitoring and evaluation mechanisms to assess the impact, effectiveness, and efficiency of drone-enabled healthcare services.

[179]Elhassan, F., & Kamal, N. (2023) The Use of Drones in Delivering Medical Supplies: Lessons Learned from African Countries. Health Policy and Planning, 38(4), 538-546. doi:10.1093/heapol/czab164

[180]Kachwanya, R., & Kihoro, J. M. (2023) Drone Technology and Healthcare Access: Overcoming Barriers in Remote Areas of Africa. Journal of Health Informatics in Africa, 8(1), 12-19. doi:10.18585/ijih.2023.16501

[181]Anozie, J., & Okanlawon, M. (2023) Evaluating the Efficacy of Drone Delivery Systems for Vaccines in Africa: A Review of Current Practices. Vaccine, 41(10), 2144-2151. doi:10.1016/j.vaccine.2023.02.021

[182]Chukwuma, A. O., & Eze, N. A. (2022) Drones as a Tool for Healthcare Delivery in Africa: The Case of Medical Supply Distribution in Remote Areas. African Journal of Health Informatics, 6(1), 15-25. doi:10.4314/ajhi.v6i1.3

[183]Essien, O. A., & Abasiubong, F. (2022) Addressing Healthcare Challenges in Nigeria: The Role of Drones in Medical Logistics. Journal of Healthcare Engineering, 2022, 7998491. doi:10.1155/2022/7998491

[184]Adeyemo, S. A., & Ogunsanya, A. (2022) Using Drones for Medical Supply Delivery in Nigeria: A Case Study of the Health Sector. BMC Health Services Research, 22, 682. doi:10.1186/s12913-022-08127-0

- Put in place, insurance and liability frameworks, especially to cover risks encountered during delivery of medical supplies etc.[185]
- Develop mechanisms for workforce protection.

5.9 Priority Areas of Research on Harnessing Drones in the Healthcare System in Africa

The following are some of the priority areas that research should focus on to advance the use of drone technology in Africa:

- Development of optimal methods for delivering essential medicines and vaccines to remote and underserved areas, using drones.
- Application of drones in controlling disease vectors, such as mosquitoes, e.g. by spraying larvicides in hard-to-reach areas and releasing genetically modified mosquitoes to control vector populations.
- Using drones to gather environmental health data to study factors affecting public health, such as pollution levels, water quality, and habitat conditions.[186]
- Evaluation of the cost-effectiveness and sustainability of drone-based healthcare interventions compared to traditional methods.
- Development of regulatory frameworks and policies to govern the safe and ethical use of drones in healthcare.[187]
- Studies on community perceptions and acceptance of drone technology in healthcare to ensure successful implementation and uptake.
- Improving drone technology, to address some technological constraints (capacity, battery strength, weather resistance issues etc).

5.10 Conclusion

The use of drones in healthcare services is on the rise and offers a variety of exciting opportunities. In many African countries, health professionals such as laboratory scientists, physicians, nurses and other medical personnel are starting to appreciate drone utility in rendering services.[188] Delivery of medical and laboratory supplies, blood products for emergency surgeries, medical specimen including biopsies, is just the starting point. Drones are the future of medical supplies in remote areas in Africa that are inaccessible by conventional land and air transport as a result of poor infrastructure, disasters, war and other tragedies.[189]

They can also deliver relief supplies for people faced with inclement weather and pandemics and in desperate need of services. Drones have the capability to change medical care as well as propel advancement of the health industry. For Africa to fully realise their benefits in healthcare, it is important for countries to address the regulatory, operational, ethical, and socio-cultural considerations identified in this chapter, to create a supportive environment.[190]

[185]Fofana, I., & Abou, A. (2023) Utilizing Drones to Improve Access to Medicines in Rural Africa: Policy Implications and Recommendations. International Journal of Health Services, 53(1)

[186]Chukwuma, A. O., & Eze, N. A. (2022) Drones as a Tool for Healthcare Delivery in Africa: The Case of Medical Supply Distribution in Remote Areas. African Journal of Health Informatics, 6(1)

[187]Elhassan, F., & Kamal, N. (2023) The Use of Drones in Delivering Medical Supplies: Lessons Learned from African Countries. Health Policy and Planning, 38(4), 538-546. doi:10.1093/heapol/czab164

[188]Hayford, K., & Mensah, E. (2023) Exploring the Use of Drones for Maternal Health in Rural Ghana: An Evaluation of Implementation Strategies. Journal of Telemedicine and Telecare, 29(2), 84-92. doi:10.1177/1357633X22113413

[189]Ghosh, S., & Nkosi, Z. (2022) Innovative Delivery Solutions: The Future of Drone Technology in African Healthcare. Telecommunications Policy, 46(7), 102231. doi:10.1016/j.telpol.2022.102231

[190]Bamgboye, E. A., & Asuquo, A. (2022) "Genomic medicine: Current applications and future directions in African healthcare." Journal of Medical Genetics, 59(4), 215-223

Application of Genomic Medicine to Advance Healthcare in Africa

6

Application of Genomic Medicine to Advance Healthcare in Africa

6.1 Background

Genomic medicine involves the use of an individual's genetic information, specifically their genome, to identify diseases and determine their causes, and to guide medical decisions, treatment, and prevention of diseases. The human genome is the complete set of genetic material, including Deoxyribonucleic Acid (DNA), that contains all the hereditary information needed to build and maintain the body of an organism.[191] DNA is considered as the human "code" or blueprint that contains instructions for creating new proteins and maintaining the body, all based on hereditary information.

The human genome, the whole of this genetic content organised into chromosomes, is a complex blueprint of our biological makeup, which holds immense potential for understanding diseases. However, understanding of genomics in Africa is still developing as a new field. This limitation contributes to poor understanding of many medical conditions and diseases such as Alzheimer's, Parkinson's, ALS (amyotrophic lateral sclerosis), and autoimmune diseases such as rheumatoid arthritis, lupus, and multiple sclerosis, due to the lack of comprehensive genomic insights.[192]

Genomic medicine can inform prospective parents with family history of serious hereditary disorders such as sickle cell anaemia whether they are carriers, and whether they might pass it on to their children. The technology can also tell if someone is likely to develop an inherited condition later in life, even if they do not yet have any symptoms.[193] Genomic medicine may also offer valuable insights into mental health disorders such as depression, schizophrenia, and bipolar disorder, which are still not fully understood.[194] There are also complex diseases with genetic components such as diabetes, heart disease, and certain cancers, and some rare diseases, many which remain undiagnosed and untreated. Personalised genomic medicine combines genetic knowledge, lifestyle and other environmental influences to understand each patient's specific health needs.

"Although it is still in its early stages, genomic medicine is beginning to make strides in Africa. Remarkable progress has been accomplished in utilising genomic information to understand gene regulation"

Public Health Genomics (PHG) is a relatively new multidisciplinary field within genomic medicine concerned with effectively and responsibly translating genome-based knowledge and technologies to improve population health.[195] PHG assesses the impact on population health of genes and their interaction with behaviour, diet, and the environment. Genomic medicine is a valuable tool for mitigating the impact of the factors that influence disease, which include heredity, lifestyle choices, and environmental factors, and alleviating the developmental and economic burdens diseases pose for governments.

Although it is still in its early stages, genomic medicine is beginning to make strides in Africa. Remarkable progress has been accomplished in utilising genomic information to understand gene regulation.[196] This helps healthcare providers to gain insights into how genes interact with one another and with the environment,

[191]Maponga, T. G., & Kadima, M. (2024) Genomic Medicine and Health Policy: Transforming Healthcare Delivery in Zimbabwe. Journal of Public Health Policy, 45(1), 115-128. doi:10.1057/s41271-023-00320-2

[192]Edokpayi, J. N., & Omoogun, D. S. (2024) Genomic Approaches to Understanding Genetic Disorders in African Populations. Journal of Community Genetics, 15(1), 75-84. doi:10.1007/s12687-023-00791-8

[193]Edokpayi, J. N., & Omoogun, D. S. (2024) Genomic Approaches to Understanding Genetic Disorders in African Populations. Journal of Community Genetics, 15(1),

[194]Baker, T. S., & Bkam, N. (2022) Genomic Health Equity: The Role of Genomic Medicine in Improving Healthcare Delivery in Africa. Global Health Action, 14(1), 2061271. doi:10.1080/16549716.2022.2061271

[195]Bamgboye, E. A., & Asuquo, A. (2022) "Genomic medicine: Current applications and future directions in African healthcare." Journal of Medical Genetics, 59(4)

[196]Olutola, A., & Ezeani, I. (2024) Genomic Medicine as a Tool for Health Promotion in African Communities. International Journal of Health Promotion and Education

to control complex biochemical functions of living organisms, particularly concerning health and diseases.[197] Potentially, this information will have major benefits towards the prevention, investigation and management of many diseases, including communicable and genetic diseases.

Research initiatives are underway in countries such as South Africa, Nigeria, and Kenya, focusing on infectious diseases, cancer, and inherited disorders. Additionally, universities and research institutions are building local capacity in genomics and bioinformatics and training local scientists and healthcare professionals. Genomic studies are also contributing to disease mapping, offering valuable insights into the genetic landscape of African populations and the prevalence and distribution of various diseases.[198]

Furthermore, public-private partnerships are emerging, and collaboration between governments, research institutions, and private companies to drive the development of genomic medicine. There are discussions taking place within research communities around the ethical, legal, and social implications (ELSI) of genomics. Through a commitment to ethical practices and fostering collaborative efforts, governments and stakeholders can harness the power of emerging technologies in genomics to improve quality of life and contribute to sustainable development.[199]

6.2 Application of Genomic Medicine in Healthcare Systems in Africa

Genomic medicine offers a promising solution to address healthcare challenges that African countries face more cost-effectively and efficiently. Genomic medicine can help public healthcare systems to address challenges, includes the following:

- **Infectious diseases:** Africa faces high rates of infectious diseases like malaria, HIV/AIDS, tuberculosis, and emerging diseases such as Ebola, posing serious public health issues.
- **Limited healthcare access:** Many people, particularly in rural areas, lack access to basic healthcare services, including check-ups, treatments, and preventive care.[200]
- **Maternal and child mortality:** High rates of maternal and child deaths are due to inadequate prenatal care, complications during childbirth, and infectious diseases.
- **Chronic diseases:** The prevalence of chronic diseases, such as diabetes, heart disease, and cancer, is increasing.
- **Healthcare system challenges:** Weak healthcare systems, limited facilities, inadequate equipment, a shortage of trained healthcare workers, and the rising issue of drug-resistant diseases exacerbate these problems.

Genomic medicine offers a promising solution to address these challenges more cost-effectively and efficiently. It adds value to public healthcare systems in Africa in the following ways:

- Genomic medicine enables healthcare providers to tailor treatment plans based on an individual's genetic makeup, resulting in more precise and effective treatment therapies, especially in diseases that exhibit genetic predisposition.[201,202]
- Genomic surveillance helps to trace the transmission pathways of infectious diseases (e.g., HIV, tuberculosis, and COVID-19), to inform control strategies and policy decisions.
- Healthcare providers can apply genomic medicine to track the spread of infectious diseases, find drug-resistant strains, and create targeted treatments such as better vaccines and medications.
- In maternal and child health, genomic research can pinpoint genetic issues that may affect pregnancy, allowing for early interventions to reduce the risks for mothers and babies.
- Genetic testing can help identify individuals at higher risk for certain diseases at an earlier stage, thereby, allowing for preventive measures or early intervention.
- Genomic medicine research initiatives foster collaborations between African institutions and international research communities, enhancing knowledge exchange and access to advanced technologies.[203]
- By studying African genomes, research can address the significant health disparities that arise from a lack of African representation in global genomic studies.
- Genomic data collected through public healthcare systems can contribute to ongoing research efforts, leading to the development of new treatments, medications, and therapies.

[197]Hennig, B., & Akinola, L. (2022) Roles of Genomics in Cancer Care: The African Experience. African Journal of Cancer, 10(1), 5-12. doi:10.1007/s13691-022-00570-5

[198]Akintunde, A. A., & Ojo, O. (2024) Genomic Medicine: Bridging the Gap in Healthcare Delivery in Africa. The Pan African Medical Journal, 38, 100-108

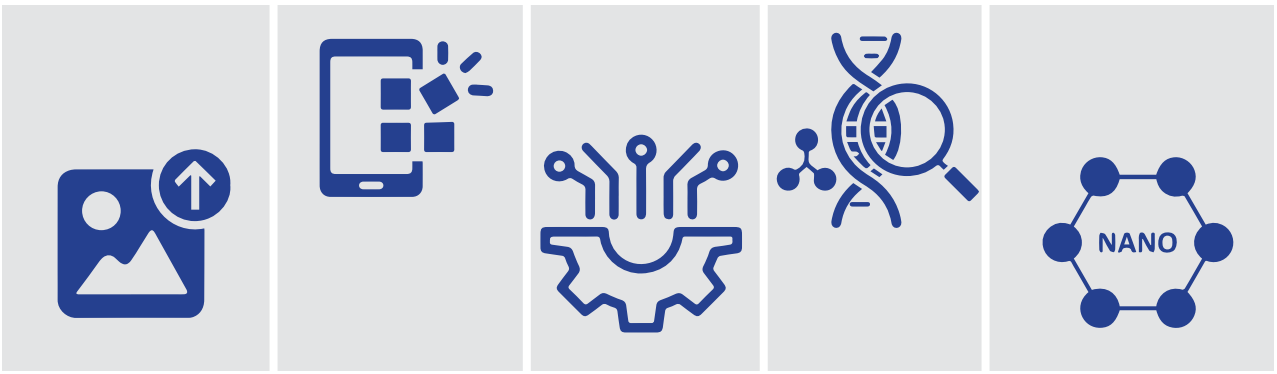
[199]Maponga, T. G., & Kadima, M. (2024) Genomic Medicine and Health Policy: Transforming Healthcare Delivery in Zimbabwe. Journal of Public Health Policy, 45(1)

[200]Edokpayi, J. N., & Omoogun, D. S. (2024) Genomic Approaches to Understanding Genetic Disorders in African Populations. Journal of Community Genetics, 15(1), 75-84

[201]Olutola, A., & Ezeani, I. (2024) Genomic Medicine as a Tool for Health Promotion in African Communities. International Journal of Health Promotion and Education, 62(1), 8-19. doi:10.1080/14635240.2023.2184769

[202]Wanjiku, E., & Karanja, W. M. (2023) "Implementing genomic healthcare services in Kenya: Challenges and opportunities." Kenya Medical Journal, 8(1), 29-36. https://doi.org/10.1109/KMJ.2023.9754087

[203]Baker, T. S., & Bkam, N. (2022) Genomic Health Equity: The Role of Genomic Medicine in Improving Healthcare Delivery in Africa. Global Health Action, 14(1)



- Genomic medicine can assist public healthcare systems to identify and address health disparities within communities and put in place targeted interventions and preventive strategies.[204]

6.3 Africa the Cradle of Humanity and the Ethical Implications of Genomic Research

The African continent is widely recognised as the cradle of humankind, with the discovery of numerous early human fossils, such as those in Ethiopia's Afar Depression. This rich genetic diversity offers a unique opportunity to study human evolution and understand the genetic basis of diseases and has attracted significant interest from pharmaceutical companies and research institutions globally.[205] While this interest can lead to groundbreaking discoveries and treatments, it also raises ethical concerns about the potential exploitation of Africa's genetic resources, including the following:

- **Biopiracy:** The unauthorised use of genetic resources without fair compensation or benefit sharing with the communities that contribute the material is a major concern.
- **Informed Consent:** It is crucial to ensure that participants in genetic research fully understand the implications of providing their genetic information.
- **Data Ownership:** Determining who owns and controls genetic data is a complex issue, with implications for research and commercialisation.
- **Benefits Sharing:** It is essential to establish mechanisms for sharing the benefits of genetic research with the communities that contribute their genetic material.

6.4 Examples of Genomic Applications in Africa

The following are some examples of application of genomic medicine in Africa to address local healthcare challenges:

- The Cancer Genomics Group at the University of Cape Town, South Africa, is researching genetic information in the form of molecular profiling of various cancer types prevalent in South Africa.
- The Southern African Human Genome Programme in South Africa focuses on genomic research to address health challenges unique to the region, including HIV/AIDS, tuberculosis, and various cancers.[206]
- The African Centre of Excellence for Genomics of Infectious Diseases (ACEGID) at Redeemer's University in Nigeria is at the forefront of using genomic medicine to track and understand infectious diseases such as Lassa fever and Ebola.
- The Sickle Cell Disease Genomic Research Network in Ghana is leveraging genomic medicine to study the genetic diversity the disease and its impact on clinical outcomes.[207]
- The Ethiopian Public Health Institute employs genomic medicine to conduct surveillance and track the spread of drug-resistant strains of tuberculosis.
- The Egyptian Human Genome Project studies the genetic diversity of the Egyptian population, to understand genetic predispositions to diseases such as diabetes, heart and blood vessel (cardiovascular) diseases, and certain cancers.[208]
- The Human, Heredity and Health in Africa (H3Africa) initiative, a collaborative research programme studies the genetic and environmental factors contributing to health and disease in African populations. The initiative studies the genomic basis of common diseases in African populations.

6.5 Nutritional Genomics and African health with a Focus on Personalised Nutrition

Genomics can also be applied to nutrition to encourage personalised and balanced nutrition for Africans as follows:

- **Nutrition research:** Nutrigenomics explores the interaction between genes, diet, and health, with the

[204]Nzolo, T., & Efe, E. (2022) Genomics and Maternal Health in Africa: Addressing Ancestry and Genetic Variability. Journal of Maternal-Fetal & Neonatal Medicine

[205]H3Africa Consortium. (2021) The H3Africa Policy Framework: Supporting Genomic and Biobank Research Across Africa. Front Genet; 12:601988. doi: 10.3389/fgene.2021.601988.

[206]George, B. L., & Ibeakanma, C. (2023) Assessing the Impact of Genomic Medicine on Cardiovascular Diseases in Africa. Cardiovascular Medicine, 23(2), 45-54

[207]Matsoukas IG. (2020) Prime Editing: Genome Editing for Rare Genetic Diseases Without Double-Strand Breaks or Donor DNA. Front Genet

[208]Delong, K. M., & Akinola, O. (2022) Barriers to Implementing Genomic Medicine in African Healthcare Systems: A Review. Health Affairs, 41(6), 568-575. doi:10.1377/hlthaff.2021.01797

potential to revolutionise healthcare, especially in Africa where there is a rise in diet-related diseases. Countries should invest in research to understand these interactions and their implications for healthcare.[209]

- **Managing disease:** By analysing genetic makeup, healthcare service providers can assess susceptibility to diseases such diabetes, heart disease, and obesity and create personalised nutritional plans to combat them. Providers can also use genetic data to develop dietary interventions tailored to individual health needs, and which optimise nutrient absorption, minimise adverse reactions, and reduce chronic disease risk.[210]
- **Integration of traditional and modern diets:** Traditional African diets, rich in whole grains, legumes, fruits, and vegetables, are generally healthy but are being replaced by Western diets that increase obesity and related diseases. Nutrigenomics can help promote the integration of traditional diets with modern practices to combat diet-related health issues.
- **Support ethnic genomics studies:** This field studies genetic variations within specific African populations, offering insights for tailored nutritional and disease prevention strategies.[211] African countries can advance research in ethnic genomics to develop specific health recommendations for different African genetic profiles.

To promote African foods and leverage the potential of nutritional genomics, African countries can:

- Invest in research to understand the nutritional composition of African foods and their impact on health.
- Educate the public about the benefits of traditional African diets and the importance of incorporating them into modern lifestyles.
- Develop policies that support the production and consumption of African foods.[212]
- Encourage chefs and food businesses to create innovative dishes using African ingredients.
- Collaborate with the private sector to develop and market African food products.

6.6 Complementary Technologies to Genomic Medicine in the Healthcare Systems

The following technologies can complement genomic medicine to improve health outcomes:

- **Machine Learning and AI:** These technologies help in interpreting complex and detailed genetic information, uncovering genetic patterns and making predictions about disease outcomes and treatment responses.
- **Digital health technologies:** Technologies such as wearable devices collect continuous health data, such as heart rate and activity levels, which can be integrated with genomic information to provide a comprehensive view of a patient's health.
- **Mobile apps:** Mobile health applications facilitate remote monitoring and management of health conditions, to enhance patient engagement and adherence to treatment plans.
- **Imaging:** Imaging technologies such as magnetic resonance imaging (MRI), computed tomography (CT) scans, and position emerging tomography (PET) scans provide detailed information about how the body is built and works that complement genomic data, aiding in accurate investigation and monitoring of diseases.[213]
- **Gene Editing:** Tools such as CRISPR and other gene-editing technologies can correct hereditary defects, providing potential cures for genetic disorders.

"Technologies such as wearable devices collect continuous health data, such as heart rate and activity levels, which can be integrated with genomic information to provide a comprehensive view of a patient's health."

[209]Bamgboye, E. A., & Asuquo, A. (2022) "Genomic medicine: Current applications and future directions in African healthcare." Journal of Medical Genetics, 59(4), 215-223. https://doi.org/10.1136/jmedgenet-2021-107124

[210]George, B. L., & Ibeakanma, C. (2023) Assessing the Impact of Genomic Medicine on Cardiovascular Diseases in Africa. Cardiovascular Medicine, 23(2), 45-54. doi:10.1007/s12630-022-01919-9

[211]Hennig, B., & Akinola, L. (2022) Roles of Genomics in Cancer Care: The African Experience. African Journal of Cancer, 10(1), 5-12. doi:10.1007/s13691-022-00570-5

[212]Baker, T. S., & Bkam, N. (2022) Genomic Health Equity: The Role of Genomic Medicine in Improving Healthcare Delivery in Africa. Global Health Action, 14(1), 2061271. doi:10.1080/16549716.2022.2061271

[213]Maponga, T. G., & Kadima, M. (2024) Genomic Medicine and Health Policy: Transforming Healthcare Delivery in Zimbabwe. Journal of Public Health Policy, 45(1), 115-128. doi:10.1057/s41271-023-00320-2

- **Nanotechnology:** This technology enables precise drug delivery to specific cells or tissues, to improve the efficacy and reducing side effects of treatments.

6.7 Human Resource Needs for Harnessing Genomic Medicine in Healthcare Systems in Africa

There is need for a diverse set of human skills and expertise to effectively apply genomic medicine in healthcare systems in Africa. These include the following:

- **Knowledge of genetics and health:** Healthcare professionals need to have a strong understanding and study of genes and how they can be applied in clinical settings. This includes knowledge of genetic testing, interpretation of results, and the implications for patient care. Similarly, policymakers and administrators in health should understand the benefits and challenges of implementing genomic medicine in healthcare systems to create policies and guidelines that support its integration into clinical practice.
- **Specialised training in genetics:** Healthcare practitioners, including physicians, nurses, and genetic counsellors, need specialised training in genetic studies. This can be achieved through workshops, courses, and certification programmes focused on genomic medicine.[214]
- **Skills in genetic counselling:** Genetic counsellors should be trained to effectively help patients and families understand the implications of genetic testing results. Building a workforce of trained genetic counsellors is essential for the successful integration of genomics into healthcare systems.
- **Bioinformatics expertise:** Given the complex nature of genomic data analysis, healthcare systems in Africa need professionals with bioinformatics expertise to analyse and interpret genetic information accurately.
- **Knowledge of legal and ethical issues in genomic medicine:** Professionals in Africa need skills and knowledge to address the ethical, legal, and social implications of genomic medicine, such as patient privacy, data security, and to ensure equity in access to genetic testing and treatment.[215]

6.8 Challenges that Africa Faces in Harnessing Genomic Medicine

Genomic medicine in Africa is in its infancy, with growing recognition of its potential to address unique health challenges on the continent. More genomic studies are needed to help map the genetic landscape of African populations, and provide crucial insights into disease prevalence, as well as support the development of targeted prevention strategies.[216] African populations exhibit greater genetic diversity compared to other regions, yet genomic databases and research studies often lack adequate representation of African genomes.[217]

Some of the challenges that hinder adoption of genomic medicine in healthcare system in Africa can be summarised as follows:

- Insufficient or lack of healthcare infrastructure, including sequencing facilities and bioinformatics resources.
- Limited funding, technical expertise, and skilled personnel, as well as inadequate laboratory facilities, which hinder the implementation of genomic medicine.
- Low levels of public awareness about the benefits and opportunities of genomic medicine, which gives rise to limited trust and understanding of the technology.[218]
- Limited or inadequate regulatory frameworks and policies governing the use of genomic technologies in healthcare, which hinders their adoption.
- Ethical concerns related to informed consent, privacy, equity, and data sharing, which require careful consideration of cultural norms and values. Additionally, issues of genetic discrimination must be addressed to build public trust.
- High cost of genomic sequencing and analysis technologies, which makes them inaccessible to many healthcare facilities and patients in Africa.[219]
- Shortage of healthcare professionals with expertise in genomics, bioinformatics, and related fields in Africa.

[214]Wanjiku, E., & Karanja, W. M. (2023) "Implementing genomic healthcare services in Kenya: Challenges and opportunities." Kenya Medical Journal, 8(1), 29-36. https://doi.org/10.1109/KMJ.2023.9754087

[215]George, B. L., & Ibeakanma, C. (2023) Assessing the Impact of Genomic Medicine on Cardiovascular Diseases in Africa. Cardiovascular Medicine, 23(2), 45-54. doi:10.1007/s12630-022-01919-9

[216]Adetunji, A., & Okunola, O. (2022) "Advances in genomic research and public health in sub-Saharan Africa." African Journal of Laboratory Medicine, 11(1), 1-8. https://doi.org/10.4102/ajlm.v11i1.1237

[217]Nzolo, T., & Efe, E. (2022) Genomics and Maternal Health in Africa: Addressing Ancestry and Genetic Variability. Journal of Maternal-Fetal & Neonatal Medicine, 35(18), 3486-3493. doi:10.1080/14767058.2021.1943060

[218]Delong, K. M., & Akinola, O. (2022) Barriers to Implementing Genomic Medicine in African Healthcare Systems: A Review. Health Affairs, 41(6), 568-575. doi:10.1377/hlthaff.2021.01797

[219]Adeyemo, A., & Mba, C. (2023) "The role of genomic medicine in the management of non-communicable diseases in Africa" Medical Science Monitor, 29

In addition, undertaking genomic research in Africa is constrained by several factors, which are summarised as follows:

- **Lack of supportive research infrastructure:** Many countries in Africa have basic genomic laboratories equipped with inadequate technologies for sequencing and analysis. Systems for storing, managing, and analysing genomic data are often insufficient, impeding research and clinical application.
- **Funding:** There is often a lack of funding for genomic research and initiatives for integrating genomics into healthcare.[220] On the other hand, the high costs associated with genomic testing and sequencing technologies can limit access for patients and healthcare providers and affect research.
- **Shortage of skilled staff:** Many African countries have a shortage of skilled healthcare professionals, geneticists, and bioinformaticians who trained in genomics.
- **Current educational** programmes may not adequately cover genomic medicine and research, resulting in a workforce that is not prepared for its implementation.[221]
- **Obtaining informed consent** for genetic testing can be complicated, particularly in communities with varying levels of understanding about genetics.[222]
- **Concerns about data privacy** and the potential misuse of genetic information pose significant ethical challenges.
- **There is often limited public knowledge** about genomics, which can lead to mistrust or scepticism about genomic testing and its implications.
- **Many countries in Africa do not have established regulatory frameworks** to guide the use of genomics in clinical practice.[223]
- **Slow and complex regulatory approval processes** for genomic tests and therapies can delay their availability in the market.
- A lack of comprehensive local genomic databases can hinder the interpretation of genetic information specific to African populations.
- Historical inequities may affect North-South collaborations, leading to instances where research benefits do not adequately accrue to African nations.[224]
- Gathering comprehensive data on dietary habits, genetic profiles, and health outcomes in African populations is crucial for research.
- Building the necessary infrastructure for genomic analysis and data management is essential.
- Raising public awareness about the importance of nutrition and genetics is crucial for behaviour change.[225]

6.9 Ethical and Socio-Cultural Consideration in Genomic Medicine and Research in Africa

Navigating the ethical and socio-cultural implications of genomic medicine in Africa requires a careful, inclusive approach that considers the unique social fabric and historical context of the continent. Effective communication is essential to improve public knowledge and acceptance of genomic medicine. The following are some of the issues that implementers and researchers should keep in mind:

- Integration of genomic medicine may conflict with established traditional practices and beliefs about health and healing.
- Stakeholders must engage with local communities to understand and respect cultural perspectives, while promoting genomic health initiatives.[226] Engaging community leaders, traditional healers, and other stakeholders in the design, implementation, and evaluation of genomic medicine programmes is crucial for building trust, promoting acceptance, and addressing community concerns.[227]
- Lack of understanding about genomic medicine can lead to fear and resistance, fuelled by misinformation or cultural beliefs. Genomic concepts can be complex and may require targeted health literacy and education efforts to ensure that individuals understand the implications of genetic testing, the role of genetics in health and disease, and the potential benefits and risks of genomic medicine.

[220]Ibrahim, A., & Eniola, O. (2020) The Future of Genomic Medicine in Africa: Systems, Resources, and Capacity Building. Global Health Research and Policy, 5, 9. doi:10.1186/s41256-020-00110-3

[221]Adeyemo, A. A., & Keshinro, A. (2023) Integrating Genomic Medicine into Healthcare Systems in Africa: Challenges and Opportunities. Journal of Medical Genetics, 60(3), 145-158. doi:10.1136/jmedgenet-2021-107405

[222]Adeyemo, A., & Mba, C. (2023) "The role of genomic medicine in the management of non-communicable diseases in Africa" Medical Science Monitor, 29, e940692. https://doi.org/10.12659/MSM.940692

[223]Edokpayi, J. N., & Omoogun, D. S. (2024) Genomic Approaches to Understanding Genetic Disorders in African Populations. Journal of Community Genetics, 15(1), 75-84. doi:10.1007/s12687-023-00791-8

[224]Adeyemo, A., & Mba, C. (2023) "The role of genomic medicine in the management of non-communicable diseases in Africa" Medical Science Monitor, 29, e940692. https://doi.org/10.12659/MSM.940692

[225]Ibrahim, A., & Eniola, O. (2020) The Future of Genomic Medicine in Africa: Systems, Resources, and Capacity Building. Global Health Research and Policy, 5, 9. doi:10.1186/s41256-020-00110-3

[226]Bamgboye, E. A., & Asuquo, A. (2022) "Genomic medicine: Current applications and future directions in African healthcare." Journal of Medical Genetics, 59(4), 215-223. https://doi.org/10.1136/jmedgenet-2021-107124

[227]Olutola, A., & Ezeani, I. (2024) Genomic Medicine as a Tool for Health Promotion in African Communities. International Journal of Health Promotion and Education, 62(1), 8-19. doi:10.1080/14635240.2023.2184769

- Sharing genetic information can strain family relationships and dynamics, particularly if predictive testing reveals predispositions to certain diseases and conditions.
- Awareness of genetic risks and conditions can influence family planning and reproductive choices, and lead to ethical dilemmas regarding the value of lives.[228]
- The introduction of genomic medicine can exacerbate existing health disparities, if access is limited to affluent populations or urban centres.[229] Efforts should be made to make genomic testing and treatments affordable and accessible to all socio-economic groups, including marginalised and underserved populations.[230]
- Due to historical exploitation of some African communities in scientific research, there is need for continued efforts to build trust and to observe ethical practices.[231]
- Successful genomic programmes must prioritise community involvement and ownership, to ensure that local perspectives shape research agendas.
- Protecting the privacy and confidentiality of genomic data is paramount to maintaining patient trust and confidence in healthcare systems.
- Legislation and policies are needed to prohibit genetic discrimination in employment, insurance, and other areas to protect individuals from discrimination.
- Healthcare providers require training and education on genomic medicine to effectively integrate genetic information into clinical practice.
- Regulatory frameworks and oversight mechanisms for genomic medicine are needed, to ensure patient safety, data integrity, and ethical conduct.

6.10 Public Policy Recommendations to Harness the Application of Genomic Medicine in Africa's Healthcare Systems

To accelerate the adoption of genomic medicine in healthcare systems in Africa, policy makers should consider the following recommendations:

- Allocate resources to establish and maintain genomic sequencing facilities, bioinformatics expertise, and laboratory equipment to support genomic research and healthcare delivery.[232] Explore diverse funding sources, such as public-private partnerships, grants, and endowments, to ensure the long-term sustainability of genomic research.
- Develop regulatory frameworks and governance mechanisms to ensure responsible collection, storage, sharing, and use of genomic data, while safeguarding patient privacy and confidentiality.[233]
- Regulatory agencies should oversee the quality, accuracy, and validity of genetic tests and ensure compliance with ethical standards and guidelines.
- Develop training programmes and educational initiatives to build the capacity of healthcare workers, researchers, and laboratory technicians in genomics, bioinformatics, and related fields.
- Ensure that genomic medicine initiatives implemented in the country are culturally sensitive, responsive to community needs, and aligned with local priorities.[234]
- Foster collaboration with international partners, academic institutions, and global health organisations to leverage expertise, resources, and best practices in genomic medicine and research.
- Increased investment in genomic research is necessary to support infrastructure development, talent cultivation, and data management.[235]
- Encourage collaboration between pharmaceutical companies and biotechnology firms, to accelerate drug discovery and development.
- Promote effective communication of scientific findings to the public. to build trust and support for genomic research.[236]
- Leverage complementary technologies, such as artificial intelligence and big data analytics, to enhance the efficiency and impact of genomic research.

[228]George, B. L., & Ibeakanma, C. (2023) Assessing the Impact of Genomic Medicine on Cardiovascular Diseases in Africa. Cardiovascular Medicine, 23(2), 45-54

[229]Edokpayi, J. N., & Omoogun, D. S. (2024) Genomic Approaches to Understanding Genetic Disorders in African Populations. Journal of Community Genetics, 15(1), 75-84. doi:10.1007/s12687-023-00791-8

[230]Akintunde, A. A., & Ojo, O. (2024) Genomic Medicine: Bridging the Gap in Healthcare Delivery in Africa. The Pan African Medical Journal, 38, 100-108. doi:10.11604/pamj.2024.38.100.28126

[231]Maponga, T. G., & Kadima, M. (2024) Genomic Medicine and Health Policy: Transforming Healthcare Delivery in Zimbabwe. Journal of Public Health Policy, 45(1), 115-128. doi:10.1057/s41271-023-00320-2

[232]Adetunji, A., & Okunola, O. (2022) "Advances in genomic research and public health in sub-Saharan Africa." African Journal of Laboratory Medicine, 11(1), 1-8. https://doi.org/10.4102/ajlm.v11i1.1237

[234]Bamgboye, E. A., & Asuquo, A. (2022) "Genomic medicine: Current applications and future directions in African healthcare." Journal of Medical Genetics, 59(4), 215-223

[235]Hennig, B., & Akinola, L. (2022) Roles of Genomics in Cancer Care: The African Experience. African Journal of Cancer, 10(1), 5-12. doi:10.1007/s13691-022-00570-5

[236]Olutola, A., & Ezeani, I. (2024) Genomic Medicine as a Tool for Health Promotion in African Communities. International Journal of Health Promotion and Education, 62(1), 8-19. doi:10.1080/14635240.2023.2184769

6.11 Research Priorities in Genomic Medicine

The following are the priority areas of research to advance genomic medicine in Africa:

- Studies of the genomes of disease-causing agents (pathogens) such as HIV, malaria, tuberculosis, Ebola, and COVID-19 to understand their evolution, drug resistance, and transmission.[237]
- Research on genetic risk factors for common and rare diseases, including cardiovascular diseases, diabetes, and various cancers.
- Personalised treatment, based on an individual's genetic makeup, particularly for conditions such as sickle cell disease and certain cancers.
- Studies on genetic factors that influence pregnancy outcomes and maternal health, including pregnancy-related high blood pressure (preeclampsia) and pregnancy (gestational) diabetes.[238]
- Studies on rare genetic disorders that may be more prevalent or present differently in African populations.
- Investigating the genetic basis of chronic diseases such as hypertension, diabetes, and cardiovascular diseases.
- Developing and testing frameworks for the ethical collection, storage, and use of genomic data, ensuring privacy and consent.

To maximise the benefits of genomic research in Africa, it is imperative to build local capacity through:

- **Enhancing funding:** Increased investment in genomic research is necessary to support infrastructure development, talent cultivation, and data management.
- **Sustainable funding mechanisms:** Exploring diverse funding sources, such as public-private partnerships, grants, and endowments, can ensure the long-term sustainability of genomic research.[239]
- **Institutional collaborations:** Fostering partnerships between universities, research institutions, and government agencies can strengthen the research ecosystem.
- **Private sector engagement:** Collaborating with pharmaceutical companies and biotechnology firms can accelerate drug discovery and development.
- **Communication of science:** Effective communication of scientific findings to the public is crucial for building trust and support for genomic research.
- **Basic science emphasis:** Strengthening foundational research in genetics and biology is essential for building a solid base for advanced genomic studies.
- **Technology integration:** Leveraging complementary technologies, such as artificial intelligence and big data analytics, can enhance the efficiency and impact of genomic research.

6.12 Conclusion

Integrating genomic technologies into healthcare systems in Africa can advance precision medicine, personalised healthcare, and genomic research on the continent. This would enhance disease prevention, diagnosis, and treatment strategies, while fostering local research capacities.[240] However, implementing genomic medicine in Africa requires a multifaceted approach that addresses research and development, policy and regulatory frameworks, capacity building, and ethical considerations.

African countries can harness the power of genomics to advance public health, improve health outcomes and achieve health equity across the continent through continued investment in research, and education, and by addressing healthcare infrastructure challenges, fostering collaboration, and prioritising ethical considerations.[241] Genomic medicine can play a crucial role in creating more effective, equitable, and sustainable healthcare systems that address the unique challenges faced by African populations, and emphasising the region's genetic diversity.[242]

[237]Ibrahim, A., & Eniola, O. (2020) The Future of Genomic Medicine in Africa: Systems, Resources, and Capacity Building. Global Health Research and Policy, 5, 9

[238]Adeyemo, A., & Mba, C. (2023) "The role of genomic medicine in the management of non-communicable diseases in Africa" Medical Science Monitor, 29

[239]Baker, T. S., & Bkam, N. (2022) Genomic Health Equity: The Role of Genomic Medicine in Improving Healthcare Delivery in Africa. Global Health Action, 14(1), 2061271

[240]Wanjiku, E., & Karanja, W. M. (2023) "Implementing genomic healthcare services in Kenya: Challenges and opportunities." Kenya Medical Journal, 8(1), 29-36.

[241]Madubuko, E. M., & Adebayo, A. (2022) "Genomic medicine in Africa: A review of the literature." African Journal of Health Sciences, 35(2), 401-410. https://doi.org/10.4314/ajhs.v35i2.2

[242]George, B. L., & Ibeakanma, C. (2023) Assessing the Impact of Genomic Medicine on Cardiovascular Diseases in Africa. Cardiovascular Medicine, 23(2), 45-54. doi:10.1007/s12630-022-01919-9

Biospecimen, Biobanking and Data Governance in Africa

7

Biospecimen, Biobanking and Data Governance in Africa

7.1 Background

A biospecimen is a biological sample taken from a living organism, such as a human, animal, or plant, which can be used for scientific research or medical purposes. Biospecimens can include a wide range of materials, such as blood, tissue, urine, saliva, hair, cells, DNA, RNA, proteins, and other biological substances.[243] The samples are collected, processed, stored, and analysed to study various aspects of health, disease, genetics, physiology, and other biological processes.

A biobank is a specialised facility or repository that stores and manages a large collection of biospecimens, such as blood, tissue, cells, DNA, RNA, and other biological samples, along with associated data and information. Biobanks serve as centralised storage facilities that collect, process, store, and distribute biospecimens for research purposes, clinical trials, epidemiological studies, genetic analyses, biomarker discovery, drug development, and other scientific investigations.[244]

7.2 Biobanks in Africa

Biobanks are essential to the proper storage and distribution of biospecimens and their associated data for current and future research. They are important in Africa for several reasons, including the following:

- They provide researchers in Africa with access to a diverse and comprehensive collection of biospecimens, to enable high-quality studies on a wide range of health issues, diseases, and genetic variations.[245]
- Biobanks play a crucial role in supporting precision medicine initiatives, by providing researchers and healthcare professionals with the resources they need to tailor medical treatments and interventions to individual patients, based on their genetic makeup, lifestyle factors, and environmental influences.[246]
- Establishing biobanks in Africa builds local research capacity and enhances scientific infrastructure. It also fosters collaborations between African researchers, institutions, and international partners, and with traditional medicine practitioners. This can help strengthen the research ecosystem in Africa, promote knowledge sharing, and empower African scientists to lead cutting-edge research projects in various fields of biomedicine and public health.[247]
- Biobanks help to reduce health disparities in Africa and to improve healthcare equity, by providing researchers with the tools and resources needed to study diseases that disproportionately affect local populations.
- Biobanks also support public health initiatives in Africa by providing data and insights that can inform disease surveillance, outbreak response, and health policy development.
- Establishing biobanks presents opportunity for African countries to develop and implement ethical and regulatory frameworks for biospecimen collection, storage, and use.

[243]Akinola, O. I., & Onwudiwe, N. (2022) Biospecimen Management in African Research Institutions: A Pathway to Better Health Outcomes. The Pan African Medical Journal, 38, 54-63. doi:10.11604/pamj.2022.38.54.25187

[244]Gafane-Matemane, L., & Nkhahle, K. (2022) "Biospecimens and biobanks: Improving health research in Southern Africa." Southern African Journal of Infectious Diseases, 37(1), 1-7 https://doi.org/10.1080/23120053.2022.2051269

[245]Alabi, A., & Akintunde, A. (2023) "Biospecimen collection and management: Best practices for biobanks in Africa." African Journal of Health Sciences, 36(2), 150-160

[246]Boonwaat, L., & Omokanye, A. (2022) "Biobanking in Africa: Challenges and opportunities for research and policy." Bioethics, 36(4), 365-377. https://doi.org/10.1111/bioe.12903

[247]Adetunji, A., & Nwonye, R. (2022) "Establishing a biobank in Africa: Ethical and regulatory considerations." African Journal of Laboratory Medicine, 11(1), 1-8. https://doi.org/10.4102/ajlm.v11i1.1238

7.3 Examples of Biobanks in Africa

Some examples of biobanks in Africa include the following:

- **The Human, Heredity and Health in Africa (H3Africa) initiative,** a collaborative research programme that studies the genetic and environmental factors contributing to health and disease in African populations. The H3Africa Biobank Network includes multiple biobanks located in various African countries, such as South Africa, Nigeria, Kenya, and Uganda, which collect and store biospecimens for genetic and genomic research.[248]
- **The South African National Cancer Biobank** is a centralised facility that collects and stores biospecimens from cancer patients in South Africa. The biobank supports cancer research, biomarker discovery, and personalised medicine initiatives by providing researchers with access to high-quality tumour samples and the associated clinical data for studying cancer biology and treatment outcomes.[249]
- **The South African National Biodiversity Institute (SANBI) Biobank:** A national biobank that collects, stores, and manages plant, animal, and microbial biospecimens, and supports research on biodiversity, conservation, and bioprospecting in South Africa.
- **The KEMRI-Wellcome Trust Biobank:** A biobank located in Kilifi, Kenya, that collects, stores, and manages biospecimens from patients with various diseases, including malaria, tuberculosis, HIV, and cancer and cardiovascular disease. The biobank supports research on disease epidemiology, treatment outcomes, and health disparities in Kenya and East Africa.[250]
- **The East African Consortium for Clinical Research (EACCR) Biobank** is a collaborative initiative involving research institutions in Kenya, Uganda, Tanzania, and Rwanda. It collects biospecimens from patients participating in clinical research studies across the East African region and supports multidisciplinary research on infectious diseases, non-communicable diseases, and other health priorities in the region.[251]
- **The Nigerian Institute of Medical Research (NIMR) Biobank** is a national facility that collects and stores biospecimens from diverse patient populations in Nigeria. The biobank supports research on infectious diseases, genetic disorders, maternal and child health, and other health challenges facing populations in Nigeria and West Africa in general.
- **The Moroccan Human Biobank** is a national biorepository that collects and stores biospecimens from Moroccan individuals for biomedical research and clinical applications. It supports studies on genetic diversity, disease susceptibility, and personalised medicine in Morocco, and collaborates with international partners to advance research initiatives in North Africa and beyond.
- **The African Genome Variation Project (AGVP) Biobank** was established as a collaborative effort among researchers from institutions across Africa and around the world. The AGVP Biobank collects and stores biospecimens, including blood samples and DNA, from diverse populations across Africa. These biospecimens are accompanied by detailed demographic, clinical, and phenotypic data, allowing researchers to study the genetic and environmental factors influencing health and diseases in African populations.[252]

7.4 Challenges and Ethical Considerations in Biobanking in Africa

Initiatives to set up biobanks in Africa must consider the controversies that surround collection and transfer of biological samples and data within and outside Africa. These controversies are complex and multifaceted, involving ethical, legal, social, and economic considerations. Some of the key controversies include the following:

- **Concerns over informed consent and ownership of biological samples and data:** It is important that specimen donors are adequately informed about how their samples and data will be used, and to obtain their explicit consent for research purposes.
- **Concerns over ethics and integrity in biobank research:** It is important to ensure transparency and accountability to maintain trust and uphold ethical standards, and to balance the potential risks and benefits of transferring biological samples and data within and outside Africa.[253]
- **Potential exploitation of Africans in sample and data transfer:** There are concerns that researchers and organisations from outside Africa may extract

[248]Gafane-Matemane, L., & Nkhahle, K. (2022) "Biospecimens and biobanks: Improving health research in Southern Africa." Southern African Journal of Infectious Diseases, 37(1), 1-7 https://doi.org/10.1080/23120053.2022.2051269

[249]Lando, R., & Mwanga, A. (2023) Biobanking Initiatives and Their Impact on Health Equity in Africa. Global Health Action, 16(1), 2273048. doi:10.1080/16549716.2023.2273048

[250]Akinola, O. I., & Onwudiwe, N. (2022) Biospecimen Management in African Research Institutions: A Pathway to Better Health Outcomes. The Pan African Medical Journal, 38, 54-63. doi:10.11604/pamj.2022.38.54.25187

[251]Ndhlovu, Z., & Chikanda, A. W. (2022) "Governance of biospecimens: Best practices from biobanks in Africa" African Journal of Health Sciences, 35(3), 300-310. https://doi.org/10.4314/ajhs.v35i3.1

[252]Alabi, A., & Akintunde, A. (2023) "Biospecimen collection and management: Best practices for biobanks in Africa." African Journal of Health Sciences, 36(2), 150-160. https://doi.org/10.4314/ajhs.v36i2.5

[253]Nkosi, Z., & Duygu, E. (2023) Regulatory Approaches to Biobanking in Africa: A Comparative Analysis of Policy Frameworks. International Journal of Health Policy and Management, 12(10), 1-9. doi:10.34172/ijhpm.2023.0130

valuable genetic or biomedical information from African samples, without adequately compensating or benefiting the source communities. In the recent COVID-19 vaccine initiative, Africans benefited the least.

- **Data privacy and security:** There are significant concerns about data security in the transfer of biological samples and associated data within and outside Africa. It is important to observe confidentiality and to protect sensitive information, such as genetic data, health records, and personal identifiers, from unauthorised access, misuse, or breaches of privacy.[254]
- **Lack of standardised protocols and quality control** measures for biospecimen collection, storage, and data management raises concerns about the integrity of test results. The lack of harmonised governance and regulatory frameworks for biological sample and data transfer in Africa can lead to inconsistencies, gaps, and challenges in oversight and accountability.[255] Countries need to establish clear guidelines, policies, and legal frameworks to govern the collection, storage, sharing, and use of biological samples and data, to ensure compliance with international standards, and protection of participants' rights.[256]
- **Disparities in research capacity, infrastructure, and resources** between African countries and high-income regions can pose challenges to the transfer of biological samples and data within and outside Africa. Investing in capacity building, infrastructure development, and technology transfer can help bridge these gaps and enhance the capabilities of African institutions to participate in global biobanking networks.

7.5 Public policy Recommendations to Improve Biospecimen Governance in Africa

For African countries to fully leverage biobanking to improve their healthcare services, policymakers and other decisionmakers should consider the following recommendations:

- Establish clear laws, regulations, and policies to govern the collection, storage, and use of biospecimens in Africa, including defining the rights and responsibilities of researchers, biobanks, participants, and other stakeholders.
- Develop institutional policies and guidelines to govern the operations of biobanks, including procedures for sample collection, processing, storage, and sharing; data management and access; quality assurance and control; governance and oversight; and stakeholder engagement to secure fair and equitable sharing of benefits realised from biospecimens in Africa.[257]
- Develop and implement comprehensive ethical guidelines that outline the principles, standards, and procedures for the ethical conduct of biobanking activities in Africa.[258]
- Implement robust data security and privacy measures to protect the confidentiality, integrity, and security of biospecimen data, including encryption, access controls, data anonymisation, and data sharing agreements.[259]
- Provide training and capacity-building programmes for researchers, biobank staff, ethics committee members, and other stakeholders to enhance their knowledge, skills, and competencies in ethical, legal, and operational aspects of biobanking.[260]
- Engage with diverse stakeholders, including researchers, participants, community representatives, policymakers, and regulatory authorities, to ensure that biobanking activities are aligned with the needs, priorities, and expectations of the populations they serve.
- Biobanks should leverage technology and innovation, by adopting advanced technologies such as AI, block chain, robotics, and cloud computing, to enhance biospecimen collection, processing, and analysis, while improving data management, integration, and security.[261]

7.6 Priority Research Areas on Application of Data and Biospecimen in Healthcare Systems in Africa

Research in the following areas can contribute to advance biobanking in healthcare systems in Africa:

- Studies on utilisation of data and biospecimens to track and analyse infectious diseases such as malaria, HIV/AIDS, tuberculosis, Ebola and COVID-19.
- Research on the rise of anti-microbial resistance, a major threat to public health globally. Biobanks can be

[254]Maponga, T. G., & Kadima, M. (2024) Genomic Medicine and Health Policy: Transforming Healthcare Delivery in Zimbabwe. Journal of Public Health Policy, 45(1), 115-128. doi:10.1057/s41271-023-00320-2

[255]Khamis, A. A., & Nascimento, M. (2024). "Biospecimen-Based Studies in African Epidemiology: A Review." African Epidemiology Journal, 5(1), 15-25

[256]Eze, N., & Nwankwo, J. (2022). "Biospecimen Research and Public Health in Africa: Opportunities and Challenges." African Journal of Public Health, 15(4), 200-210

[257]Okeke, T., & Iwuoha, A. (2020) The Role of Biobanks in Strengthening Research Capacity and Healthcare Delivery in Nigeria. Journal of Community Genetics, 11(2), 192-200. doi:10.1007/s12687-020-00443-1

[258]Chung, S. P., & Maduka, O. (2023) Ethical Governance of Biobank Research: Perspectives from African Researchers. Journal of Medical Ethics, 49(1), 25-32. doi:10.1136/medethics-2021-107526

[259]Ibidapo, O., & Makanjuola, O. (2024) A Regulatory Framework for Biobanks in Africa: Bridging the Gaps in Data Governance. Journal of Health Regulation, 8(1), 15-27. doi:10.1016/j.jhr.2023.01.001

[260]Olutola, A., & Ezeani, I. (2024) Genomic Medicine as a Tool for Health Promotion in African Communities. International Journal of Health Promotion and Education, 62(1), 8-19. doi:10.1080/14635240.2023.2184769

[261]Alabi, A., & Akintunde, A. (2023) "Biospecimen collection and management: Best practices for biobanks in Africa." African Journal of Health Sciences, 36(2), 150-160. https://doi.org/10.4314/ajhs.v36i2.5

used to track the emergence and spread of resistant pathogens, as well as to develop new antimicrobial therapies.

- Clinical research to help develop more effective therapeutic solutions for resolving and managing issues caused by non-infectious diseases that can be inherited or caused by idiopathic mutations (for example thalassemia, sickle cell disease, G6PD deficiency and trisomies).[262]
- Research on screening programmes and diagnostic tools, based on biospecimen analysis, to analyse genetic variations of individuals for early detection of diseases such as cancer, and to develop tailored treatment.
- Pharmacogenetic testing and production of personalised medicine based on specimen and biospecimen stored in biobanks.[263]
- Investigating the factors affecting maternal and child health outcomes using biospecimens from mothers and infants.
- Studies on nutritional deficiencies and their impact on child development, using biospecimen.

- Developing systems to integrate and manage health data and biospecimens effectively.
- Research on ethical issues related to the collection, storage, and use of biospecimens.

7.7 Conclusion

Advancing biospecimen, biobanking, and data governance in Africa requires a holistic and proactive approach that prioritises ethical conduct, community ment, data integrity, and capacity building through research collaborations. The long-term sustainability of biobanks in Africa is critical to ensuring advancement of medical research and improving healthcare.[264] This document does not adequately address the financial models necessary to achieve this sustainability. It is essential to explore and implement robust funding strategies to maintain biobank operations in African countries and to ensure their ongoing contribution to healthcare innovation. Public-private partnerships, grants, and government funding and support are some of the ways sustainable funding can be achieved.

Establishing biobanks in Africa will significantly advance medical research and healthcare outcomes across the continent. However, it is imperative to develop and implement standardised protocols across all biobanking facilities to facilitate data sharing and collaboration among African researchers and ensure high quality and comparability of biospecimens and data.[265] The effectiveness, impact and benefits of having such standardised protocols across biobanks in Africa should be measured using a comprehensive impact assessment framework.[266] By promoting ethical, responsible, and inclusive utilisation of biospecimens and biobanks, researchers, policymakers, and stakeholders can contribute to the advancement of science, healthcare, and society's well-being in Africa and beyond.

[262]Lando, R., & Mwanga, A. (2023) Biobanking Initiatives and Their Impact on Health Equity in Africa. Global Health Action, 16(1), 2273048. doi:10.1080/16549716.2023.2273048

[263]Eze, N., & Nwankwo, J. (2022) "Biospecimen Research and Public Health in Africa: Opportunities and Challenges." African Journal of Public Health, 15(4), 200-210

[264]Nkosi, Z., & Duygu, E. (2023) Regulatory Approaches to Biobanking in Africa: A Comparative Analysis of Policy Frameworks. International Journal of Health Policy and Management, 12(10), 1-9. doi:10.34172/ijhpm.2023.0130

[265]Gafane-Matemane, L., & Nkhahle, K. (2022) "Biospecimens and biobanks: Improving health research in Southern Africa." Southern African Journal of Infectious Diseases, 37(1), 1-7 https://doi.org/10.1080/23120053.2022.2051269

[266]Chung, S. P., & Maduka, O. (2023) Ethical Governance of Biobank Research: Perspectives from African Researchers. Journal of Medical Ethics, 49(1), 25-32. doi:10.1136/medethics-2021-107526

Exploring Genetically-Based Vector Control Technologies to Control Infectious Diseases in Africa

8

Exploring Genetically-Based Vector Control Technologies to Control Infectious Diseases in Africa

8.1 Introduction

Genetically-Based Vector Control (GBVC) technologies are developed through genetic manipulation techniques to control the population of disease-carrying vectors, such as mosquitoes, flies, and ticks and so on.[267] The genetic manipulations are of various forms including the following:

- **Sterile Insect Technique (SIT)**, where sterile insects, which cannot reproduce, are released into the wild to reduce the vector population. This method has been successfully used to manage diseases such as dengue fever spread by mosquitoes.[268] Both field trials and real-world application have shown that SIT can significantly reduce disease transmission in people.
- **The Wolbachia Incompatible Insect Technique (IIT):** Insects that carry a bacterium called Wolbachia, which makes them reproductively incompatible with their wild counterparts, are released in the wild, thus eventually decreasing their population. Studies have demonstrated that Wolbachia-infected mosquitoes can interfere with the replication and transmission of pathogens within mosquito populations, leading to a reduction in disease transmission to humans.[269]
- **Gene Drive Technology:** Gene drives are advanced genetic systems that ensure a particular genetic trait is passed on to nearly all offspring, thereby spreading desired genes rapidly throughout a population.[270] There are different types of gene drives, each with varying mechanisms and purposes. In vector control, gene drives can be engineered to, for example, reduce the ability of mosquitoes to transmit diseases such as malaria by either reducing their population or altering their capacity to carry and spread the pathogen.[271]
- **CRISPR/Cas9-based Genetic Modification:** CRISPR/Cas9 technology enables scientists to make precise changes to the DNA of organisms to reduce their ability to spread diseases or to reproduce. Studies have shown that using CRISPR/Cas9 or RNAi can lead to smaller insect populations and less disease transmission, both in the lab and in real-world trials.[272]
- **RNA Interference (RNAi):** This is a technique that uses small Ribonucleic Acid (RNA) molecules to turn off specific genes in organisms, affecting their ability to reproduce, develop, or spread diseases.[273] Researchers have used RNAi to create mosquitoes resistant to diseases such as dengue, showing its potential for controlling disease transmission. Beyond disease control, RNAi is also used in gene therapy, pest control, and in studying gene functions in various organisms. It also holds promise for treating genetic disorders like Huntington's disease.

8.2 Benefits of Applying GBVC Technologies in Fighting Infectious Disease in Africa

GBVC technologies offer several potential benefits for fighting infectious diseases in Africa, particularly those transmitted by mosquitoes, such as malaria, dengue fever, chikungunya and zika, and can contribute to reducing the populations of tsetse flies that cause sleeping sickness. Using GBVC to control disease in Africa has the following advantages:

- They target specific vectors instead of being broad spectrum whereby even non-target organisms are affected.
- They generally have long-term effectiveness, thus reducing the need for repeated application. However, some GBVC methods, such as the Sterile Insect Technique (SIT), do require repeated applications.

[267]Rasgon, J. L. (2009). "Using transgenic Aedes mosquitoes for vector control." Journal of Visualized Experiments.

[268]Kittayapong, P., Ninphanomchai, S., Limohpasmanee, W., Chansang, C., Chansang, U., & Mongkalangoon, P. (2019). Combined sterile insect technique and incompatible insect technique: the first proof-of-concept to suppress aedes aegypti vector populations in semi-rural settings in thailand. PLOS Neglected Tropical Diseases, 13(10), e0007771. https://doi.org/10.1371/journal.pntd.0007771

[269]Raban, R. R., et al. (2020). "Progress towards engineering gene drives for population control." Journal of Experimental Biology

[270]Champer, J., Buchman, A., & Akbari, O. (2016). Cheating evolution: engineering gene drives to manipulate the fate of wild populations. Nature Reviews Genetics, 17(3), 146-159. https://doi.org/10.1038/nrg.2015.34

[271]Macias, V., Ohm, J., & Rasgon, J. (2017). Gene drive for mosquito control: where did it come from and where are we headed?. International Journal of Environmental Research and Public Health, 14(9), 1006. https://doi.org/10.3390/ijerph14091006

[272]Alphey, L. (2014). "Genetic Control of Mosquitoes." Annual Review of Entomology

[273]Ngô, H., Tschudi, C., Gull, K., & Ullu, E. (1998). Double-stranded rna induces mrna degradation intrypanosomabrucei. Proceedings of the National Academy of Sciences, 95(25), 14687-14692. https://doi.org/10.1073/pnas.95.25.14687

- They also may have minimal negative effects on the ecosystem including water resources and non-target organisms.[274]
- They can be integrated with other vector control approaches such as bed nets, insecticide-treated clothing, and antimalarial drugs.

8.3 Ethical and Regulatory Considerations on the Use of GBVCs for Public Healthcare in Africa

Some of the ethical and regulatory issues that African countries should consider in applying GBVC technologies include the following:

- **Community involvement:** Involving communities and individuals affected by GBVC interventions in the decision-making process is crucial.
- **Informed consent:** It is important to ensure that individuals and communities give informed consent in areas where these technologies are being tested or implemented, to respect their autonomy and human rights.[275]
- **Transparency:** The scientific community should maintain transparency in the development and deployment of the GBVC technologies. It is important to take into account potential resistance and scepticism from communities due to cultural, religious or social beliefs. Addressing these concerns calls for a multidisciplinary approach.

Regulatory frameworks governing the use of GBVC technologies for public health interventions in Africa are still evolving, and vary between countries and regions.[276] However, there are existing regulatory bodies and guidelines that can provide guidance and oversight for the deployment of these interventions. They include the following:

- **Biosafety regulations:** Many African countries have established biosafety regulations to ensure the safe use, handling, and transportation of genetically modified organisms (GMOs), including GBVC technologies. These regulations may include requirements for risk assessment, containment measures, monitoring and surveillance, and public consultation.[277] For example, several countries in the ECOWAS region have established comprehensive legal frameworks to regulate genetically modified organisms (GMOs) and living modified organisms (LMOs). Mauritania, Burkina Faso, Senegal, Mali, and Niger have implemented specific laws that define GMOs and LMOs, with a focus on the modification of genetic material through modern biotechnology. These regulations also address derived products, which are substances obtained from GMOs or LMOs.
- **National regulatory authorities:** Most countries typically have their own national regulatory authorities, who oversee the use of GMOs and other biotechnologies, including GBVC interventions. These authorities may develop regulations, guidelines, and approval processes for the research, development, field testing, and commercialisation of GBVC technologies.[278]
- **Regional regulatory structures:** Regional organisations, such as the African Union (AU) and regional economic communities (RECs), may play a role in harmonising regulations and guidelines for GBVC interventions across multiple countries within a region. For example, the African Union Development Agency-New Partnership for Africa's Development (AUDA-NEPAD) is supporting African countries to strengthen biosafety regulatory systems. In 2016, ECOWAS drafted a regional biosafety law for its member states, which was approved in 2020, during the Fifty-Seventh Ordinary Session, along with a 2020-2026 environmental action plan.[279] The legal structures ensure a standardised approach to managing biotechnological risks, with ECOWAS providing regional regulations that align with national laws to promote consistent governance across member states.[280]
- **Environmental laws:** Environmental law mechanisms are also integral to regulating GBVC technologies, ensuring that environmental impact is assessed and managed according to national and international standards.[281] Additionally, pharmaceutical regulations can be applied to validate health-related benefits claimed by GBVC technologies, ensuring that they meet necessary standards for public health interventions.[282]

[274]Windbichler, N., et al. (2011). "A synthetic homing endonuclease-based gene drive system in the human malaria mosquito." Nature.

[275]Sinkins, S. P., & Gould, F. (2006). "Gene drive systems for insect disease vectors." Nature Reviews Genetics.

[276]WHO. (2017). "Global vector control response 2017–2030." World Health Organization.

[277]Report of the High-Level African Union Panel on Emerging Technologies (APET) on Gene Drives for Malaria Control and Elimination in Africa (2018) AUDA-NEPAD, South Africa

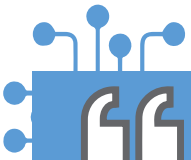
[278]Akinbo, O., Obukosia, S., Ouedraogo, J., Sinebo, W., Savadogo, M., Timpo, S., … & Ambali, A. (2021). Commercial release of genetically modified crops in africa: interface between biosafety regulatory systems and varietal release systems. Frontiers in Plant Science, 12. https://doi.org/10.3389/fpls.2021.605937

[279]Glover, B., Akinbo, O., Savadogo, M., Timpo, S., Lemgo, G., Sinebo, W., … & Ambali, A. (2018). Strengthening regulatory capacity for gene drives in africa: leveraging nepad's experience in establishing regulatory systems for medicines and gm crops in africa. BMC Proceedings, 12(S8). https://doi.org/10.1186/s12919-018-0108-y

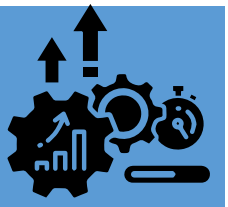
[280](Sanbi), T. and Barros, E. (2023). The african continent should consider a harmonized consultative and collaborative effort towards coordinated policy and regulatory guidelines across the fields of biotechnology. Frontiers in Bioengineering and Biotechnology, 11. https://doi.org/10.3389/fbioe.2023.1211789

[281]Wafula, D., Waithaka, M., Komen, J., & Karembu, M. (2012). Biosafety legislation and biotechnology development gains momentum in africa. Gm Crops & Food, 3(1), 72-77. https://doi.org/10.4161/gmcr.19708

[282]Komen, J., Tripathi, L., Mkoko, B., Ofosu, D., Oloka, H., & Wangari, D. (2020). Biosafety regulatory reviews and leeway to operate: case studies from sub-sahara africa. Frontiers in Plant Science, 11. https://doi.org/10.3389/fpls.2020.00130



> African governments should build local capacity in research, monitoring, and evaluation of vector control programmes. This includes having training programmes for scientists, healthcare workers, and community leaders, as well as investing in infrastructure and laboratory facilities, while avoiding unnecessary duplication of research and development efforts across all countries.



- **Ethics committees:** Research involving GBVC technologies may be subjected to review by institutional ethics committees or national bioethics committees, to ensure that ethical principles, such as informed consent, beneficence, and non-maleficence, are upheld.
- **International guidelines:** International organisations, such as the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), and the Convention on Biological Diversity (CBD), provide guidance and recommendations for the responsible use of biotechnologies, including GBVC interventions. These guidelines may inform national and regional regulatory frameworks in Africa.
- **Multilateral agreements:** Multilateral agreements such as the Cartagena Protocol on Biosafety, provide a framework for the safe transfer, handling, and use of GMOs, including GBVC technologies, across international borders. African countries that are parties to such protocols may adopt the provisions into their national regulatory systems.
- **Stakeholder engagement**, including consultations with local communities, civil society organisations, and other relevant stakeholders, is essential to ensure that regulatory frameworks for GBVC interventions reflect societal values, concerns, and priorities.

8.4 Policy Recommendations to support Optimal Application of GBVCs in Africa

African governments should consider implementing the following recommendations to optimise the application of GBVC technologies in their programmes and services:

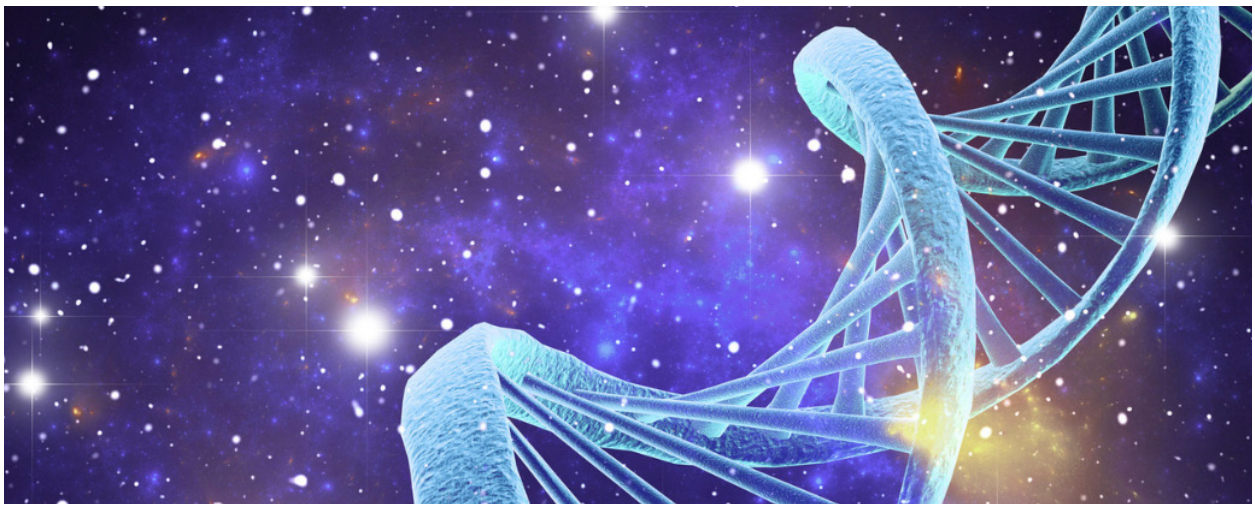
- Prioritise investment in research and development, to enhance the efficacy and safety of GBVC technologies. This includes raising funding for studies on genetic modifications, vector behaviour, and ecosystem impact.[283] Advocate for policy support at the national, regional, and international levels to prioritise investment in Genetically-Based Vector Control technologies as part of broader efforts to combat vector-borne diseases in Africa.
- Foster collaboration between governments, research institutions, non-governmental organisations (NGOs), and international agencies to share knowledge, resources, and expertise in implementing vector control strategies.
- Implement comprehensive community engagement and education programmes to raise public awareness and acceptance of GBVC technologies. This should involve consultation with local communities, addressing concerns, and providing accurate information about the benefits and risks associated with the technologies. Best practices in data portability and existing Environmental, Social, and Health Impact Assessment (ESHIA) processes should be embraced and promoted.[284]
- Develop robust regulatory frameworks to govern the deployment of GMOs for vector control. This includes putting in place risk assessment protocols, monitoring systems, and mechanisms for public consultation and participation in decision-making on GMO adoption and use.[285]
- Build local capacity in research, monitoring, and evaluation of vector control programmes. This includes having training programmes for scientists, healthcare workers, and community leaders, as well as investing in infrastructure and laboratory facilities, while avoiding unnecessary duplication of research and development efforts across all countries.[286]
- Promote an integrated approach to vector control that combines genetically-based strategies with other interventions such as insecticide-treated bed

[283]Bonsall, M. B. (2021). "Vector Control, Optimal Control, and Vector-Borne Disease Dynamics." In Population Biology of Vector-Borne Diseases

[284]Conteh, L., & Mace, J. (2020) Economic Implications of Genetically Engineered Vector Control in African Health Systems. Health Policy and Planning, 35(4), 461-470.

[285]James, A. A. (2005). "Gene drive systems in mosquitoes: rules of the road." Trends in Parasitology. Diabate, A., & Djouaka, R. (2022) Impact of Genetically Engineered Vectors on Malaria Transmission Dynamics: Insights from Field Trials. Malaria Journal, 21, 123.

[286]Osei, K. S., & Badu, K. (2020) "Ethics and public perception of genetically modified mosquitoes in Africa: A systematic review." Journal of Environmental Sciences, 94, 23



nets, indoor residual spraying, and environmental management. This holistic approach maximises effectiveness while minimising environmental impact and the risk of insecticide resistance.

- Ensure that the deployment of genetically-based vector control technologies adheres to ethical principles, including respect for human rights, informed consent, and social equity.

8.5 Priority Research Areas in the Development and Application of GBVC Technologies in Public Healthcare Systems in Africa

Research in the following priority areas of GBVC technologies can help advance their adoption into healthcare systems in Africa:

- Understanding the genetics and biology of vector species prevalent in Africa, such as mosquitoes (e.g., Anopheles, Aedes, and Culex species), tsetse flies, and sandflies.
- Investigating vector-host interactions, including feeding behaviour, breeding habitats, and host preferences.[287]
- Identifying genetic targets for vector control interventions, including genes associated with vector competence, reproduction, and behaviour.
- Conducting robust regional mechanisms and transboundary risk assessments to effectively manage and monitor the intentional spread of gene drives across populations and borders.
- Assessing the impact of environmental changes on vector distribution, abundance, and disease transmission patterns.
- Conducting social science research to understand community perceptions, attitudes, and behaviours related to genetically-based vector control technologies.
- Developing culturally sensitive and context-specific communication strategies to engage communities in decision-making processes and risk assessment.
- Studying the ethical, legal, and social considerations related to the deployment of genetically modified organisms (GMOs) for vector control.[288]
- Evaluating the potential risks and benefits of genetically-based vector control technologies from a social perspective, including issues of equity, justice, and consent.
- Research on early warning systems to detect and respond to emerging threats posed by vector-borne diseases and vector control interventions.[289]
- Strengthening regulatory and institutional frameworks for biosafety, biosecurity, and ethical oversight of genetically-based vector control technologies.[290]

8.6 Conclusion

GBVC) technologies offer great promise in the fight against vector-borne diseases, especially in Africa where these diseases claim thousands of lives each year. They are a great asset in public health and can specifically target and significantly reduce the populations of vectors, and support effective disease management. They offer the most promising long-term vector control, providing a sustainable alternative to traditional insecticide methods and minimising the environmental and health risks associated with pesticide use. To fully benefit from these emerging technologies, African countries should put in place regulatory and governance frameworks to support their development and use, as well as policies that support innovations.

[287]Fuchs, J., & Akuffo, H. (2024) Innovative Vector Management Strategies in Africa: A Focus on Biotechnologies. Health Systems & Reform, 10(2), e1986145

[288]Alphey, L. (2014). "Genetic Control of Mosquitoes." Annual Review of Entomology.

[289]Beech, C., & Wiegand, C. (2023) "Assessing the ecological risks of genetically modified vectors for malaria control in Africa." Ecological Applications, 33(1),

[290]Beaghton, A., et al. (2017). "Gene drive for population genetic control: non-functional resistance and parental effects." Proceedings of the Royal Society B.

Exploring Gene Drive Technology for Malaria Elimination in Africa

9

©FreePik

Exploring Gene Drive Technology for Malaria Elimination in Africa

9.1 Background

Each year, malaria infections result in hundreds of thousands of deaths in sub-Saharan Africa, with the majority of fatalities occurring in children under five. In 2022, 94% of all malaria cases globally and 95% of deaths were recorded in Africa; children under 5 years of age accounted for about 78% of all malaria deaths in Africa.[291] Thousands of lives, mostly of young children, are lost every year, which undermines efforts for increased life expectancy and improved wellbeing for the socio-economic transformation of the continent.[292] New tools are required to combat malaria and other vector-borne diseases on the continent.

Gene drive modified mosquitoes (GDMMs) have the potential to address Africa's persistent malaria problem but are still in the early stages of development and testing. Gene drive technology is a powerful genetic engineering tool that enables scientists to modify the genetic makeup of a population of organisms to ensure that a particular gene is passed on to a higher proportion of offspring than would occur naturally through Mendelian inheritance. Gene drive attempts to bias the inheritance of a particular gene so that it is passed on to the majority of offspring, as opposed to the typical 50% inheritance rate for most genes.[293]

Gene drive technology offers a new and potentially transformative method for overcoming many challenges in controlling the transmission of vector-borne diseases. While the technology is being explored for other diseases carried by mosquitoes, the research has been most vigorous in Anopheles mosquitoes, which are responsible for transmitting malaria in Africa, because this is arguably where new solutions are most urgently needed. The High-Level African Panel on Emerging Technologies recommended in its recent report, Gene Drives for Malaria Control and Elimination in Africa, that "Africa should invest in the development and regulation of gene drive technology, whose greatest and most urgent application will be in malaria control and elimination".

9.2 Research in Gene Drive Technology for Malaria Elimination in Africa

The following are some of the research studies currently being conducted in Africa on gene drives:

- Burkina Faso is a key player in gene drive research for malaria elimination through the Target Malaria project, a collaboration of researchers seeking to develop genetically modified mosquitoes with gene drive technology, to reduce malaria transmission. Field trials will be used to assess the effectiveness and safety of these modified mosquitoes in real-world settings.[294] If successful, this technology could significantly contribute to malaria elimination efforts in Burkina Faso and serve as a model for other malaria-endemic regions.
- The Uganda Virus Research Institute (UVRI) is researching gene drive mosquitoes as part of efforts to combat malaria in Uganda. The project is implemented in partnerships with international organisations and research institutions.
- Researchers in Mali are involved in co-producing knowledge related to gene drive mosquitoes for malaria eradication. The work involves examining how researchers, stakeholders, and local communities frame the concept of "co-development" between the Global North (such as the UK) and the Global South (like Mali). [295]
- Tanzania is actively involved in developing genetically modified mosquitoes with gene drive technology. Researchers from the Ifakara Health Institute in Tanzania are exploring the feasibility of using gene drive mosquitoes to control malaria transmission. Implementing gene drive technology in Tanzania could potentially lead to sustainable reductions in malaria incidence and contribute to achieving malaria elimination goals.

No gene drive mosquitoes have been deployed yet in Africa, and no field trials have been conducted anywhere in the world. The deployment of the technology will require it to be studied in a malaria transmission environment and the relevant regulatory approvals granted with appropriate stakeholder involvement.[296]

[291]World Health Organisation. Malaria Fact Sheet. https://www.who.int/news-room/fact-sheets/detail/malaria

[292]Dando, S. J., & Gleave, K. (2023) Gene-Editing for Vector Control: A Review of Gene-Drive Applications in Africa. Biotechnology Advances, 61, 107045

[293]Report of the High-Level African Union Panel on Emerging Technologies (APET) on Gene Drives for Malaria Control and Elimination in Africa (2018) AUDA-NEPAD, South Africa

[294]Boakye DA, Tetteh J, Appawu M, Adakudugu J. (2023) Lessons from the engagement of local communities in the piloting of genetically modified mosquitoes for controlling river blindness vectors in Ghana. Acta Trop.

[295]Banni, M., & Sogoba, N. (2022) A Review of Gene Drive Approaches for Malaria Vector Control in Africa: Ethical and Ecological Considerations. African Journal of Health Sciences

[296]Clements, A., & Lwande, W. (2023) Gene Drive Technologies for Malaria Control: A Path Forward in Africa. PLOS Neglected Tropical Diseases, 17(5)

9.3 Potential Benefits of Applying Gene Drive Technology to Fight Malaria in Africa

Gene drive technology offers innovative tools to control and eventually eradicate the disease-transmitting mosquitoes.[297] The anticipated benefits of using gene drive technology to combat malaria in Africa include the following:

- Gene drive technology will enable the precise targeting of malaria-transmitting mosquitoes, such as Anopheles species, by introducing genetic modifications that reduce their ability to transmit the malaria parasite.
- The technology could be used to reduce the sise of the population of malaria-transmitting mosquitoes in specific geographic areas, thereby decreasing the overall malaria transmission risk.
- It offers a potential tool for managing insecticide resistance in malaria-transmitting mosquito populations.
- Unlike traditional vector control methods that require continuous application and monitoring, gene drive technology has the potential to produce sustained and long-lasting effects on mosquito populations.[298]
- The technology can be tailored to address specific challenges and contexts related to malaria transmission in different regions of Africa. Customising gene drive interventions to target local mosquito species, transmission dynamics, and environmental conditions allows for the development of targeted and context-specific strategies to control malaria effectively in diverse African settings.[299]
- Gene drive technology can be used to target difficult-to-reach segments of the vector population, and of offering protection independent of other malaria interventions such as behavioural change, adoption of bed nets, or ready access to health care.
- Gene drive technology provides an additional tool to complement existing malaria control strategies, such as use of bed nets, insecticides, and antimalarial drugs, by reducing mosquito populations and preventing disease transmission.[300]

9.4 Ethical and Social-Cultural Considerations in Implementing Gene Drive Technology to Control Malaria in Africa

Researchers and other stakeholders should take the following considerations into account when deploying gene drive technologies to eliminate malaria:

- Engaging with communities in areas where the technology will be introduced is critical, through consultations, advisory boards, and educational outreach efforts. This can help to build trust, contribute to understanding community perspectives, and ensure that the voices of community members are heard in decision-making processes.[301]
- Informed consent is important in gene drive research. Researchers and public health authorities should take steps to ensure that individuals and communities have clear, understandable information about gene drive technology, its potential implications, and the risks and benefits associated with its use.
- Evaluating the potential risks and uncertainties associated with gene drive technology is vital to mitigate adverse ecological impacts and unintended consequences.
- Transparency in communication, decision-making processes, and research activities is crucial for building trust and credibility in the use of gene drive technology. Researchers should make efforts to provide transparent information to stakeholders, including local communities, policymakers, and the broader public, about research goals, methods, results, and potential implications of gene drive interventions.[302]

[297]Coulibaly YI, Traoré AB, Diallo D, Keita S, Toure MA. (2024) Social and cultural factors influencing the introduction of genetically modified mosquitoes to reduce malaria transmission in Guinea. Acta Trop.

[298]Coly, A., & Diagne, N. (2024) Gene Drive Strategies for Malaria Control: Lessons Learned from Field Trials in Africa. Acta Tropica,

[299]Diabate A, Dayo GK, Alves Silva J, Krishna R, Soumana M, Diallo M, Dao A, Perez K, Chandre F, Dicko A. (2021) Building and deploying proof-of-principle gene drive system in the wild reveals required levels of homing for effective population suppression. Proc Natl Acad Sci U S A.

[300]Chacko, J., & Nautiyal, P. (2022) "Gene editing and gene drives as strategic tools for vector control in Africa." Transgenic Research, 31(1), 27-39

[301]Bastos, C. M., & Boulton, A. (2022) "Ethical considerations for deploying gene drive technology in Africa." Bioethics, 36(2), 135-148. https://doi.org/10.1111/bioe.12815

[302]Banni, M., & Sogoba, N. (2022) A Review of Gene Drive Approaches for Malaria Vector Control in Africa: Ethical and Ecological Considerations. African Journal of Health Sciences, 23(3), 121-130

9.5 Potential Challenges and Risks Associated With the Implementation of Gene Drive Technology for Malaria Control in Africa

Implementation of gene drive technology faces several challenges and limitations, as follows:

- Long-term funding is limited, but necessary not only for research and development, but also for monitoring and managing gene drive releases over time.
- Developing and implementing gene drive technology in Africa will involve navigating complex regulatory frameworks.
- Technical multidisciplinary capacity is limited. Implementing gene drive interventions requires expertise in genetics, entomology, and vector control, a challenge in most African settings.[303]
- Many researchers do not adequately engage local communities, policymakers, and stakeholders in decision-making, potentially leading to resistance and low social acceptance of the technology in Africa.[304]
- Harmonisation of the biosafety and environmental regulatory requirements in risk assessments is also needed.

9.6 Regulatory Support to Support Responsible and Ethical Use of Gene Drive Technology in Malaria Control

Regulatory bodies can implement the following strategies to ensure the responsible and ethical use of gene drive technology in malaria control programmes:

- **Enhance and expedite existing regulatory frameworks:** Rather than developing entirely new frameworks, regulatory bodies can expedite the implementation and operationalisation of existing genetic modification and biosafety frameworks, particularly those under the Cartagena Protocol. The Convention on Biological Diversity (CBD) also offers guidance for risk assessment of gene drive organisms, which should be adopted.[305]
- **Conduct thorough risk assessments**, to identify and evaluate potential risks associated with gene drive technology in malaria control. The assessment results should be published on government websites and in the Cartagena Biosafety Clearinghouse (BCH) mechanism. This ensures transparency and public access to information.[306]
- **Enhance and adapt existing ethical review committees or advisory panels** to assess the ethical implications of gene drive interventions within the framework of established mandates.
- **Facilitate meaningful engagement** of local communities, stakeholders, and affected populations in decision-making on gene drive technology for malaria control. Countries can leverage the existing Environmental, Social, and Health Impact Assessment (ESHIA) processes and environmental laws that are well-established in other domains.[307]
- **Promote transparency in regulatory processes**, decision-making, and communication about gene drive technology for malaria control.
- **Invest in capacity building and training programmes** to enhance the expertise and knowledge of regulatory officials, researchers, and stakeholders on gene drive technology.
- **Establish mechanisms** for monitoring and evaluating the implementation and impact of gene drive interventions in malaria control. There is a need to establish regional frameworks or leverage existing ones, to ensure effective evaluation, communication, and monitoring of the transboundary movement of gene drive interventions, as well as any new or emerging malaria interventions.[308]

9.7 Policy Recommendations on sustainable Deployment of Gene Drive Technology

Below are some policy recommendations that African countries can implement to support the application of gene drive technology in malaria control:

- **Involve relevant stakeholders** in discussions, planning, and decision-making to ensure their perspectives and concerns are considered.
- **Establish multidisciplinary teams of researchers**, policymakers, public health authorities, and community representatives to work together on gene drive projects.
- **Provide regular updates** on implementation, share information openly, and adhere to ethical standards to build trust and accountability among stakeholders.[309]
- **Provide capacity-building opportunities** and training programmes for policymakers, public health authorities, and community representatives to enhance their understanding of gene drive technology.

[303]Fofana A, Diakite M, Konate L, Sangare AK. (2021) Public acceptance and ethical implications of utilizing gene drive technology for malaria control in Mali. Malar J. 20(1):4

[304]Koffi, A. A., & Alia, A. (2024) Potential Applications of Gene-Drive Technology Against Malaria in Africa: Current Insights and Future Directions. American Journal of Tropical Medicine and Hygiene, 110(6)

[305]Garba A, Sidikou F, Molinier P, Djibo A, Hugonnet S. (2024) Capacity building and infrastructure development for genetically modified mosquito research and release in Niger: challenges and opportunities. Acta Trop.

[306]Coulibaly YI, Traoré AB, Diallo D, Keita S, Toure MA. (2024) Social and cultural factors influencing the introduction of genetically modified mosquitoes to reduce malaria transmission in Guinea. Acta Trop.

[307]Labbé, P., & Wilke, K. (2023) Gene Drive Technologies in the African Context: Bridging Science, Ethics, and Community Engagement. BMC Public Health, 23, 123

[308]Coly, A., & Diagne, N. (2024) Gene Drive Strategies for Malaria Control: Lessons Learned from Field Trials in Africa. Acta Tropica

[309]Report of the High-Level African Union Panel on Emerging Technologies (APET) on Gene Drives for Malaria Control and Elimination in Africa (2018) AUDA-NEPAD, South Africa

- Collaborate with existing platforms, such as research consortia, public health organisations, and civil society groups, to leverage their expertise, resources, and support.
- Adopt and adapt existing ethical guidelines to govern gene drive deployment and ensure that they remain relevant and adaptable to future technologies.[310]
- Streamline and align biosafety and environmental regulations.
- Establish quality assurance and management mechanisms for gene drive technology.

9.8 Priority Research and Development Areas for Gene Drives in Africa

Research on gene drive technologies should cover the following priority areas, to promote their adoption in African public health systems:

- Environmental risk assessment for gene drive applications, founded in a problem formulation approach and addressed using specific operational protection goals.
- Investigations into how the gene drive technology will potentially interact with existing interventions, such as Long-Lasting Insecticide Nets (LLINs), Indoor Residual Spraying (IRS), Artemisinin-based Combination Therapies (ACTs) and vaccines, on a case-by-case basis, depending on the nature and intended effect of the gene drive.[311]
- Investigations into the potential for selection or evolution of resistance to the genetic transformations, and examination of the stability and spread of the gene drives, under conditions of potential mutations in the targeted alleles, framed as potential and evaluated on a case-by-case basis.
- Investigations into the effects of potential resistance to insecticides currently used for malaria control, and strategies for introducing gene drive mosquitoes in communities with insecticide-resistant wild populations, considering the specific context and intended outcomes.
- Systematic investigations into the ecology and potential gene flow within various populations of dominant malaria-transmitting mosquitoes of different species on a case-by-case basis. These should be conducted through the national or regional Environmental, Social, and Health Impact Assessment (ESHIA) and Strategic Environment Assessment (SEA) processes and approached on a case-by-case basis according to the gene drive's nature and intended effects.[312]
- Sociological, anthropological, and human behaviour studies on how communities would respond to the implementation of gene drive for malaria mosquitoes, conducted on a case-by-case basis, and considering the specific context of replacement versus suppression strategies.[313]
- Economic evaluations to determine the potential gains and opportunities for synergy with other interventions in the implementation of gene drives, evaluated on a case-by-case basis.
- Health, social and environmental impact assessments to identify any potential negative impacts and mitigation strategies, using SEA approaches, ideally conducted on a regional basis.

9.9 Conclusion

Research on gene drive is expected to take several more years before the technology to be ready for field testing. However, as research continues, it is important to agree on best practices for responsible development and testing to lay the necessary groundwork for implementation. In 2018, the AU High Level Panel on Emerging Technologies published recommendations for the development of gene drive-modified mosquitoes, and provided comprehensive guidance covering technical, regulatory and ethical aspects of research that can guide applications in public health.[313] Work from the AUDA-NEPAD Integrated Vector Management (IVM) programme shows that low-threshold gene drive-modified products can be tested in a safe and ethical manner, although this will require significant advanced planning and coordination by researchers, funders, regulators, and policymakers. In determining the future of this technology, decision-makers, communities and other stakeholders must weigh concerns about the potential risks of gene drive-modified mosquito products against the potential benefit of ending the long and deadly history of malaria in Africa.

The existing biosafety laws, ESHIA, and SEA mechanisms provide adequate frameworks to systematically assess these risks and benefits. Researchers and decision-makers can leverage these established processes without reinventing the wheel for each new technology. Although they hold great promise to help combat vector-borne diseases, the use of gene drive technology raises legal, ethical, ecological, and social concerns, including potential unintended consequences, biodiversity impacts, and regulatory challenges especially around transboundary movement.[315] Effective regional coordination is therefore crucial, along with the implementation and compliance with existing laws such as the ECOWAS biosafety law. Responsible research and governance frameworks are necessary to ensure that gene drive applications are deployed safely, ethically, and effectively, given their potential risks and benefits.

[310]Ndindah, J., & Mugo, H. (2024) Socioeconomic Impacts of Implementing Gene Drive Technology for Malaria Control in Africa. Global Health Action, 17(1),

[311]Garba A, Sidikou F, Molinier P, Djibo A, Hugonnet S. (2024) Capacity building and infrastructure development for genetically modified mosquito research and release in Niger: challenges and opportunities. Acta Trop.

[312]Kamdem, C., & Diabate, A. (2023) Field Applications of Gene Drive Technologies in Vector Control: A Case Study from Africa. International Journal of Tropical Insect Science, 43(1)

[313]Boakye DA, Tetteh J, Appawu M, Adakudugu J. (2023) Lessons from the engagement of local communities in the piloting of genetically modified mosquitoes for controlling river blindness vectors in Ghana. Acta Trop.

[314]Report of the High-Level African Union Panel on Emerging Technologies (APET) on Gene Drives for Malaria Control and Elimination in Africa (2018) AUDA-NEPAD, South Africa

[315]Ndindah, J., & Mugo, H. (2024) Socioeconomic Impacts of Implementing Gene Drive Technology for Malaria Control in Africa. Global Health Action, 17(1), 2020570

One Health Concept and its Implementation in Africa

10

© FreePik

One Health Concept and its Implementation in Africa

10.1 Background

One Health is a globally relevant "integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals and ecosystems. It recognises the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are intricately linked and inter-dependent."[316] It is a collaborative, multisectoral, and transdisciplinary approach, implemented at the local, national, regional and global levels, to achieve optimal health outcomes that recognise the interconnection between people, animals, plants, and their shared environment.[317] It evolved from the recognition that an interdisciplinary approach is required to understand and address complex health problems and that the health of humans, animals and the environment are inextricably linked. One Health approaches involve collaboration between human health, veterinary, and environmental sectors to monitor, detect, and respond to diseases like Ebola, Rift Valley Fever, and Avian Influenza. It emphasises the idea that the health of humans, animals, and ecosystems are closely interconnected and that addressing health issues in one sector can have a positive or negative impact on the others.

In recent decades, the One Health approach has gained traction in combatting zoonotic diseases, infectious agents shared between animals and people, which are a formidable challenge. Evolving conditions due to factors such as climate change, land use change (e.g., deforestation and agricultural intensification), and increasing cross-border travel and trade have contributed to the emergence of these diseases.[318]

The One Health approach also plays a crucial role in addressing global challenges such as climate change and sustainable development. It mobilises multiple sectors, disciplines and communities to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development. There is added value achieved through this unified approach in terms of health metrics, cost savings, and environmental services – One Health can save lives by improving the efficient use of resources (finances, infrastructure, and personnel) and the quality and timeliness of healthcare delivery.[319]

Internationally, the tripartite organisations, namely the Food and Agriculture Organisation of the United Nations (FAO), the World Organisation for Animal Health (OIE), and the World Health Organization (WHO), provide a model of a multisectoral approach through mandated inter-agency collaboration, and endorsement of One Health to facilitate sustained collaboration for zoonotic disease control at the local, subnational, national, regional, and international level.[320]

One Health approach also plays a critical role in achieving the Sustainable Development Goals (SDGs) targets related to good health and well-being (SDG 3), clean water and sanitation (SDG 6), and life on land (SDG 15). Additionally, the One Health framework supports the African Union's Agenda 2063 and the Africa Health Strategy 2016-2030, by promoting integrated and sustainable health practices that address the complex interplay between human, animal, and environmental health.[321] African countries can leverage One Health to meet both continental and global health objectives.

However, despite the increasing awareness of the benefits and value of the approach, lack of communication and coordination between human health, animal health, and environment sectors can still hinder its implementation. The Africa CDC endorses its use in addressing the shared human, animal and environmental health threats in Africa.[322] A One Health approach is necessary to deliver effective and efficient infectious disease surveillance, disease prevention and control, as well as public health emergency preparedness and response to achieve AU's vision in Agenda 2063: the Africa We Want.

[316]Akudjedu, J. M., & Nkrumah, F. (2021) One Health in Africa: An Integrated Approach to Combat Zoonotic Diseases. African Journal of Health Sciences, 38(3), 229. doi:10.4314/ajhs.v38i3.5

[317]ibid

[318]Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." BMC Public Health, 23(1), 450 https://doi.org/10.1186/s12889-023-15703-4

[319]Makoni, M. (2023) "Adopting One Health approaches to enhance disease surveillance in Africa." The Lancet Planetary Health, 7(2), e130. https://doi.org/10.1016/S2542-5196(22)00345-X

[320]Wanyonyi, S. S., & Muchemi, J. (2024) "Evaluating the effectiveness of One Health policy frameworks in African nations" Journal of Social Medicine, 15(1), 75-85. https://doi.org/10.1016/j.socmed.2024.01.010

[321]Rwabigwi, J., & Bobe, S. (2023) Adopting One Health in Africa: A Case Study from Tanzania. Journal of Environmental and Public Health, 2023, 5642101. doi:10.1155/2023/5642101

[322]Chanda, E. K., & Masalila, H. (2022) "One Health frameworks for predicting zoonotic diseases in Africa." Journal of Zoonotic Diseases, 7(3), 175-185. https://doi.org/10.1007/s41575-022-00344-1

10.2 Application of One Health Approach in Africa

The following are some of the ways in which the One Health approach is being implemented across Africa:

- **Strengthening surveillance systems:** African countries are developing and strengthening surveillance systems using the One Health approach, to monitor zoonotic diseases (diseases transmitted between animals and humans such as Ebola, Rift Valley Fever, and avian influenza).
- **Rapid response to disease outbreaks:** Countries deploy rapid response teams composed of professionals drawn from human health, veterinary medicine, and wildlife sectors are deployed to detect and respond promptly to disease outbreaks.
- **Conservation:** One Health principles are integrated into conservation efforts to preserve biodiversity and natural habitats, which are crucial for maintaining ecosystem balance and reducing disease transmission risks. For example, managing wildlife health prevents the spread of diseases such as tuberculosis and anthrax from wildlife to domestic animals and humans.[323]
- **Reducing risk of disease:** Measures to improve the health of livestock, also reduce the risk of diseases transmitted from animals to humans through food consumption or direct contact.
- **Climate change adaptation:** One Health is integrated into climate change adaptation strategies to address the health impacts of environmental changes. This includes promoting resilient agricultural practices and mitigating the effects of climate-related health hazards.[324]
- **Addressing antibiotic resistance:** Antibiotic resistance is a global health concern, and Africa is no exception. One Health strategies promote the responsible use of antibiotics in both human healthcare and agriculture (in livestock), as well as environmental stewardship to minimise contamination with antimicrobial residues.
- **Improving food safety:** One Health principles are applied to improve food safety standards, monitor foodborne illnesses that can affect both humans and animals, and implement practices that reduce the risk of contamination along the food chain.[325]
- **Integrated development:** One Health approach encourages integrated planning and development of health infrastructure that considers the needs of both human and animal populations.

> One Health approach also plays a critical role in achieving the Sustainable Development Goals (SDGs) targets related to good health and well-being (SDG 3), clean water and sanitation (SDG 6), and life on land (SDG 15).

10.3 Examples of One Health Application in Africa

The One Health concept has been actively tested and applied in various African countries, to address a range of health challenges that intersect human, animal, and environmental health. Some successful examples include the following:

- In Kenya, the One Health approach has been used to monitor and control zoonotic diseases such as Rift Valley Fever and avian influenza, which can impact both human and animal populations. In Uganda, collaborative efforts between the human

[323]Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." BMC Public Health, 23(1), 450 https://doi.org/10.1186/s12889-023-15703-4

[324]Da Silva, F. J., & Azevedo, J. (2024) One Health and Climate Change: Impacts on Public Health in Africa. Journal of Environmental Management, 325, 116418. doi:10.1016/j.jenvman.2023.116418

[325]Eze, E. A., & Okonkwo, C. (2023) Strengthening Veterinary Surveillance Systems: A One Health Approach in the African Context. Tropical Animal Health and Production, 55(2), 123. doi:10.1007/s11250-023-03322-0

health, veterinary, and wildlife sectors have been instrumental in monitoring diseases such as Ebola and addressing outbreaks.[326]

- In Tanzania, biodiversity conservation initiatives also address sustainable land use practices that benefit both wildlife and human populations, promoting healthier ecosystems and reducing disease transmission risks. Botswana has implemented One Health strategies to manage wildlife health and mitigate human-wildlife conflicts, such as when diseases such as anthrax affect both wildlife and livestock.
- Several African countries have integrated One Health approaches into food safety systems, ensuring that agricultural practices and food production are managed in ways that minimise health risks for consumers and workers alike.
- In Ethiopia, efforts have been made to integrate One Health into climate change adaptation strategies, recognising the impact of environmental changes on health outcomes for both humans and animals.
- Many African countries have established One Health platforms and task forces that bring together professionals from human health, veterinary medicine, environmental science, agriculture, and other sectors to collaborate on health issues.[327] They also implement capacity building programmes to train health workers, veterinarians, and environmental scientists in One Health principles and practices.

Other examples of the application of One Health approach include the following:

- During the Ebola outbreak in West Africa (2014-2016), Guinea, Sierra Leone, and Liberia implemented One Health approaches to contain the spread of the virus.[328] The response included coordination between human health agencies, veterinary services, and wildlife experts to understand the transmission dynamics, conduct surveillance, and engage communities in prevention and control efforts.
- In East Africa, Rift Valley Fever outbreaks have been managed using One Health strategies, which involve collaboration between human health authorities, veterinary services, and environmental agencies. This approach includes early warning systems based on climate and environmental factors, vaccination campaigns for livestock, and public health education on reducing human exposure to infected animals and their products.[329]
- In pastoralist communities in Somalia and Kenya, where livestock plays a crucial role in livelihoods and nutrition, One Health principles are applied to improve animal health, food safety, and human health outcomes. This consists of vaccination campaigns against zoonotic diseases such as brucellosis and tuberculosis, promoting hygiene practices during animal handling and food preparation, and integrating veterinary services with primary healthcare initiatives.
- In Zambia and Tanzania, One Health approaches have been used to enhance malaria control efforts by addressing vector control and environmental management. This is done through coordinated efforts between health ministries, environmental agencies, and local communities to implement use of insecticide-treated bed nets, indoor residual spraying, and habitat modification to reduce mosquito breeding sites.
- In Uganda and Kenya, One Health strategies are applied to prevent waterborne diseases such as cholera, by improving access to safe water sources, sanitation facilities, and hygiene education. This involves collaboration between health authorities, water and sanitation agencies, and community leaders to promote clean water practices, ensure proper sanitation infrastructure, and conduct disease surveillance to detect outbreaks early.[330]
- Many rural communities across Africa benefit from integrated health services that apply One Health principles. For example, mobile health clinics provide healthcare services to both humans and livestock, addressing basic healthcare needs while also promoting animal health and disease prevention.
- In regions where access to clean water and sanitation is limited, waterborne diseases such as cholera and typhoid pose significant health threats. One Health initiatives combine efforts to improve water quality, sanitation infrastructure, and hygiene practices. For example, in communities along Lake Victoria in Kenya, Tanzania, and Uganda, integrated approaches that involve health education, environmental management,

[326]Kanyinji, K., & Zulu, M. (2021) Integrating Human, Animal, and Ecosystem Health in Zambia: One Health in Action. Journal of Health and Pollution, 11(30), 210404. doi:10.5696/2156-9614-11.30.210404

[327]Mwanga, J. R., & Kilonzo, B. S. (2022) "Integrating human, animal, and environmental health: One Health perspectives in Africa." Environmental Science & Policy, 133, 12-19. https://doi.org/10.1016/j.envsci.2022.10.014

[328]Ademe, S. K., & Glaziou, P. (2023) "Integrating One Health approaches into national health policies in Africa." Global Health Action, 16(1), 2081589 https://doi.org/10.1080/16549716.2023.2081589

[329]Da Silva, F. J., & Azevedo, J. (2024) One Health and Climate Change: Impacts on Public Health in Africa. Journal of Environmental Management, 325, 116418. doi:10.1016/j.jenvman.2023.116418

[330]Mbonye, A. K., & Rukundo, A. (2024) Engaging Communities in One Health Initiatives: Lessons from Uganda. Journal of Community Health, 49(2), 205-213. doi:10.1007/s10900-023-01286-4

and improved water treatment have reduced the incidence of waterborne diseases.[331]

- Preventing the spread of infectious diseases across national boundaries requires cross-border disease surveillance and control. In West Africa, some countries such as Ghana, Burkina Faso, and Côte d'Ivoire have established cross-border One Health committees and surveillance networks.[332] These initiatives facilitate information sharing, joint response planning, and harmonised control measures for diseases such as avian influenza and tuberculosis, which affect both humans and animals.

10.4 Complementary Technologies to Adaptation of the One Health Approach in the Healthcare System

The following technologies can complement One Health approach in the African healthcare system:

- **Health Information Systems**, such as electronic medical records, health data management, and surveillance systems can integrate human and animal health data for comprehensive analysis and decision-making.
- **Genomics and Molecular Diagnostics**, such as Next-Generation Sequencing (NGS) facilitate rapid and accurate identification of pathogens and characterisation of disease outbreaks, enabling epidemiological investigations and targeted control measures.
- **Geographic Information Systems (GIS)** are used to analyse spatial data related to disease outbreaks, environmental factors, and animal populations, to understand disease transmission dynamics and guide intervention strategies.[333]
- **Blockchain and Digital Ledger Technologies** ensure transparent and secure sharing of health data across stakeholders, while maintaining privacy and data integrity. Supply Chain Management tracks and verifies the authenticity of pharmaceuticals, vaccines, and medical supplies, reducing the prevalence of counterfeit products and ensuring quality healthcare delivery.
- **Predictive Analytics** is used to analyse large datasets, forecast disease outbreaks, identify high-risk areas, and optimise resource allocation for prevention and response efforts.
- **Biological and vaccine technologies** facilitate the development of vaccines, diagnostic and therapeutic products for zoonotic diseases and antimicrobial-resistant pathogens, addressing threats to human and animal health.[334]
- **IoT (Internet of Things) and sensor technologies** are used to monitor air and water quality, temperature, and vector populations, providing real-time data for early warning systems and ecosystem health assessment.

[331]Akudjedu, J. M., & Nkrumah, F. (2021) One Health in Africa: An Integrated Approach to Combat Zoonotic Diseases. African Journal of Health Sciences, 38(3), 229-243. doi:10.4314/ajhs.v38i3.5

[332]Wanyonyi, S. S., & Muchemi, J. (2024) "Evaluating the effectiveness of One Health policy frameworks in African nations" Journal of Social Medicine, 15(1), 75-85. https://doi.org/10.1016/j.socmed.2024.01.010

[333]Rwabigwi, J., & Bobe, S. (2023) Adopting One Health in Africa: A Case Study from Tanzania. Journal of Environmental and Public Health, 2023, 5642101. doi:10.1155/2023/5642101

[334]Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." BMC Public Health, 23(1), 450 https://doi.org/10.1186/s12889-023-15703-4

10.5 Human Resource Needs for Harnessing One Health in Africa

While there are efforts underway to build capacity and enhance interdisciplinary collaboration in the application of One Health in Africa, the following factors contribute to the existing capacity gaps:

- Many African countries lack formal training programmes that integrate human health, veterinary medicine, environmental science, and other relevant disciplines.[335] This limits the number of professionals with expertise in One Health approaches. There is need for ongoing training and capacity-building on One Health and integrated health approaches, and emerging diseases, and new diagnostic tools.
- Expertise in One Health is often concentrated in urban centres and academic institutions. In contrast, rural and remote areas, where many health challenges are most acute, may lack sufficient skilled personnel.[336]
- Budgetary constraints and competing health priorities may limit investments in training programmes and interdisciplinary research initiatives that support One Health principles.
- Fragmentation between human health, animal health, and environmental sectors hinders collaborative efforts and the implementation of integrated health strategies.
- Policymakers, healthcare professionals, and communities may have limited awareness of One Health's benefits, which can impact support for its adoption and resource allocation.[337]

10.6 Ethical and Socio-Cultural Considerations in the Application of the One Health Approach in the Health System in Africa

Efforts to adopt One Health approach in African countries should consider key socio-cultural issues, including the following:

- Livestock and domestic animals have cultural and economic significance in many African societies. Practices such as pastoralism and animal husbandry are integral to the livelihoods of communities and food security. One Health initiatives should consider the role animals play in communities and engage owners in disease prevention and health promotion efforts.
- Most African societies value community participation and collective decision-making. To ensure that they are culturally appropriate, sustainable, and accepted, One Health interventions should engage local communities, traditional leaders, and community health workers.[338]
- Gender dynamics play a significant role in health-seeking behaviours and healthcare access in Africa. Women often have primary responsibility for household health and nutrition, including animal care. One Health programmes should address gender-specific needs and roles, to promote equitable access to services and information.
- Religious and spiritual beliefs influence health perceptions and behaviours in many African communities. Understanding and respecting these beliefs is essential to promote acceptance of One Health interventions.[339]
- Effective communication is crucial for disseminating health information and promoting behaviour change. One Health initiatives should use local languages and culturally appropriate communication channels (such as community gatherings, radio, and drama) to reach diverse populations.
- Diseases, particularly zoonotic diseases, can carry stigma in some communities. It is important to address stigma through education, awareness campaigns, and community engagement for effective disease prevention, detection, and treatment.[340]
- Traditional food preparation and consumption practices, as well as water management practices, may affect health outcomes and disease transmission. One Health approaches should consider these practices to promote safe food handling, water sanitation, and hygiene practices.
- Indigenous knowledge and practices related to land use, natural resource management, and environmental conservation play a role in health outcomes. Incorporating traditional ecological knowledge into One Health strategies can promote sustainable environmental practices and improve community health.[341]

[335]Mbonye, A. K., & Rukundo, A. (2024) Engaging Communities in One Health Initiatives: Lessons from Uganda. Journal of Community Health, 49(2), 205-213. doi:10.1007/s10900-023-01286-4

[336]Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." BMC Public Health, 23(1), 450 https://doi.org/10.1186/s12889-023-15703-4

[337]Wanyonyi, S. S., & Muchemi, J. (2024) "Evaluating the effectiveness of One Health policy frameworks in African nations" Journal of Social Medicine, 15(1), 75-85. https://doi.org/10.1016/j.socmed.2024.01.010

[338]Salami, H. A., & Phillips, W. A. (2023) "Community engagement in One Health: A strategy for combating zoonotic diseases in Africa" Journal of Community Health, 48(2), 293-301. https://doi.org/10.1007/s10900-022-01210-2

[339]Akudjedu, J. M., & Nkrumah, F. (2021) One Health in Africa: An Integrated Approach to Combat Zoonotic Diseases. African Journal of Health Sciences, 38(3), 229-243

[340]Mbonye, A. K., & Rukundo, A. (2024) Engaging Communities in One Health Initiatives: Lessons from Uganda. Journal of Community Health, 49(2), 205-213. doi:10.1007/s10900-023-01286-4

[341]Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." BMC Public Health

10.7 Policy Recommendations to Promote Application of One Health Approach in the Healthcare System in Africa

To increase the use of the One Health approach in Africa, policymakers should consider the following recommendations:

- Develop and implement national One Health policies and strategies that integrate human health, animal health, and environmental health considerations.
- Establish mechanisms for multi-sectoral collaboration and coordination among health, agriculture, environment, wildlife, and other relevant sectors.
- Invest in training and capacity building initiatives to equip healthcare professionals, veterinarians, environmental scientists, and policymakers with interdisciplinary skills in One Health approaches.[342]
- Integrate One Health principles into educational curricula at universities and training institutions.
- Support research initiatives that prioritise One Health topics, including zoonotic diseases, antimicrobial resistance, environmental health, and food safety.
- Implement community engagement strategies to raise awareness about One Health concepts and principles. Foster partnerships with local communities, traditional leaders, and civil society organisations to promote behaviour change and sustainable health practices.
- Provide financial incentives, grants, and funding mechanisms to support One Health initiatives at national, regional, and local levels.
- Harmonise regulatory frameworks across health, agriculture, environment, and other relevant sectors to facilitate integrated approaches to disease control, food safety, and environmental management.[343]
- Establish monitoring and evaluation frameworks to assess the impact of One Health interventions on health outcomes, environmental sustainability, and socio-economic development.

10.8 Priority Research Areas in the Application of One Health Approach in Public Healthcare Systems in Africa

Research or study in the following priority areas can inform and advance the application of One Health approach in African public health systems:

- Epidemiology of zoonotic diseases, as well as the transmission dynamics, and risk factors.
- Linkages between environmental degradation, climate change, and human health outcomes.[344]
- Foodborne diseases, food safety practices, and microbial contamination in food chains.
- Health financing mechanisms and resource allocation for integrated health interventions.
- Community perceptions, knowledge, and practices related to One Health concepts.
- Opportunities for collaboration between researchers and practitioners from human health, animal health, environmental sector to address complex health challenges.[345]

10.9 Conclusion

One Health emphasises the interconnectedness between human and animal health and the environment. To be successful, One Health initiatives demand communication, coordination, and collaboration across multiple sectors, disciplines, and levels of government. Undoubtedly, One Health has its challenges: collaboration and integration are not easy, and the benefits of taking a One Health approach may require a longer time frame to measure success.[346]

Although the One Health concept has existed for some time, until recently, its use had been hampered by a lack of financing for research and development. A lack of tools, methodologies, and leadership to drive the agenda forward also affected its adoption. Implementing One Health projects remains complex because it invariably entails collaboration among multiple parties. However, using a One Health framework enables us to better understand the synergies between different efforts to address human, animal, and ecological health issues. It also provides a mechanism for us to better understand the ways in which these issues can be antagonistic, and how we can mitigate the risk of addressing one area.

[342]Eze, E. A., & Okonkwo, C. (2023) Strengthening Veterinary Surveillance Systems: A One Health Approach in the African Context. Tropical Animal Health and Production, 55(2), 123. doi:10.1007/s11250-023-03322-0

[343]Mwanga, J. R., & Kilonzo, B. S. (2022) "Integrating human, animal, and environmental health: One Health perspectives in Africa." Environmental Science & Policy, 133, 12-19. https://doi.org/10.1016/j.envsci.2022.10.014

[344]Rwabigwi, J., & Bobe, S. (2023) Adopting One Health in Africa: A Case Study from Tanzania. Journal of Environmental and Public Health, 2023, 5642101. doi:10.1155/2023/5642101

[345]Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." BMC Public Health, 23(1), 450 https://doi.org/10.1186/s12889-023-15703-4

[346]Chanda, E. K., & Masalila, H. (2022) "One Health frameworks for predicting zoonotic diseases in Africa." Journal of Zoonotic Diseases, 7(3), 175-185. https://doi.org/10.1007/s41575-022-00344-1

Harnessing Emerging Technologies to Improve Maternal, Neonatal and Child Health in Africa

11

Harnessing Emerging Technologies to Improve Maternal, Neonatal and Child Health in Africa

11.1 Background

Maternal, neonatal and child health (MNCH) encompasses the health of women during pregnancy, childbirth and postnatal period and the health of newborns and children. Maternal health covers prenatal care, skilled attendance at birth and obstetric care to prevent and manage complications during childbirth.[347] Neonatal health refers to health of newborn infants during the first 28 days of life. It encompasses safe delivery, care to newborns, managing newborn infections and complications of prematurity, low birth weight and birth defects. Child health focuses on the physical, mental and social well-being of children from infancy to adolescence. During this period, healthcare services focus on preventing and managing childhood illnesses, supporting healthy growth and development, and providing immunisation.

MNCH programmes are particularly important in the low to middle income countries because of the limitations of healthcare services. According to the World Health Organization, almost all (99%) of maternal deaths occur in developing countries, and 68% occur in sub-Saharan Africa alone.[348] An estimated 5.2 million children under 5 years died globally from preventable and treatable causes in 2021.[349] Sub-Saharan Africa remains the region with the highest under-5 mortality rate in the world, with one in 13 children dying before turning five. Despite improvements in maternal and child health over the past two decades, about 800 women still die in Africa every day,[350] mostly from preventable causes related to pregnancy complications and childbirth. Although a 39% decline in maternal mortality was observed between 2003-2021, the rate is still one of the largest in the world.[351]

Emerging health technologies offer opportunities to improve maternal health outcomes across sub-Saharan Africa, where access to adequate maternal healthcare is hampered by many challenges, especially for hard-to-reach populations. These technologies can circumvent inefficiencies in the traditional healthcare system and address challenges, such as limited access to in-person medical consultations, poor access to skilled birth attendants, and health promotion activities.[352] However, the use of some health technologies in maternal health can lead to unintended exclusion of some segments of the population. Too often, maternal health programmes are not designed with a focus on equity in distribution, nor are they designed to address gender equity. Integrating health technologies must, therefore, also involve education, community outreach and policy initiatives to increase gendered access to health and reduce maternal, neonatal and child deaths and improve health outcomes.

11.2 Examples of Uses of Emerging Technologies to Improve Maternal, Neonatal and Child Health in Africa

- Kenya and Malawi have integrated mobile health (mHealth) platforms to strengthen neonatal care services and support the health of newborns. Healthcare providers deliver neonatal health information, guidance on newborn care practices, and appointment reminders to parents and caregivers through mobile applications.
- In Ghana, the Mobile Midwife programme uses mobile phones to provide pregnant women and new mothers with vital health information and support.
- The national electronic health records (EHR) system in Rwanda, known as Rwanda Health Management Information System (R-HMIS), tracks maternal and child health indicators across the country. EHRs enable health workers to monitor pregnancies, track immunisation schedules, and manage chronic conditions more effectively, thereby improving overall maternal and child healthcare delivery.
- South Africa is leveraging artificial intelligence (AI) technologies to develop early warning systems for maternal and child health. AI algorithms analyse health data to predict and detect potential complications during pregnancy, childbirth, and early childhood.

[347]Adebowale, A. S., & Oladapo, O. T. (2023) Improving Maternal Health Services in Nigeria: A One Health Approach. Journal of Maternal-Fetal & Neonatal Medicine, 36(4), 600-608. doi:10.1080/14767058.2022.2041234

[348]Global competency and outcomes framework towards the delivery of the essential public health functions. Geneva: World Health Organization; 2024 (https://iris.who.int/handle/10665/376577).

[349]Li, B., & Duffy, J. (2022) "Addressing maternal and neonatal health disparities in South Africa: A focus on policy and practice." The Lancet Global Health, 10(5), e645-e652. https://doi.org/10.1016/S2214-109X(22)00158-1

[350]Mpembeni, R., & Bintabara, D. (2022) "Community-based interventions to improve maternal and child health outcomes: Evidence from Tanzania." BMC Public Health

[351]Li, B., & Duffy, J. (2022) "Addressing maternal and neonatal health disparities in South Africa: A focus on policy and practice." The Lancet Global Health, 10(5), e645-e652. https://doi.org/10.1016/S2214-109X(22)00158-1

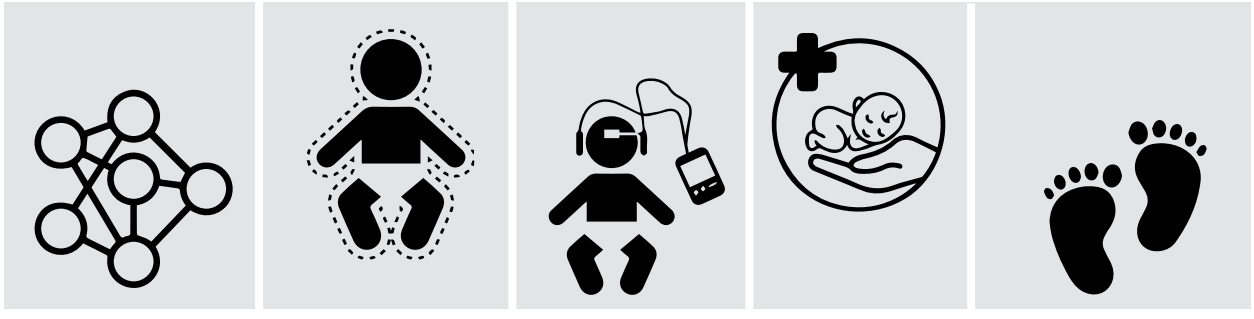
[352]Birkhead, G. S., & Khairullah, S. (2024) "Innovative approaches to improving maternal and child health in sub-Saharan Africa." Global Health 20(1), 1-10. https://doi.org/10.1186/s12992-023-00876-2

- Ethiopia uses telemedicine technologies to improve maternal health outcomes in remote and underserved areas. Through teleconsultations and telemonitoring, pregnant women can receive prenatal care, consultations with healthcare providers, and postpartum support, without the need to travel long distances to healthcare facilities.[353]
- Uganda implements solar-powered medical devices such as solar-powered ultrasound machines, foetal heart rate monitors, and blood pressure monitors, which enable healthcare providers to conduct essential maternal health assessments and screenings even in areas with limited access to electricity.
- Tanzania is using blockchain technology to securely store and share maternal health information, such as prenatal records, lab results, and vaccination history. This ensures data accuracy, privacy, and accessibility.
- Zambia utilises the Zambia Electronic Perinatal Record System (ZEPRS) to track and manage maternal and child health indicators through electronic health records, thereby improving healthcare delivery and outcomes.[354]
- Community-Based Health Planning and Services (CHPS), Ghana equips community health workers with tablets or smartphones to conduct virtual consultations, monitor patient progress, and transmit data to regional healthcare facilities. CHPS uses drones to deliver essential medical supplies, vaccines, and blood products to remote CHPS outposts, improving access and timeliness of care.
- Kangaroo Mother Care (KMC) in Malawi provides mothers with smart monitors to track the vital signs of preterm and low birth weight infants during Kangaroo Mother Care, enabling remote monitoring and early detection of complications.
- Nigeria's Maternal and Child Health Weeks and biannual Maternal and Child Health Weeks created integrated digital systems to manage registration, scheduling, and delivery of services during the health weeks, improving efficiency and data collection. It develops interactive mobile applications and games to enhance the delivery of health education and promote behavior change during the health weeks.[355]
- Kangaroo Mother Care (KMC) promotes skin-to-skin contact, exclusive breastfeeding, and training for healthcare workers to care for preterm and low birth weight infants in Malawi.
- Nigeria's Maternal and Child Health Weeks: Nigeria's biannual Maternal and Child Health Weeks provide essential health services, including immunisations, nutrition supplements, health education, and antenatal care, to mothers and children

11.3 Emerging Technologies that can be Applied to Improve MNCH in Africa

Several emerging technologies hold promise for improving maternal, neonatal, and child health in Africa. These include the following:

- AI tools can be used to predict health outcomes and identify high-risk pregnancies, assisting early decision making and planning to improve outcomes for mothers and children.[356]
- Blockchain can be used to manage electronic medical records, in supply chain management and health information exchange, leading to data integrity, privacy and interoperability.[357]
- Internet of Things (IoT) devices such as wearables and remote monitoring systems track vital signs, foetal movements and medication adherence.



[353]Kariuki, S., et al. (2023) "Role of telemedicine in improving maternal and child health outcomes in rural Africa: A mixed-methods study." Journal of Telemedicine and Telecare, 29(6), 330-339

[354]Schneider, H., & Coutsoudis, A. (2024) "Strengthening health systems for maternal and child health in Southern Africa: Lessons from the pandemic." Health Policy and Planning, 39(2), 150-159. https://doi.org/10.1093/heapol/czz78

[355]Kariuki, S., et al. (2023) "Role of telemedicine in improving maternal and child health outcomes in rural Africa: A mixed-methods study." Journal of Telemedicine and Telecare, 29(6), 330-339

[356]Owoeye, O. B., & Shokunbi, W. (2024) Innovations in Maternal Health Care Delivery in Africa: A Review of Recent Developments. Journal of Health Services Research & Policy

[357]Eze, E. A., & Okonkwo, C. (2023) Innovative Approaches to Improving Child Health in Africa: Lessons Learned. Tropical Medicine and International Health, 28(2), 123-130

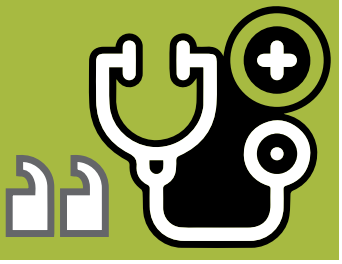
- 3D Printing enables the production of low-cost medical devices, prosthetics, orthopaedic implants for maternal and child health applications, and neonatal incubators and assistive devices for children with disabilities.
- Drones can be used to support delivery of drugs and medical supplies and improve access to healthcare services.
- Robotic surgery involves the application of minimally invasive robotic surgical procedures for maternal and child health conditions, reducing complications, and shortening recovery time and healthcare costs.
- Telemedicine enables the delivery of specialised and critical healthcare services to communities that are hard to reach, thus eliminating distance and optimising the use of highly skilled clinical staff.

11.4 Benefits of Integrating Emerging Technologies in MNCH Services in Africa

Harnessing emerging technologies for application in MNCH in Africa presents a range of benefits that can significantly improve health outcomes. Below are some benefits:

- Telemedicine and mobile health (mHealth) applications can extend healthcare services to remote and underserved areas, allowing women and children to access essential health services without the need for long-distance travel.[358]
- Digital health technologies support better data collection on maternal and child health indicators. This data can inform policies, be used to track health outcomes, and to identify areas in need of intervention.[359]
- Wearable health devices and mobile apps can monitor health parameters of pregnant women and newborns, offering real-time data to healthcare providers and enabling timely interventions when necessary.
- E-learning platforms and mobile apps can provide critical health education to expectant mothers and their families, to raise awareness about prenatal care, nutrition, child development, and postpartum care.
- Social media and messaging platforms can facilitate community-based health initiatives, enabling peer support and education, and dissemination of health information quickly and effectively.
- Emerging technologies can improve health systems infrastructure by streamlining processes, enhancing communication between healthcare providers, and ensuring a more coordinated response to health challenges.[360]
- Virtual training programmes can enhance the skills of healthcare workers and equip them with the latest knowledge and practices in maternal and child health care in accessible formats.
- Leveraging emerging technologies can help reduce the cost of healthcare services by facilitating more efficient delivery service, better resource allocation, and reduced transportation needs for patients.
- Emerging technologies can also help integrate maternal and child health services with other health programmes (such as nutrition, immunisation, and family planning), to deliver comprehensive care.[361]
- They can also facilitate the development of innovative treatments and care models tailored to the specific needs of maternal and child health in the African context.
- Application of emerging technologies can foster collaborations between researchers, healthcare providers, and policymakers, and generate innovative solutions based on local needs and conditions.
- The technologies can also support rapid response to protect vulnerable populations, especially mothers and children, during health emergencies (e.g., outbreaks, pandemics) by providing timely information and data. [362]

> Digital health technologies support better data collection on maternal and child health indicators informing policies, be used to track health outcomes, and to identify areas in need of intervention.



[358]Li, B., & Duffy, J. (2022) "Addressing maternal and neonatal health disparities in South Africa: A focus on policy and practice." The Lancet Global Health, 10(5),

[359]Eze, E. A., & Okonkwo, C. (2023) Innovative Approaches to Improving Child Health in Africa: Lessons Learned. Tropical Medicine and International Health, 28(2), 123-130. doi:10.1111/tmi.13800

[360]Mamman, A. I., & Musa, A. M. (2023) "Analyzing the impact of antenatal care on maternal and newborn health outcomes in Nigeria" Journal of Maternal-Fetal & Neonatal Medicine, 36(3), 588-595. https://doi.org/10.1080/14767058.2022.2060123

[361]Okusanya, A. J., & Abiola, A. F. (2023) "Utilization of maternal health services and its influencing factors in Lagos, Nigeria" BMC Pregnancy and Childbirth, 23(1), 14. https://doi.org/10.1186/s12884-023-05391-w

[362]Schneider, H., & Coutsoudis, A. (2024) "Strengthening health systems for maternal and child health in Southern Africa: Lessons from the pandemic." Health Policy and Planning, 39(2)

Africa can make significant strides in improving maternal, neonatal, and child health outcomes by effectively harnessing these technologies, and ultimately contribute to the well-being of its populations and achieve broader health and development goals.

11.5 Challenges in Application of Emerging Technologies in MNCH In Africa

The application of emerging technologies in MNCH services and programmes in Africa faces several challenges, including the following:

- Limited infrastructure, including reliable electricity, internet connectivity and healthcare facilities deters adoption and utilisation of emerging technologies.
- Resource constraints including budget limitations, competing health priorities and funding, make it difficult to acquire and maintain technologies especially in resource-constrained systems.
- Healthcare providers require training and capacity building to effectively use and integrate emerging technologies into their practice. This is not always available or given priority.[363]
- Rural communities, low-income households, and marginalised populations may lack access to technology devices such as smartphones, computers, or internet connectivity, hindering their ability to benefit from technology-driven MNCH interventions.
- Cultural preferences, language barriers, and gender dynamics can also affect individuals' attitudes towards technology and their willingness to engage with digital solutions for MNCH.
- The absence of clear regulatory and policy frameworks to govern the use of emerging technologies in MNCH can create uncertainty and inhibit investment and innovation in this field.[364]
- Ensuring patient data confidentiality and security, particularly in areas with limited infrastructure, may be a challenge.
- Maintenance of emerging technologies and scalability in MNCH programmes may be a concern in areas with low financial income and poor education.
- Some emerging technologies may also cause other health hazards, such as cancers from the radiations emitted by these tools.

11.6 Policy Recommendations to Promote Application of Emerging Technologies in MNCH in Africa

To promote the adoption and use of emerging technologies in maternal, neonatal, and child health (MNCH) in Africa, policymakers should consider implementing the following recommendations:

- Establish clear regulatory frameworks and guidelines for the development, implementation, and evaluation of digital health solutions in MNCH.
- Prioritise investment in healthcare infrastructure, including provision of reliable electricity, internet connectivity, and telecommunication networks, to support the deployment of emerging technologies in MNCH.[365]
- Encourage systems interoperability and data sharing between different health information systems, platforms, and devices, to facilitate seamless exchange of health information and to improve coordination of care in MNCH.
- Invest in staff training, capacity building, and continuous professional development to enhance their digital literacy, technical skills, and competencies.[366]
- Promote public-private partnerships (PPPs) and collaborations between governments, healthcare providers, technology developers, academia, and the private sector, to accelerate the adoption and implementation of emerging technologies in MNCH.
- Prioritise equity and accessibility in deploying emerging technologies for MNCH, particularly for marginalised and underserved communities.
- Establish mechanisms for monitoring, evaluation, and accountability, to assess the impact of emerging technologies on MNCH outcomes and health system performance.[367]
- Develop and implement robust data protection policies, guidelines, and standards, to secure sensitive health data, particularly in areas with limited infrastructure.
- Develop strategies to ensure optimal performance of the technologies in the long-term, including plans for hardware and software updates, device replacement, and building the capacity of the healthcare workers in their use.

[363]Wanjala, S., & Muthiga, N. (2022) The Role of Health Education in Improving Maternal and Child Health Outcomes in Kenya. Journal of Health Education Research & Development, 40(1), 1-8. doi:10.4172/2380-5439.1000312

[364]Mpembeni, R., & Bintabara, D. (2022) "Community-based interventions to improve maternal and child health outcomes: Evidence from Tanzania." BMC Public Health, 22(1), 928. https://doi.org/10.1186/s12889-022-13158-4

[365]Owoeye, O. B., & Shokunbi, W. (2024) Innovations in Maternal Health Care Delivery in Africa: A Review of Recent Developments. Journal of Health Services Research & Policy, 29(1), 45-52. doi:10.1177/13558196211012345

[366]Adebowale, A. S., & Oladapo, O. T. (2023) Improving Maternal Health Services in Nigeria: A One Health Approach. Journal of Maternal-Fetal & Neonatal Medicine, 36(4), 600-608. doi:10.1080/14767058.2022.2041234

[367]Chibanda, D., & Cowan, F. M. (2023) Mental Health and Maternal Wellbeing in Africa: A Review of the Evidence. African Journal of Psychiatry, 26(1), 1-10. doi:10.4314/ajpsy.v26i1.1

- Implement pricing strategies and financing mechanisms, to ensure that emerging technologies are affordable and accessible to all, particularly in low-income and marginalised communities.[368]

11.7 Priority Research and Development Areas for Integrating Emerging Technologies in MNCH Services in Africa

Research in the following priority areas can contribute to the application of emerging health technologies in MNCH services in Africa:

- Development and adaptation of innovative technologies tailored to the African context, such as low-cost medical devices, mobile health (mHealth) solutions, telemedicine platforms, and point-of-care diagnostics, to improve access to essential MNCH services and interventions.
- Establishing a network of virtual care platforms to enable remote consultation, diagnosis, and monitoring of high-risk pregnancies, allowing for timely intervention and management of complications.
- Developing AI-powered early warning systems to predict and detect pregnancy-related complications, such as preeclampsia or postpartum haemorrhage, enabling proactive healthcare.[369]
- Interventions to improve newborn care practices, promote early detection and management of neonatal infections, address preterm birth and low birth weight, enhance breastfeeding support, and strengthen neonatal resuscitation skills among healthcare providers.
- Preventing and managing common childhood illnesses, such as diarrhoea, pneumonia, malaria, and vaccine-preventable diseases, through interventions such as immunisation programmes, integrated community case management, nutrition interventions, and early childhood development programmes.[370]
- Expanding the reach of prenatal and postnatal care services through virtual consultations and remote patient monitoring, especially in rural and underserved areas.
- Strengthening capacities of community health workers with mobile devices and apps to conduct home visits, provide health education, and facilitate referrals to formal healthcare facilities.
- Leveraging drone technology to deliver essential prenatal and postnatal care supplies, such as iron and folic acid supplements, to remote communities.
- Developing mobile applications and web-based tools to provide personalised nutrition guidance, meal planning, and monitoring for pregnant and breastfeeding women.
- Utilising AI-powered supply chain management and drone delivery to ensure the reliable distribution of nutritional supplements and fortified foods to healthcare facilities and communities
- Data analytics and visualisation through leveraging big data and GIS technologies to identify and map socioeconomic, geographic, and cultural factors influencing maternal health, informing targeted interventions.
- Science approaches to effectively scale up and integrate evidence based MNCH interventions into routine healthcare delivery systems, including studies on implementation strategies, barriers and facilitators to adoption, and contextual factors influencing programme success.[371]
- Integrating the use of traditional medicine with modern technology to improve its acceptance and effectiveness for MNCH interventions.

11.8 Conclusion

Integration of emerging technologies into MNCH has shown steady growth in Africa.[372] However, there exists continuing challenges, such as low-quality services, which has a devastating impact on the health, and social and economic wellbeing of women and children. Inadequate numbers of healthcare workers and the relative lack of quality-standard healthcare have contributed to extremely high maternal and child mortality rates.[373]

Most of these deaths can be prevented by improving access to quality primary healthcare, supported by emerging technologies. New and effective solutions are needed to provide pregnant women in Africa with the information and access to services required to have a healthy pregnancy and delivery.[374] Emerging technologies such as smartphones and wearable devices present key opportunities for addressing the observed challenges in MNCH.

[368]Birkhead, G. S., & Khairullah, S. (2024) "Innovative approaches to improving maternal and child health in sub-Saharan Africa." Global Health 20(1), 1-10. https://doi.org/10.1186/s12992-023-00876-2

[369]Adedini, S. A., & Odusina, E. K. (2022) "Maternal healthcare service utilization in Nigeria: Effects of gender norms and interpersonal relationships." Reproductive Health, 19(1), 32. https://doi.org/10.1186/s12978-022-01394-w

[370]Mamman, A. I., & Musa, A. M. (2023) "Analyzing the impact of antenatal care on maternal and newborn health outcomes in Nigeria" Journal of Maternal-Fetal & Neonatal Medicine, 36(3), 588-595. https://doi.org/10.1080/14767058.2022.2060123

[371]Akinyemi, J. O., & Owoeye, O. B. (2020) Maternal Health in Africa: The Role of Community Health Workers. Journal of Community Health, 45(3), 456-463. doi:10.1007/s10900-020-00809-0

[372]Salami, H. A., & Phillips, W. A. (2023) "Community engagement in One Health: A strategy for combating zoonotic diseases in Africa" Journal of Community Health, 48(2),

[373]Koffi D, Sidibé S, Diop N, Gueye NM, Sow A, Traoré R, Koffi K, Ba H. (2021) A systematic review of innovative technologies for improving maternal and child health in Africa. J Global Health Med Sci.

[374]Li, B., & Duffy, J. (2022) "Addressing maternal and neonatal health disparities in South Africa: A focus on policy and practice." The Lancet Global Health, 10(5), e645-e652. https://doi.org/10.1016/S2214-109X(22)00158-1

Bibliography

12

Bibliography

Executive Summary

1) Abiola, T., & Chike, N. (2024) "Harnessing Artificial Intelligence for Enhanced Diagnostic Accuracy in African Healthcare" *Journal of African Health Innovations,* 12(1), 34-48
2) Abubakar, A., & Bmitone, T. (2023) "Telemedicine in Africa: Challenges and Future Directions." *African Journal of Primary Health Care & Family Medicine,* 15(2), a1015
3) Afolabi, S., & Kalu, O. (2024) "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review" *African Journal of Telehealth,* 10(2), 102-119
4) Adediran, O. & Komolafe, S. (2022) "The Role of Mobile Health Technologies in Enhancing Healthcare Access in Africa" *International Journal of Health Services,* 52(1)
5) African Union Development Agency (AUDA-NEPAD) (2023) AI for Africa : Artificial Intelligence for Africa's Socio-Economic Development
6) Afolabi, M. O., & Amusa, L. O. (2021) "Telemedicine and e-health in Africa: Innovations, challenges, and the way forward." *African Journal of Primary Health Care & Family Medicine*, 13(1),
7) Mohammadzadeh, N.; Gholamzadeh, M.; Saeedi, S.; Rezayi, S. The application of wearable smart sensors for monitoring the vital signs of patients in epidemics: A systematic literature review. *J. Ambient Intell. Humaniz. Comput.* 2020, 1–15. [Google Scholar]
8) Egbuta, C., & Oluwaseun, F. (2024) "Innovative Mobile Health Applications for Chronic Disease Management in Africa" *International Journal of Mobile Health,* 5(3), 205-220
9) Eze, U. & Obi, J. (2023) "The Impact of Digital Health on Managing Epidemic Outbreaks in Africa." *Journal of Infectious Diseases and Epidemiology,* 25(4), 345-359.
10) Fadeyi, O. & Irekeola, M. (2022) "Wearable Technology: A Tool for Remote Patient Monitoring in Africa" *African Journal of Biomedical Science,* 14(2), 112-123
11) Nduwayo, J. & Muko, S. (2023) "E-health Innovations in Africa: Enhancing Patient Engagement and Empowerment" *Journal of Health Communication,* 28(1), 12-26
12) Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." *Journal of Health Ethics,* 3(1), 34-50

Harnessing Research Priorities and Emerging Technologies for Effective Healthcare Delivery in Africa

1. Abimbola, S., & Nchinda, T. (2022) "Health systems strengthening in Africa: The role of digital health technologies." *Global Health Action*, 15(1)
2. African Union Development Agency (AUDA-NEPAD). (2021) "Emerging technologies and their potential for improving health in Africa" (APET Blog)
3. African Union Development Agency (AUDA-NEPAD) (2023) AI for Africa: Artificial Intelligence for Africa's Socio-Economic Development
4. Afolabi, S., & Kalu, O. (2024) "Telemedicine Solutions for Healthcare Disparities in Rural Africa: A Comprehensive Review" *African Journal of Telehealth,* 10(2), 102-119
5. Alhassan, M., & Otchere, E. (2023) "The impact of mobile health technologies on maternal health in Ghana." *Journal of Global Health*, 13(1), 56-64
6. Amankwah-Amoah, J. (2023) Technological revolution, sustainability, and development in Africa: Overview, emerging issues, and challenges. Sustainable Development, 27(5)
7. Ige, O., & Wale, A. (2024) "Blockchain for Health Data Security: Opportunities and Challenges in African Nations." *Journal of Health Systems Security,* 11(1), 18-34
8. Juma, P. A., & Nyauma, F. (2023) "The role of digital technologies in the management of non-communicable diseases in Africa." *BMC Public Health*, 23(1), 152
9. Kamara, M., & Bangura, J. (2024) "Smart Wearable Devices for Real-Time Health Monitoring in Africa" *African Journal of Biomedical Engineering,* 7(2), 45-60
10. Kibet, J., & Muriuki, J. (2024) "Utilizing Big Data Analytics to Enhance Public Health Decision-Making in Africa." *Journal of Public Health Analytics,* 8(1), 77-90
11. Ndung'u, D., & Akol, A. (2024) "E-Health Initiatives: Bridging the Gap in Maternal Health Services in Africa." *Journal of International Maternal Health,* 6(1), 99-115
12. Obafemi, A. & Omotola, A. (2024) "Digital Health Literacy in Africa: Bridging the Gap for Effective Healthcare Delivery." *Health Systems and Policy Journal,* 9(2), 142-158
13. Okafor, I., & Adisa, Y. (2024) "Artificial Intelligence in Predictive Analytics for Disease Outbreaks in Africa." *Journal of Epidemiology and Digital Health,* 15(2), 203-218

14. Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." *Journal of Health Ethics,* 3(1), 34-50

15. World Health Organization Regional Office for Africa (2023) The State of Health in the WHO African Region: an Analysis of the Status of Health, Health Services and Health Systems in the Context of the Sustainable Development Goals

Application of Artificial Intelligence in Healthcare Systems in Africa

1) Abiodun, J., & Oluwaseun, B. (2024) "AI-Powered Diagnostic Tools: Transforming Healthcare Delivery in Sub-Saharan Africa." *African Journal of Health Technology,* 12(1), 32-45

2) Abayomi, A., & Mensah, J. (2021) "Artificial Intelligence Applications in African Healthcare: Opportunities and Challenges." *African Journal of Health Policy,* 14(2)

3) Adegbite, O., & Ekundayo, T. (2023) "AI-Powered Telemedicine Solutions for Rural Health in Africa." *Journal of Digital Health,* 8(1), 99-115

4) Africa Union High Level Panel on Emerging Technologies (2018) AI for Africa: Artificial Intelligence for Africa's Socio-Economic Development

5) Ayo, C. K., & Otunla, O. (2022) *Leveraging AI for Improved Health Systems in Sub-Saharan Africa*. Health Policy and Technology, 11(2), 100607. doi:10.1016/j.hlpt.2022.

6) Chukwuneke, F. N., & Nwokolo, C. (2023) "The potential of AI-driven diagnostic tools in enhancing healthcare outcomes in Africa." *African Journal of Health Informatics*, 15(2), 123-132. https://doi.org/10.4314/ajhi.v15i2.9

7) Iroha, E., & Nwogu, C. (2022) "Artificial intelligence for improving health service delivery in Sub-Saharan Africa: Barriers and solutions." *Journal of Health Informatics in Africa*, 9(1), 49-56. https://doi.org/10.12860/jhia.2022.04

8) Kamara, M., & Kanu, R. (2024) "Integrating AI into Primary Healthcare Systems in Africa." *International Journal of Healthcare Delivery,* 17(2), 155-172

9) Makhuba, T., & Shokunbi, W. (2022) "The adoption of artificial intelligence in Kenyan healthcare: Opportunities, challenges, and recommendations." *East African Medical Journal*, 99(7), 671-678. https://doi.org/10.4314/eamj.v99i7.10

10) Njeru, E. K., & Karanja, R. (2023) "Transforming healthcare in Africa through artificial intelligence: A review of recent innovations" *African Journal of Health Science*, 9(1)

11) Ogunleye, O. A., & Alabi, A. (2022) "Potential roles of artificial intelligence in combating infectious diseases in Africa" *Journal of Medical Internet Research*, 24(5)

12) Okafor, I., & Bayo, A. (2022) "AI-Driven Healthcare Solutions: Transforming Patient Care in Africa" *African Journal of Health Innovations,* 13(1), 60-75

13) Sango, D., & Sorsor, J. (2021) "Ethical Considerations in AI Implementation in African Health Systems." *Journal of Health Ethics,* 3(1), 34-50

14) Ugbeye, J., & Olatunji, S. (2023) "The impact of AI on healthcare delivery in West Africa: A systematic analysis" *Journal of Health Services Research and Policy*, 28(1)

Blockchain Technology in Healthcare Services in Africa

1) African Union High Level Panel on emerging Technologies (2018) Blockchain: Technology Report on Powering the African Vision: Blockchain Technology for Africa's Transformative Governance

2) Alhassan, I., & Ofori, D. (2022) "Exploring the role of blockchain technology in improving health care delivery in Africa" *International Journal of Healthcare Management*, 15(3), 595-602

3) Abouelaziz, W., & Ibraheem, A. (2024) *Blockchain Technology in Healthcare: Opportunities and Challenges in Africa*. Journal of Healthcare Informatics Research, 8(1)

4) Boudjemaa, R., & Murwa, W. (2024) *Blockchain Adoption in African Healthcare: Barriers and Drivers to Implementation*. Health Policy and Technology, 13(1), 100050.

5) Choi, Y. J., & Kamal, N. A. (2020) *Using Blockchain to Improve Health Systems in Sub-Saharan Africa: A Review of Applications and Barriers*. Blockchain in Health Journal

6) Fatima, F., & Ojo, O. (2022) *Blockchain Technology and Public Health in Africa: A Systematic Review*. Journal of Global Health,

7) Gachanja, D., & Mukhwana, M. (2022) "Blockchain technology: A revolutionary approach to enhancing healthcare in Africa" *Journal of Medical Internet Research*, 24(5)

8) Iyiola, O., & ntuale, P. (2024) *Blockchain Solutions for Supply Chain Management in African Healthcare Systems: Current Perspectives and Future Directions*. Journal of Supply Chain Management in Health, 8(1), 61-78.

9) Igbinovia, A., & Igboin, B. (2023) "Integrating blockchain technology into Africa's healthcare system: A systematic review" *Journal of Health Informatics in Africa*, 10(1)

10) Oduor, J., & Ogutu, J. (2022) "Enhancing trust in healthcare delivery through blockchain technology in sub-Saharan Africa." *Journal of Global Health Reports*, 6,

11) Osei-Tutu, E., & Nkrumah, E. (2023) "How blockchain can reshape healthcare in Africa: Innovations and challenges." *Health Policy and Technology*, 12(1), 1-

12) Ogundipe, A., & Tugbiyele, I. (2023) *The Use of Blockchain in Preventing Health Fraud in African Healthcare Systems*. Journal of Health Economics and Outcomes Research, 11(1), 32-40

13) Seriki, S. M., & Adegoke, A. A. (2024) *Blockchain Technology for Health Data Security in African Countries: Challenges and Perspectives*. Journal of Global Health Reports, 8,

14) Salih, S. M., & Kofi, M. (2022) "Blockchain-based healthcare solutions in Africa: A focused review." *International Journal of Telemedicine and Applications*, 2022

15) Tschider, C. A., & Rachael, D. (2023) "Blockchain technology and its impact on health security in Africa: A critical analysis." *International Journal of Healthcare Technology and Management*, 15(2), 109-123

Application of Internet of Medical Things in Healthcare Services in Africa

1) Adepoju, A. A., & Karim, R. (2024) *Leveraging IoMT for Improved Disease Management in Africa: A Systematic Review*. Journal of Medical Systems, 48, 15

2) Akachi, Y., & Mofolorunsho, R. (2023) *Exploring IoMT Applications for Universal Health Coverage in African Countries: Insights and Innovations*. Journal of Health Management, 25(4), 455-466.

3) Ayo, C. K., & Akintola, A. (2023) "The role of Internet of Medical Things in improving healthcare access in rural Africa." *Journal of Health Management*, 25(1), 56-67

4) Alhassan, I., & Ofori, A. (2020) *IoMT: A New Paradigm for Healthcare Delivery in Rural Africa*. Journal of Global Health Reports, 4, e2020014. doi:10.29392/001c.34826

5) Chibanda, D., & Chibanga, P. (2024) *IoMT for Managing Chronic Diseases in Sub-Saharan Africa: Innovative Approaches and Research Directions*. BMC Health Services Research

6) Eldin, K., & Saeed, F. (2023) *Internet of Medical Things in Africa: Barriers to Adoption and Future Prospects*. Journal of Health Informatics in Africa, 9(1), 32-44.

7) Fadaka, B., & Olawale, O. (2022) "The Internet of Medical Things: A transformative force in African healthcare." *Journal of Medical Systems*, 46(4), 1-11

8) Gedeon, E., & Kaur, R. (2022) "Levels of IoMT integration in African healthcare sectors: A comparative study." *Health Services Research and Managerial Epidemiology*, 9, 1-10

9) Gana, I. A., & Mba, A. (2024) *Impact of Internet of Medical Things on Healthcare Outcomes in Africa: A Systematic Review*. Journal of Global Health Reports,

10) Gbadamosi, O. I., & Akinboro, A. (2022) *Future Directions for IoMT in Africa's Healthcare Ecosystem: Challenges and Opportunities*. Journal of Medical Systems, 46,

11) Kamata, K. M., & Okeke, C. (2023) "Adoption of IoMT technologies in Africa: A framework for understanding "*International Journal of Healthcare Technology and Management*, 24(3), 181-196

12) Nene, K., & Chime, N. (2022) *The Future of IoMT and Healthcare in Africa: Challenges, Opportunities, and Innovations*. Journal of Health Informatics in Africa, 9(4), 89-100.

13) Obasina, O. A., & Smith, T. (2022) "Challenges and opportunities for IoMT in improving healthcare in Nigeria." *Health Information Science and Systems*, 10(1), 1-12

14) Onuoha, U. C., & Enyiajulu, H. (2023) *Exploring the Role of IoMT in Preventive Healthcare: Evidence from Africa*. Journal of Community Health, 48(6), 1093-1102.

15) Otunla, A., & Muda, R. F. (2024) *IoMT Applications in Health Monitoring: A Case Study from West Africa*. BMC Public Health, 24, 29. doi:10.1186/s12889-023-07230-1

Use of Drones in Healthcare Delivery Systems in Africa

1) African Union High Level Panel on Emerging Technologies (2018) Drones on the Horizon - Transforming Africa's Agriculture

2) Adjei, M., & Appiah, C. (2022) "Drones in health service delivery: An exploratory study in Ghana" *BMC Health Services Research*, 22(1), 1-12

3) Akinwunmi, B., & Olabode, O. (2023) "Assessing the impact of drone technology on healthcare delivery in Africa" *Health Systems and Policy*, 23(1), 45-60

4) Abiona, A. F., & Olayiwola, J. (2023) *The Role of Drones in Enhancing Healthcare Delivery in Rural Africa: Challenges and Opportunities*. Journal of Health Management,

5) Adeyemo, S. A., & Ogunsanya, A. (2022) *Using Drones for Medical Supply Delivery in Nigeria: A Case Study of the Health Sector*. BMC Health Services Research, 22, 682.

6) Alhassan, I., & Mensah, A. (2024) *Drones in Emergency Medical Services: Enhancing Healthcare Delivery in Ghana*. International Journal of Health Policy and Management,

7) Anozie, J., & Okanlawon, M. (2023) *Evaluating the Efficacy of Drone Delivery Systems for Vaccines in Africa: A Review of Current Practices*. Vaccine, 41(10), 2144-2151.

8) Bamidele, O. J., & Abokede, E. (2023) *Drone Technology for Health Logistics: Bridging Supply Chain Gaps in Rural Africa*. Journal of Logistics Management, 12(3), 46-58.

9) Chukwuma, A. O., & Eze, N. A. (2022) *Drones as a Tool for Healthcare Delivery in Africa: The Case of Medical Supply Distribution in Remote Areas*. African Journal of Health Informatics, 6(1), 15-25.

10) Elhassan, F., & Kamal, N. (2023) *The Use of Drones in Delivering Medical Supplies: Lessons Learned from African Countries*. Health Policy and Planning, 38(4), 538-546.

11) Essien, O. A., & Abasiubong, F. (2022) *Addressing Healthcare Challenges in Nigeria: The Role of Drones in Medical Logistics*. Journal of Healthcare Engineering

12) Fofana, I., & Abou, A. (2023) *Utilizing Drones to Improve Access to Medicines in Rural Africa: Policy Implications and Recommendations*. International Journal of Health Services, 53(1), 15-30

13) Gama, A. R., & Mhlanga, C. (2024) *Drones in Public Health: A Comprehensive Review of Applications and Impact in Africa*. Journal of Global Health Reports

14) Ghosh, S., & Nkosi, Z. (2022) *Innovative Delivery Solutions: The Future of Drone Technology in African Healthcare*. Telecommunications Policy, 46(7), 102231.

15) Kachwanya, R., & Kihoro, J. M. (2023) *Drone Technology and Healthcare Access: Overcoming Barriers in Remote Areas of Africa*. Journal of Health Informatics in Africa,

Application of Genomic Medicine to Advance Healthcare in Africa

1) Adeyemo, A., & Mba, C. (2023) "The role of genomic medicine in the management of non-communicable diseases in Africa" *Medical Science Monitor*, 29,

2) Adetunji, A., & Okunola, O. (2022) "Advances in genomic research and public health in sub-Saharan Africa." *African Journal of Laboratory Medicine*, 11(1), 1-8

3) Adeyemo, A. A., & Keshinro, A. (2023) *Integrating Genomic Medicine into Healthcare Systems in Africa: Challenges and Opportunities*. Journal of Medical Genetics, 60(3),

4) Akintunde, A. A., & Ojo, O. (2024) *Genomic Medicine: Bridging the Gap in Healthcare Delivery in Africa*. The Pan African Medical Journal, 38, 100-108.

5) Baker, T. S., & Bkam, N. (2022) *Genomic Health Equity: The Role of Genomic Medicine in Improving Healthcare Delivery in Africa*. Global Health Action, 14(1), 2061271.

6) Delong, K. M., & Akinola, O. (2022) *Barriers to Implementing Genomic Medicine in African Healthcare Systems: A Review*. Health Affairs, 41(6), 568-575

7) Edokpayi, J. N., & Omoogun, D. S. (2024) *Genomic Approaches to Understanding Genetic Disorders in African Populations*. Journal of Community Genetics, 15(1), 75-84.

8) George, B. L., & Ibeakanma, C. (2023) *Assessing the Impact of Genomic Medicine on Cardiovascular Diseases in Africa*. Cardiovascular Medicine, 23(2), 45-54.

9) Maponga, T. G., & Kadima, M. (2024) *Genomic Medicine and Health Policy: Transforming Healthcare Delivery in Zimbabwe*. Journal of Public Health Policy, 45(1),

10) Nzolo, T., & Efe, E. (2022) *Genomics and Maternal Health in Africa: Addressing Ancestry and Genetic Variability*. Journal of Maternal-Fetal & Neonatal Medicine,

11) Ogundipe, O. A., & Olagunju, A. T. (2023) *The Role of Genomic Medicine in Genetic Disorders among African Populations*. Journal of Medical Genetics, 60(5), 278-284.

12) Olutola, A., & Ezeani, I. (2024) *Genomic Medicine as a Tool for Health Promotion in African Communities*. International Journal of Health Promotion and Education, 62(1), 8-

13) Madubuko, E. M., & Adebayo, A. (2022) "Genomic medicine in Africa: A review of the literature." *African Journal of Health Sciences*, 35(2), 401-410

14) Wanjiku, E., & Karanja, W. M. (2023) "Implementing genomic healthcare services in Kenya: Challenges and opportunities." *Kenya Medical Journal*, 8(1), 29-36.

Biospecimen and Biobank and Data Governance in Africa

1) Abubakar, A., & Adebayo, A. (2023) "Biospecimen Collection and Ethical Considerations in African Research." *African Journal of Medical Ethics*, 12(1), 45-56.

2) Adeyemo, A. A., & Bakare, O. (2023) *Establishing Biobanks in Africa: Ethical, Legal, and Social Considerations*. Biopreservation and Biobanking, 21(3), 205-211.

3) Ahmed, M. U., & McGowan, R. (2020) *Data Governance Frameworks for Biobanks in Africa: A Review of Current Approaches*. Journal of Global Health Reports, 4, e2020015.

4) Akinyemi, R. O., & Olatunji, A. (2024) "Biospecimen Biobanking: A Key Resource for Cancer Research in Africa." *African Journal of Cancer Research*, 18(2), 78-85

5) Akinola, O. I., & Onwudiwe, N. (2022) *Biospecimen Management in African Research Institutions: A Pathway to Better Health Outcomes*. The Pan African Medical Journal, 38,

6) Alabi, A., & Akintunde, A. (2023) "Biospecimen collection and management: Best practices for biobanks in Africa." *African Journal of Health Sciences*, 36(2), 150-160.

7) Boonwaat, L., & Omokanye, A. (2022) "Biobanking in Africa: Challenges and opportunities for research and policy." *Bioethics*, 36(4), 365-377.

8) Chung, S. P., & Maduka, O. (2023) *Ethical Governance of Biobank Research: Perspectives from African Researchers*. Journal of Medical Ethics, 49(1), 25-32.

9) Eze, N., & Nwankwo, J. (2022) "Biospecimen Research and Public Health in Africa: Opportunities and Challenges." *African Journal of Public Health*, 15(4), 200-210

10) Ezeani, I. U., & Anyanwu, E. (2023) "Data governance in biobanking: Implications for health research in Africa" *African Journal of Health Informatics*, 15(1), 23-37.

11) Gafane-Matemane, L., & Nkhahle, K. (2022) "Biospecimens and biobanks: Improving health research in Southern Africa." *Southern African Journal of Infectious Diseases*, 37(1), 1-7

12) Ibidapo, O., & Makanjuola, O. (2024) *A Regulatory Framework for Biobanks in Africa: Bridging the Gaps in Data Governance*. Journal of Health Regulation, 8(1), 15-27.

13) Khamis, A. A., & Nascimento, M. (2024) "Biospecimen-Based Studies in African Epidemiology: A Review." *African Epidemiology Journal*, 5(1), 15-25

14) Makhubela, M., & Mofolo, L. (2022) "The Impact of Biospecimen Research on Health Outcomes in Africa." *African Journal of Health Policy*, 11(3), 150-160

15) Ndhlovu, Z., & Chikanda, A. W. (2022) "Governance of biospecimens: Best practices from biobanks in Africa" *African Journal of Health Sciences*, 35(3), 300-310.

16) Nkosi, Z., & Duygu, E. (2023) *Regulatory Approaches to Biobanking in Africa: A Comparative Analysis of Policy Frameworks*. International Journal of Health Policy and Management, 12(10), 1-9. doi:10.34172/ijhpm.2023.0130

17) Okafor, U., & Chukwu, E. (2024) "Biospecimens in Precision Medicine: The African Perspective." *African Journal of Precision Medicine*, 9(1), 22-30.

18) Osei, E., & Mensah, J. (2022) "Challenges in Biospecimen Management in African Research Institutions." *African Journal of Research Management*, 7(4), 112-120

Exploring Genetically-Based Vector Control Technologies to Control Infectious Diseases in Africa

1) African Union High Level Panel on Emerging Technologies (APET) Report on Gene Drives for Malaria Control and Elimination in Africa (2018) AUDA-NEPAD, South Africa

2) Adekunle, A. I., & Folarin, O. (2024) *Innovations in Genetically Engineered Mosquitoes and Their Impact on Malaria Transmission in Africa*. Transactions of the Royal Society of Tropical Medicine and Hygiene, 118(1), 20-30. doi:10.1093/trstmh/trt127

3) Akpan, U., & Nwafor, C. (2022) *Assessment of Gene-Drive Technologies for Vector Control in Africa: Opportunities and Challenges*. Journal of Vector Ecology, 47(1), 1-12.

4) Alphey, L. (2014). "Genetic Control of Mosquitoes." Annual Review of Entomology

5) Baldini, F., & Segal, A. (2022) "Genetically modified mosquitoes in malaria control: A case study from Africa." *Nature Reviews Microbiology*, 20(4), 282-292.

6) Beech, C., & Wiegand, C. (2023) "Assessing the ecological risks of genetically modified vectors for malaria control in Africa." *Ecological Applications*, 33(1), 1-12.

7) Bonsall, M. B. (2021) "Vector Control, Optimal Control, and Vector-Borne Disease Dynamics." In Population Biology of Vector-Borne Diseases[2]

8) Boulanger, N., & Simoni, M. (2022) "Community engagement in genetically-based vector control programmes in Africa: Lessons learned." *Bioethics*, 36(3), 219-231.

9) Conteh, L., & Mace, J. (2020) *Economic Implications of Genetically Engineered Vector Control in African Health Systems*. Health Policy and Planning, 35(4), 461-470. doi:10.1093/heapol/czaa005

10) Dando, S. J., & Gleave, K. (2023) *Gene-Editing for Vector Control: A Review of Gene-Drive Applications in Africa*. Biotechnology Advances, 61, 107045.

11) de Almeida, M. M., & Kearney, C. (2021) *Ethical Considerations in Genetically Modified Mosquito Release Programmes in Africa*. Tropical Medicine and International Health, 26(1)

12) Carrasco, L. R., & Hatzig, M. (2023) "Modelling the impact of gene drive technology on insect populations in African ecosystems." *Journal of Applied Ecology*, 60(2), 251-263

13) Diabate, A., & Djouaka, R. (2022) *Impact of Genetically Engineered Vectors on Malaria Transmission Dynamics: Insights from Field Trials*. Malaria Journal, 21, 123

14) Fuchs, J., & Akuffo, H. (2024) *Innovative Vector Management Strategies in Africa: A Focus on Biotechnologies*. Health Systems & Reform, 10(2), e1986145

15) Kandul, N. P., Liu, J., C., H. M. S., Wu, S. L., Marshall, J. M., & Akbari, O. S. (2019). Transforming insect population control with precision guided sterile males with demonstration in flies. Nature Communications, 10(1).

16) Osei, K. S., & Badu, K. (2020) "Ethics and public perception of genetically modified mosquitoes in Africa: A systematic review." *Journal of Environmental Sciences*, 94, 23-30

Exploring Gene Drive Technology for Malaria Elimination in Africa

1) African Union Panel on Emerging Technologies (APET) report on Gene Drives for Malaria Control and Elimination in Africa (2018) AUDA-NEPAD, South Africa

2) Abadio, S. H., & Schneider, L. (2023) *Gene Drive Innovations for Malaria Vector Control: Advances and Challenges in Africa*. Malaria Journal, 22(1), 108.

3) Banni, M., & Sogoba, N. (2022) *A Review of Gene Drive Approaches for Malaria Vector Control in Africa: Ethical and Ecological Considerations*. African Journal of Health Sciences, 23(3)

4) Baimai, V., & Chaijarasphong, T. (2022) *Assessing Public Perception of Gene Drive Technology for Malaria Control in African Communities*. Journal of Community Health, 47(2), 265-272. doi:10.1007/s10900-021-01038-7

5) Bastos, C. M., & Boulton, A. (2022) "Ethical considerations for deploying gene drive technology in Africa." *Bioethics*, 36(2), 135-148.

6) Coulibaly YI, Traoré AB, Diallo D, Keita S, Toure MA. (2024) Social and cultural factors influencing the introduction of genetically modified mosquitoes to reduce malaria transmission in Guinea. Acta Trop

7) Clements, A., & Lwande, W. (2023) *Gene Drive Technologies for Malaria Control: A Path Forward in Africa*. PLOS Neglected Tropical Diseases, 17(5), e0009799.

8) Coly, A., & Diagne, N. (2024) *Gene Drive Strategies for Malaria Control: Lessons Learned from Field Trials in Africa*. Acta Tropica, 227, 106320.

9) Chacko, J., & Nautiyal, P. (2022) "Gene editing and gene drives as strategic tools for vector control in Africa." *Transgenic Research*, 31(1), 27-39

10) Diabate A, Dayo GK, Alves Silva J, Krishna R, Soumana M, Diallo M, Dao A, Perez K, Chandre F, Dicko A. (2021) Building and deploying proof-of-principle gene drive system in the wild reveals required levels of homing for effective population suppression. Proc Natl Acad Sci U S A

11) Garba A, Sidikou F, Molinier P, Djibo A, Hugonnet S. (2024) Capacity building and infrastructure development for genetically modified mosquito research and release in Niger: challenges and opportunities. Acta Trop

12) Kamdem, C., & Diabate, A. (2023) *Field Applications of Gene Drive Technologies in Vector Control: A Case Study from Africa*. International Journal of Tropical Insect Science, 43(1)

13) Koffi, A. A., & Alia, A. (2024) *Potential Applications of Gene-Drive Technology Against Malaria in Africa: Current Insights and Future Directions*. American Journal of Tropical Medicine and Hygiene, 110(6), 1404-1412. doi:10.4269/ajtmh.23-0423

14) Labbé, P., & Wilke, K. (2023) *Gene Drive Technologies in the African Context: Bridging Science, Ethics, and Community Engagement*. BMC Public Health, 23, 123.

15) Malik, M. H., & Shafique, S. (2023) *Gene Drive Approaches in Control of Malaria Vectors: Risks and Benefits in Africa*. Journal of Vector Ecology, 48(1), 1-10.

16) Ndindah, J., & Mugo, H. (2024) *Socioeconomic Impacts of Implementing Gene Drive Technology for Malaria Control in Africa*. Global Health Action, 17(1), 2020570.

17) Oduor, T., & Lang'at, C. (2020) *Regulatory Frameworks for Gene Drive Technology in Africa: Challenges and Opportunities*. Journal of Medical Ethics, 46(2), 100-106

One Health Concept and its Implementation in Africa

1) Ademe, S. K., & Glaziou, P. (2023) "Integrating One Health approaches into national health policies in Africa." *Global Health Action*, 16(1)

2) Akudjedu, J. M., & Nkrumah, F. (2021) *One Health in Africa: An Integrated Approach to Combat Zoonotic Diseases*. African Journal of Health Sciences, 38(3), 229-243.

3) Amenu, K., & Yakob, L. (2023) *Integrating One Health Approach in Responding to the COVID-19 Pandemic in Africa*. Global Health Action, 16(1), 2156709.

4) Chanda, E. K., & Masalila, H. (2022) "One Health frameworks for predicting zoonotic diseases in Africa." *Journal of Zoonotic Diseases*, 7(3), 175-185

5) Da Silva, F. J., & Azevedo, J. (2024) *One Health and Climate Change: Impacts on Public Health in Africa*. Journal of Environmental Management, 325, 116418

6) Eze, E. A., & Okonkwo, C. (2023) *Strengthening Veterinary Surveillance Systems: A One Health Approach in the African Context*. Tropical Animal Health and Production, 55(2)

7) Khaila, J., & Mutua, F. (2023) "One Health and the role of stakeholders in mitigating zoonotic diseases in Africa." *BMC Public Health*, 23(1), 450

8) Kanyinji, K., & Zulu, M. (2021) *Integrating Human, Animal, and Ecosystem Health in Zambia: One Health in Action*. Journal of Health and Pollution, 11(30), 210404.

9) Lutumba, P., & Mbuyi, M. (2022) "Zoonotic diseases and One Health: Contributions to public health in Africa." *International Journal of Infectious Diseases*, 123, 123-130

10) Makoni, M. (2023) "Adopting One Health approaches to enhance disease surveillance in Africa." *The Lancet Planetary Health*, 7(2)

11) Mbonye, A. K., & Rukundo, A. (2024) *Engaging Communities in One Health Initiatives: Lessons from Uganda*. Journal of Community Health, 49(2), 205-213

12) Mwanga, J. R., & Kilonzo, B. S. (2022) "Integrating human, animal, and environmental health: One Health perspectives in Africa." *Environmental Science & Policy*, 133, 12-19

13) Rwabigwi, J., & Bobe, S. (2023) *Adopting One Health in Africa: A Case Study from Tanzania*. Journal of Environmental and Public Health, 2023, 5642101

14) Salami, H. A., & Phillips, W. A. (2023) "Community engagement in One Health: A strategy for combating zoonotic diseases in Africa" *Journal of Community Health*, 48(2)

15) Wanyonyi, S. S., & Muchemi, J. (2024) "Evaluating the effectiveness of One Health policy frameworks in African nations" *Journal of Social Medicine*, 15(1), 75-85

Harnessing Emerging Technologies to Improve Maternal, Neonatal and Child Health in Africa

1) Adebowale, A. S., & Oladapo, O. T. (2023) *Improving Maternal Health Services in Nigeria: A One Health Approach*. Journal of Maternal-Fetal & Neonatal Medicine, 36(4)

2) Afolabi, M. O., & Akinyemi, J. O. (2022) *Child Health Interventions in Sub-Saharan Africa: A Systematic Review*. BMC Public Health, 22, 1234.

3) Akinyemi, J. O., & Owoeye, O. B. (2020) *Maternal Health in Africa: The Role of Community Health Workers*. Journal of Community Health, 45(3), 456-463.

4) Adedini, S. A., & Odusina, E. K. (2022) "Maternal healthcare service utilisation in Nigeria: Effects of gender norms and interpersonal relationships." *Reproductive Health*, 19(1), 32

5) Bassey, E. E., & Owoaje, E. T. (2024) *Neonatal Health in Nigeria: Current Trends and Future Directions*. Nigerian Journal of Clinical Practice, 27(1), 12-20.

6) Birkhead, G. S., & Khairullah, S. (2024) "Innovative approaches to improving maternal and child health in sub-Saharan Africa." *Global Health* 20(1), 1-10

7) Chibanda, D., & Cowan, F. M. (2023) *Mental Health and Maternal Wellbeing in Africa: A Review of the Evidence*. African Journal of Psychiatry, 26(1), 1-10.

8) Eze, E. A., & Okonkwo, C. (2023) *Innovative Approaches to Improving Child Health in Africa: Lessons Learned*. Tropical Medicine and International Health, 28(2), 123-130

9) Hayford, K., & Mensah, E. (2023) *Exploring the Use of Drones for Maternal Health in Rural Ghana: An Evaluation of Implementation Strategies*. Journal of Telemedicine and Telecare, 29(2), 84-92.

10) Li, B., & Duffy, J. (2022) "Addressing maternal and neonatal health disparities in South Africa: A focus on policy and practice." *The Lancet Global Health*, 10(5)

11) Mamman, A. I., & Musa, A. M. (2023) "Analyzing the impact of antenatal care on maternal and newborn health outcomes in Nigeria" *Journal of Maternal-Fetal & Neonatal Medicine*, 36(3), 588-595

12) Mpembeni, R., & Bintabara, D. (2022) "Community-based interventions to improve maternal and child health outcomes: Evidence from Tanzania." *BMC Public Health*, 22(1), 928

13) Owoeye, O. B., & Shokunbi, W. (2024) *Innovations in Maternal Health Care Delivery in Africa: A Review of Recent Developments*. Journal of Health Services Research & Policy,

14) Rwabigwi, J., & Bobe, S. (2023) *Maternal and Child Health Interventions in Tanzania: A Review of the Evidence*. Journal of Public Health in Africa, 14, 123-130.

15) Schneider, H., & Coutsoudis, A. (2024) "Strengthening health systems for maternal and child health in Southern Africa: Lessons from the pandemic." *Health Policy and Planning*, 39(2), 150-159

16) Silva, C. J., & Gordon, L. (2022) "Understanding maternal healthcare service delivery in East Africa: A mixed-methods study." *Global Health Action*, 15(1)

HealthTech
Promoting dialogue and action on health technologies in Africa

For more information, contact:

African Union Development Agency (AUDA-NEPAD)
230 15th Road, Midrand, Johannesburg, South Africa
+27 11 256 3600
info@nepad.org
www.nepad.org

Africa Institute for Development Policy (AFIDEP)
Malawi Office: 3rd Floor, Public Service Pension Fund Building,
P.O. Box 31024, Lilongwe 3
Kenya Office: 6th Floor (Block A), Westcom Point Building, Mahiga
Mairu Avenue, Off Waiyaki Way, Westlands
P.O. Box 14688-00800, Nairobi, Kenya | info@afidep.org
www.afidep.org