Microbes and Infectious Diseases 2024; 5(3): 972-990

Microbes and Infectious Diseases

Journal homepage: https://mid.journals.ekb.eg/

Review article

One health approach in the fight against yellow fever in Nigeria

Seyi Samson Enitan[1]*, Daniel Sudan Gbise[2], Banenat Bajehson Dogonyaro[3], Samuel Sunday Eke[4], Unata Michael Iduh[5], Michael Olugbamila Dada[1], Olaitan Abosede Adebola[6], Osakue Eguagie Osareniro[1], Grace Amarachi John-Ugwuanya[7], Grace Eleojo Itodo[8], Richard Yomi Akele[9], Okeoghene Marcel Edafetanure-Ibeh[10], Rhoda Temilola Akinpelu[11], Adeiye Adedoyin Oluwayemis[12], Omotayo Esther Oyewopo[13], Lily Amarachukwu Innocent-Sunday[1], Ayomide Oluwatobiloba Okuneye[1]

1- *Department of Medical Laboratory Science, School of Public and Allied Health, Babcock University, Ilishan-Remo, Nigeria.*
2- *Epidemiology Laboratory, Diagnostic & Outstation Makurdi, National Veterinary Research Institute, Vom, Nigeria.*
3- *Department of Virology, National Veterinary Research Institute, Vom, Nigeria.*
4- *Biology Unit, Air Force Institute of Technology, Kaduna, Nigeria.*
5- *Department of Medical Microbiology, School of Medical laboratory science, Usmanu Danfodiyo University Sokoto, Sokoto, Nigeria.*
6- *Department of Microbiology, Ministry of Defense, Kwara, Nigeria*
7- *Medbury Medical Services, Ikeja, Lagos, Nigeria*
8- *Microbiology Department, Federal Medical Centre Lokoja, Kogi State, Nigeria.*
9- *Department of Biomedical Science, School of Applied Science, University of Brighton, London, United Kingdom.*
10- *Department of Environmental and Occupational Health, Texas A&M School of Public Health, 212 Adriance Lab Rd, College Station, TX 77843, United States of America*
11- *Department of Medical Microbiology, National Orthopaedic Hospital, Dala, Kano, Nigeria*
12- *Department of Medical Laboratory Science, Federal Neuropsychiatric Hospital Aro, Abeokuta, Nigeria*
13- *Department of Veterinary Medicine, University of Agriculture, Makurdi, Nigeria.*

ARTICLE INFO

Article history:
Received 14 February 2024
Received in revised form 10 March 2024
Accepted 14 March 2024

Keywords:
Mosquitoes
One health strategies
Vaccination
Vector control
Yellow fever

ABSTRACT

Background: Yellow fever (YF) remains a significant public health concern in Nigeria, with sporadic outbreaks causing considerable morbidity and mortality. This zoonotic viral disease is transmitted primarily by Aedes mosquitoes, posing a constant threat to human populations. Although vaccination efforts have been ongoing for years, outbreaks still occur, underscoring the need for a comprehensive approach to combat YF. In Nigeria, adopting a One Health approach is imperative for effective yellow fever control. This approach recognizes the intricate interplay between human health, animal health, and the environment. Key strategies include the implementation of travel advisories, widespread vaccination campaigns, and early detection and reporting of cases. Surveillance efforts extend to both human and non-human primate populations to monitor the circulation of the virus accurately. Community engagement plays a vital role in this approach, with local communities actively participating in efforts to eliminate mosquito breeding sites. Integrated mosquito management techniques, such as the use of insecticides and repellents, are promoted alongside community-led interventions to reduce breeding grounds, such as removing stagnant water. By embracing the principles of One Health and implementing coordinated efforts across regions within Nigeria, we can strive towards the eradication of yellow fever. This holistic approach holds the potential to mitigate the burden of disease and pave the way for a future free from the threat of yellow fever outbreaks in Nigeria.

Introduction

Yellow fever (YF) is a zoonotic viral infection caused by a flavivirus (Yellow fever virus) that is spread through the bites of infected mosquitoes [1, 2]. The disease is endemic in parts of Africa and South America where people and

DOI: 10.21608/MID.2024.270125.1800
* *Corresponding author:* Seyi Samson Enitan
E-mail address: enitans@babcock.edu.ng

mosquitoes coexist and is a major cause of morbidity and mortality in sub-Saharan Africa. It is also a growing global public health problem as outbreaks have been reported in other countries, including Brazil and China [1-3]. Yellow Fever has a profound impact on global health, disproportionately affecting populations in tropical regions of Africa and the Americas. The World Health Organization (WHO) estimates that over 200,000 cases of YF occur annually, with up to 60,000 deaths [4]. The majority of these cases occur in Africa, particularly in Central and West Africa, where an estimated 84% of global cases occur. The major trend in YF in Africa is an increasing number of cases, due to a combination of factors such as population growth, urban migration, deforestation, and climate change. Additionally, the growing number of international travelers from endemic regions, who may spread the disease to new areas, is also a contributing factor [5].

Yellow fever remains a significant public health concern in Nigeria, with sporadic outbreaks causing considerable morbidity and mortality. The disease places a heavy burden on healthcare systems, strains economies, and compromises the well-being of communities already facing numerous health challenges [6, 7]. Furthermore, the potential for international spread poses a global threat, particularly in an era of increased travel and globalization. The transmission dynamics of yellow fever are complex, involving a delicate balance between human hosts, animal reservoirs, and the *Aedes aegypti* mosquito vector. Interconnected factors contribute to the spread of the virus, creating a challenging landscape for control efforts. Mosquito vectors serve as efficient carriers, transmitting the virus between humans and animals, while urbanization, globalization, and deforestation alter ecosystems, influencing the behavior and habitats of both hosts and vectors. Recognizing these interconnections is fundamental to devising effective strategies that address the root causes of yellow fever transmission [8, 9].

Despite the existence of an effective vaccine, the complex interplay of ecological, social, and health factors continues to fuel the spread of the disease, necessitating a multifaceted and collaborative approach for effective control and prevention. In recent years, the "One Health" approach has emerged as a comprehensive strategy that recognizes the interconnectedness of human, animal, and environmental health, providing a promising framework for tackling the intricate challenges posed by yellow fever [10-13].

One Health is a collaborative, multisectoral, and transdisciplinary approach—working at the local, national, regional and global levels—with the goal of achieving optimal health outcomes that recognize the interconnection between people, animals, plants, and their shared environment [14]. The One Health approach stands out as a paradigm shift in disease control strategies. Applying this holistic approach to yellow fever involves understanding the ecological dynamics of the virus, recognizing the role of animals as potential reservoirs, and appreciating the environmental factors that shape vector habitats [15, 16]. By integrating expertise from various disciplines, including human and veterinary medicine, ecology, and environmental science, the One Health approach offers a synergistic and sustainable strategy for combating yellow fever [13]. Conventional approaches to yellow fever control have often focused on isolated interventions, such as vaccination campaigns and vector control measures. While these efforts have been critical, they may fall short in addressing the broader ecological and social determinants that facilitate the spread of the virus. The One Health approach addresses this gap by fostering collaboration across sectors, breaking down silos between human and animal health, and recognizing the importance of environmental conservation. This integrative strategy not only enhances the effectiveness of interventions but also promotes resilience against future outbreaks [16, 17].

The virology of yellow fever virus

The yellow fever virus (YFV) **(Figure 1)** is a type of arbovirus belonging to the Flaviviridae family. Structurally, it is an enveloped virus that has a spherical shape with a diameter of around 40-50 nm [1]. It possesses a single-stranded, positive-sense RNA genome that is approximately 11 Kb in length. The viral genome encodes for three structural proteins, which are the capsid protein (C), membrane protein (M), and envelope protein (E). The capsid protein forms the core of the virus, which protects and maintains the genomic RNA. The membrane protein anchors the capsid protein to the host cell membrane, and it also provides a structural support for the envelope protein. The envelope protein is essential for viral attachment and entry into the host cells, as well as for viral pathogenesis.

The outer envelope of the YFV is studded with about 180 copies of the envelope protein, which are responsible for binding to the host receptor, triggering membrane fusion, and initiating viral entry into the host cell. The envelope protein is also critical for the induction of viral neutralizing antibodies, which are targeted by the immune system during infection. However, the YFV is known to evade the immune system by suppressing the host's innate immune response, which allows the virus to propagate rapidly and cause severe disease. The viral genome also encodes for seven non-structural proteins, which facilitate viral replication, transcription, and translation within the host cells [1, 9, 18].

The physical properties of YFV are documented to exhibit a buoyant density that ranges from 1.16 g/mL to 1.20 g/mL in sucrose gradients. YFV is stable between pH 7.0-8.0 and can maintain its infectivity at 4°C for several weeks, and can withstand low pHs for brief periods. The virus is sensitive to heat, UV radiation, and disinfectants, and it can be effectively inactivated by exposure to heat at 60°C for 30 min, or by ultraviolet radiation for 20-40 min. The structure and properties of YFV are critical factors that determine its ability to invade host cells, replicate, and cause severe disease [2,3,4, 18, 19].

Yellow fever outbreaks and changing epidemiology in Nigeria

Yellow fever outbreaks present significant public health challenge in endemic regions of West and Central Africa, including Nigeria, where periodic outbreaks occur due to factors like low vaccination coverage, urbanization, and ecological changes [2, 3, 9]. The initial occurrence of yellow fever in Nigeria was documented in Lagos in 1864, followed by recurrent outbreaks reported up until 1996. There was then a period of 21 years during which no additional confirmed cases were recorded until September, 2017 [20]. and then November, 2020 [21] with major outbreaks in five states (Bauchi, Benue, Delta, Ebonyi and Enugu) **(Figure 2)**. From 1 January to 31 August 2021, a total of 1,312 suspected cases were reported in 367 Local Government Areas (LGAs) across 36 States including the Federal Capital Territory (FCT) [22]. The 2023 yellow fever outbreak in Nigeria **(Figure 3)** posed significant challenges, with a total of 3,217 suspected cases reported across 594 Local Government Areas (LGAs) in 36 states, including the Federal Capital Territory (FCT). The distribution of cases highlights the widespread nature of the outbreak, with notable incidences reported in Bauchi, Katsina, Plateau, and Taraba states. Key findings reveal 42 presumptive positive cases, primarily identified in various health facilities across the country. These cases were concentrated in states such as Bauchi, Enugu, and Ondo. Furthermore, 48 inconclusive cases were recorded, emphasizing the diagnostic complexities involved in confirming yellow fever infections. Confirmatory testing conducted at IP Dakar identified 24 confirmed cases, with the majority clustered in Adamawa, Bauchi, and Enugu states. Unfortunately, the outbreak led to nine deaths, underscoring the severity of the situation and the urgency of response efforts. Analysis of demographic data reveals a slightly higher incidence rate among males, with the majority of cases affecting individuals aged 30 years and below. This demographic trend emphasizes the importance of targeted vaccination campaigns, especially among younger populations [23].

Interconnected factors contributing to yellow fever spread

The spread of yellow fever in Nigeria is influenced by a complex interplay of factors spanning human health, animal health, and the environment [6, 7, 24, 25]. Mosquito vectors play a pivotal role in transmitting the virus between humans and animals. Urbanization, globalization, and deforestation further exacerbate the spread, affecting the habitats and behaviors of both human and animal hosts. Understanding these interconnected factors is crucial for devising comprehensive strategies to curb the transmission and impact of yellow fever **(Table 1)**.

Insect vector

In Nigeria, the presence of insect vectors significantly influences the spread of yellow fever (YF) across the country. YF is primarily transmitted by mosquitoes, notably *Aedes aegypti* and *Aedes albopictus.* These mosquitoes serve as carriers of the virus, transmitting it to humans through bites [6, 7]. The virus primarily circulates in a zoonotic cycle involving non-human primates, such as monkeys, as reservoir hosts. Mosquitoes become infected when they feed on viremic primates, initiating a replication process within the mosquito's midgut before spreading to other tissues, including the salivary glands. Following an incubation period of 10 to 14 days, the virus can be transmitted to a new host when an infected mosquito takes a blood meal. This efficient transmission cycle perpetuates YF

spread within Nigeria. *Aedes aegypti* and *Aedes albopictus*, prevalent throughout Nigeria, contribute significantly to YF outbreaks in various regions. These mosquitoes pose a considerable risk, transmitting the virus from person to person and potentially from animal populations to humans, amplifying the likelihood of outbreaks. It is vital to recognize that only female mosquitoes transmit the virus to humans, with humans serving as incidental hosts incapable of transmitting the virus back to mosquitoes [24, 25, 26].

Wildlife and reservior hosts

Wildlife, particularly primates and rodents, play a significant role in the epidemiology of yellow fever (YF) within Nigeria's endemic regions. The yellow fever virus (YFV) primarily circulates between mosquitoes and non-human primates, such as monkeys and apes, in tropical areas of Nigeria. Mosquito species like Aedes and Haemogogus act as vectors, transmitting the virus to primates, which then serve as reservoir hosts. Dense vegetation areas like forests and reservoirs provide ideal habitats for both the mosquitoes and primates, facilitating the spread of the disease [6, 7].

Monkeys, while not the primary cause of YF, are crucial in its transmission. Often referred to as "jungle fever," YF frequently occurs in remote or jungle regions where monkeys reside. These animals develop viremia when infected with YFV, meaning the virus is present in their bloodstream. Infected mosquitoes feed on these monkeys, subsequently transmitting the virus to other monkeys and humans. While monkeys can be infected with YFV, they are not the primary hosts; instead, the disease primarily spreads through Aedes mosquito species, which feed on both humans and monkeys [24, 25].

Although monkey-to-human transmission of YF is rare, precautions are necessary in endemic areas. It's crucial to avoid contact with monkey bodily fluids and take steps to prevent mosquito bites. Monitoring infected primate and rodent populations helps in assessing the risk of YF outbreaks. Proper wildlife management and surveillance can potentially reduce YF transmission. While other animals, like small mammals and certain birds, may carry the virus, they typically do not develop significant viremia and are not considered significant reservoir hosts of YFV [26, 27].

Moreover, in tropical regions of Nigeria, particularly West Africa, bats also contribute to YF transmission. Bats act as reservoir hosts, carrying and spreading the virus without exhibiting symptoms. Infected bats shed the virus in their feces and urine, which can contaminate food or water sources, leading to human and animal infections [6, 7].

Bats are particularly crucial in regions where humans and mosquitoes are not primary virus hosts. In these areas, the virus is maintained and transmitted within bat populations, with humans at risk of infection through contaminated fruits or water. While not all bats carry YFV, specific species serve as vectors of the disease. Protective measures, such as avoiding contact with bats and their excreta, and refraining from consuming raw or undercooked wild meat, are vital when traveling in YF-endemic regions [28, 29].

Forest

Forests are integral to Nigeria's ecological balance, serving as vital habitats for diverse plant and animal species crucial to our ecosystem. However, forests also play a significant role in the transmission dynamics of the YFV within the country. The unique ecological characteristics of Nigerian forests, coupled with the presence of key hosts and vectors, contribute to the spread of YFV [6, 7].

Nigerian forests harbor non-human primates, such as monkeys and apes, which serve as reservoir hosts for YFV. These primates are highly susceptible to YFV infection, facilitating viral amplification within their populations. Furthermore, the dense vegetation and varied microhabitats within Nigerian forests provide ideal breeding grounds for mosquito vectors. Mosquitoes, crucial in transmitting the virus, thrive in these environments, utilizing tree holes, leaf axils, and other water-holding containers for breeding. The warm and humid climate prevalent in Nigerian forests further enhances mosquito activity, promoting viral replication within mosquito vectors [25, 26].

Climate change

Furthermore; climate change poses a significant threat to the fight against YF, necessitating urgent mitigation efforts for the country's future [6, 7]. The impact of climate change on YF trends in Nigeria and other endemic regions is profound, altering environmental conditions conducive to virus transmission. Rising

temperatures and changing rainfall patterns create favorable habitats for mosquitoes, intensifying the risk of YF transmission. With increasing temperatures, previously unsuitable areas become hospitable for mosquito survival, leading to population growth and expansion into new territories. This expansion amplifies the likelihood of disease transmission in regions previously unaffected by YF. Furthermore, alterations in rainfall patterns affect mosquito breeding habitats, further exacerbating the proliferation of mosquito populations and subsequent YF transmission dynamics [30, 31, 32, 33].

Population migration

Population migration is another significant factor influencing the spread of yellow fever (YF) within Nigeria's borders. Migrants originating from countries experiencing YF outbreaks can introduce the disease to new regions, potentially triggering outbreaks in non-endemic areas. Additionally, migration disrupts access to healthcare and vaccination services, exacerbating the risk of YF outbreaks [6, 7].

Migration patterns impact YF prevalence in two key ways. Firstly, individuals relocating from high-incidence YF areas to low-incidence regions can introduce the disease to new populations. Conversely, migrants moving from low-incidence areas to high-incidence regions face heightened susceptibility to YF infection. This movement of non-immune individuals contributes to the spread of YF within endemic areas. Economic factors primarily drive population migration in Nigeria. However, natural disasters, climate change, and environmental degradation also compel migration as communities seek safety and stability. Political instability and conflict further drive population displacement as individuals flee for security. These factors underscore the pivotal role of population movement in shaping YF transmission dynamics within Nigeria's endemic regions [23-25].

The concept of one health

According to the World Health Organization, One Health **(Figure 4)** is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent [15, 33]. It epitomizes a transformative shift in disease control strategies and transcends disciplinary boundaries, advocating for collaboration and coordination among diverse sectors to prevent and manage diseases that can be transmitted between animals and humans, known as zoonoses, while simultaneously safeguarding ecosystem health. By acknowledging the multifaceted relationships between these components, One Health strives to harness the synergies between human, animal, and environmental health for mutual benefit, while mitigating potential adverse consequences [12]. This holistic perspective underscores the importance of addressing health challenges at their roots, embracing a comprehensive understanding of health that encompasses not only physical well-being but also social, economic, and ecological factors [13].

One Health strategies for yellow fever prevention and control

Adopting a One Health approach is essential for effective yellow fever prevention and control. It aims to promote health and well-being through effective management of the natural resources that sustain all life on earth [15]. This approach recognizes that YF is zoonotic, meaning it is transmitted from animals to humans, especially through the bite of infected mosquitoes. It also recognizes that factors such as deforestation, population migration, climate change, land use, and wildlife trade can have a profound effect on public health. [11-13]. By using a multidisciplinary and collaborative approach, One Health approach attempts to address these issues by integrating human, animal, and environmental health policies, frameworks, and practices in the fight against YF. Vaccination programs are paramount, encompassing immunization for both humans and animal reservoirs. Surveillance and early detection efforts focus on monitoring human cases, animal populations, and mosquito breeding sites. Vector control measures, including the use of insecticides and habitat modification, play a critical role. Community engagement through health education initiatives ensures a holistic strategy, integrating human health, animal health, and environmental health components [14,16,17] **(Table 2)**.

Insect vector Control

In Nigeria, controlling the mosquito population stands as a pivotal aspect in the fight against yellow fever [6]. Eliminating breeding sites, particularly stagnant water and overgrown vegetation, emerges as a crucial strategy. Mosquitoes typically lay their eggs in stagnant

water, necessitating the removal of potential breeding grounds from homes and communities. This encompasses the disposal of items like empty containers and old tires that can collect water, thereby curbing mosquito proliferation. Additionally, the utilization of insecticides and repellents plays a significant role in mosquito control efforts. These interventions can be administered through spraying activities or by employing mosquito nets treated with insecticides. Such measures have demonstrated efficacy in reducing YF incidence rates across various regions of Nigeria [6, 7].

The exploration of genetically modified mosquitoes presents a promising avenue in the fight against YF within Nigeria. One approach involves engineering mosquitoes to be resistant to the yellow fever virus (YFV), thereby impeding their ability to transmit the disease to humans. Another strategy entails releasing genetically modified mosquitoes programmed to produce offspring with reduced viability, thus diminishing the mosquito population over time. Despite their potential, the adoption of genetically modified mosquitoes raises ethical and environmental considerations. Concerns linger regarding the impact on indigenous species and the ecosystem's long-term stability following the release of modified organisms. Hence, while genetically modified mosquitoes offer prospects in YF control, careful deliberation and extensive research are essential to mitigate risks and ensure their safety and efficacy [2, 23, 24, 25].

Wildlife and reservior hosts control

Controlling wildlife and reservoir hosts stands as a critical component in the fight against yellow fever (YF) and the mitigation of outbreak risks. With a diverse range of potential hosts including primates, rodents, and bats, implementing effective prevention measures is imperative. One essential strategy involves minimizing human-wildlife contact, particularly in regions endemic to yellow fever. This necessitates raising awareness among local communities about the risks associated with wildlife interaction, specifically with primates and bats, and promoting behaviors that reduce exposure. Encouraging practices such as proper waste management and securing food sources can help deter wildlife from human-inhabited areas [6, 7].

Avoiding the consumption of raw or undercooked meat from wild animals emerges as another crucial measure to prevent yellow fever transmission. Consumption of contaminated meat poses a significant risk of infection, especially if sourced from animals that may harbor the virus without exhibiting symptoms. Implementing regulations and public health campaigns to discourage bush meat consumption and advocate for safe food handling practices are essential steps in reducing the risk of exposure to yellow fever and other zoonotic diseases [19, 21].

Furthermore, minimizing yellow fever spread among wildlife populations is paramount for preventing spillover into human communities. This necessitates the implementation of surveillance programs to monitor the prevalence of the yellow fever virus in wildlife populations, particularly in regions where the virus is endemic. Surveillance efforts should focus on key reservoir hosts such as primates and bats to promptly detect and respond to outbreaks [23, 24].

Deforestation control

In Nigeria, combating deforestation emerges as a crucial aspect in the fight against yellow fever (YF) and the mitigation of outbreak risks. Deforestation, characterized by the widespread cutting down of trees for purposes like agriculture, mining, and settlement, poses significant challenges. While purported as a control measure, its adverse effects far outweigh its benefits, particularly concerning YF transmission dynamics. The repercussions of deforestation on YF epidemiology and transmission within Nigeria are profound. Firstly, deforestation fragments forest ecosystems, disrupting the natural habitats of wildlife. This displacement often leads wild animals to migrate to urban and suburban areas, increasing the likelihood of human-wildlife contact and YF transmission [6, 7].

Furthermore, deforestation can trigger several impacts on YF transmission dynamics in endemic regions like Nigeria. These include the fragmentation of forests, destruction of wildlife habitats, alterations in climate patterns, changes in water availability, and shifts in vector distribution. Fragmentation of forests fosters increased mosquito populations carrying the virus and expands the potential human hosts dwelling in and around forested areas. Destruction of wildlife habitats facilitates the spread of the virus, heightening the risk of human infection. Climate changes may foster dense vegetation, providing breeding grounds for

mosquitoes and amplifying YF transmission. Reduced water availability could alter mosquito habitats, resulting in elevated vector-borne disease cases, including YF. Additionally, the redistribution of vectors may occur as forests give way to alternative land uses like agriculture [16, 18].

Thus, promoting sustainable forestry practices is imperative in Nigeria to mitigate deforestation's adverse impacts on the environment and public health. By implementing measures to curb deforestation and preserve forest ecosystems, Nigeria can effectively address the underlying factors contributing to YF transmission and safeguard public health. It is imperative to adopt strategies that prioritize sustainable land use practices, preserving forest ecosystems, and minimizing human-wildlife interactions to mitigate the risk of YF outbreaks in Nigeria [6, 7, 25].

Climate change control

Addressing climate change emerges as a critical component in the fight against yellow fever (YF) and the protection of vulnerable communities from its impact. Implementing measures to mitigate climate change is essential to ensure that resources and infrastructure are available to control the spread of the disease effectively [29, 30]. These measures encompass a range of strategies tailored to Nigeria's context:

Firstly, transitioning to renewable energy sources, such as solar, wind, geothermal, and hydropower, holds promise in reducing reliance on fossil fuels and curbing greenhouse gas emissions. This shift can contribute significantly to mitigating climate change and subsequently minimizing the environmental conditions conducive to YF transmission [31].

Furthermore, promoting energy efficiency initiatives, such as using energy-efficient appliances and constructing energy-efficient buildings, can help reduce energy demand and mitigate climate change effects. Investing in public transportation infrastructure and clean transportation alternatives like bicycles and electric vehicles can also play a pivotal role in reducing greenhouse gas emissions from the transportation sector within Nigeria [29, 32]. Afforestation and reforestation efforts are paramount in Nigeria's climate change mitigation strategy. By planting more trees, the country can enhance carbon sequestration, effectively removing carbon dioxide from the atmosphere and mitigating the impacts of climate change. Additionally, implementing a carbon tax on fossil fuels and other carbon-emitting activities can incentivize companies and individuals to reduce their carbon footprint, contributing to overall climate change mitigation efforts [33, 34].

Encouraging sustainable agricultural practices is vital in Nigeria's fight against climate change and YF transmission. Practices such as organic farming and reduced tillage can help minimize greenhouse gas emissions associated with agricultural activities. Additionally, reducing waste generation and implementing effective waste management strategies can mitigate methane emissions from landfills, further contributing to climate change mitigation efforts [31, 32].

Population migration control

To counteract the detrimental effects of population migration on YF transmission, comprehensive control measures are indispensable. These measures encompass various strategies aimed at discouraging population movement, including:

Economic development: Prioritize investments in economic growth initiatives within YF-endemic regions. This includes fostering industries such as tourism and agriculture, which can drive local economies without significantly increasing migration pressure [8,35]. Environmental protection targeting YF vector habitats: Implement environmental conservation efforts with a specific emphasis on mitigating mosquito breeding grounds. This may involve initiatives like habitat restoration, water management, and waste disposal programs tailored to reduce vector proliferation [36, 37].

Education and skills development for YF awareness and vector control: Integrate YF education and vector control training into educational curricula and skill development programs. By empowering communities with knowledge about YF transmission and prevention methods, individuals are better equipped to take proactive measures to protect themselves and their surroundings [8].

Social safety nets with YF healthcare access: Strengthen social welfare systems to ensure access to YF vaccinations, healthcare services, and sanitation infrastructure in both origin and destination areas. This can help mitigate the health risks associated with YF outbreaks and reduce the likelihood of migration driven by healthcare disparities [35].

Political stability for effective YF response: Foster political stability and governance

structures conducive to rapid and effective responses to YF outbreaks. A stable political environment enables timely allocation of resources, coordination among stakeholders, and implementation of public health interventions necessary for YF containment [36].

Information and Communication Technology for YF Surveillance and Response: Harness advancements in Information and Communication Technology (ICT) to enhance YF surveillance, communication, and response mechanisms. Utilize mobile technology and digital platforms to disseminate YF-related information, facilitate remote healthcare consultations, and streamline outbreak reporting systems [5, 10, 26, 37].

Vaccination and immunization coverage

Vaccination is a cornerstone intervention in combating yellow fever (YF) transmission. The YF vaccine is readily available, safe, and highly effective, offering protection for up to 10 years. It comprises a live, attenuated virus providing lifelong immunity for most recipients [38, 39]. The World Health Organization (WHO) strongly recommends vaccination for individuals residing in or traveling to YF-endemic areas. Additionally, individuals unable to receive the vaccine should take precautions against mosquito bites to prevent virus transmission [40]. Some countries mandate proof of YF vaccination for entry, necessitating travelers to verify requirements before departure. However, the YF vaccine may not be suitable for everyone, such as those with weakened immune systems, pregnant women, and very young infants, who should refrain from vaccination. Consultation with healthcare providers is recommended for those uncertain about vaccine eligibility. Efforts to bolster immunization programs in Nigeria are underway, with intensified routine immunization campaigns targeting infants and children [22].

Immunization against YF is a critical public health intervention in Nigeria. According to data from the World Health Organization (WHO), the YF immunization coverage in Nigeria is estimated to be around 63% [40]. This coverage is relatively low for a country (with estimated population of over 200 million) that is endemic for YF, and highlights the need for increased efforts to ensure that more people are vaccinated against this disease. The Nigerian government has been working to increase immunization coverage through various initiatives, including mass vaccination campaigns and the integration of YF vaccination into routine immunization schedules [22]. The map of Nigeria showing states and year of implementation of yellow fever mass vaccination campaigns from 2013 – 2023 is presented in **Figure 5** below. In addition to government efforts, individuals can also play a role in increasing YF immunization coverage by ensuring that they and their families receive the vaccine. This is especially important for those who live in or travel to areas that are endemic for YF. It is recommended that individuals receive the YF vaccine every 10 years to ensure ongoing protection against the disease [41-43]. Overall, while YF immunization coverage in Nigeria is still relatively low, there are ongoing efforts to increase coverage and reduce the burden of this disease in the country [6,7]. Continuous monitoring of YF vaccine effectiveness is paramount, although no significant mutations affecting vaccine efficacy have been reported as of October 2021. Nonetheless, vigilance against viral evolution remains crucial. YF, manifests flu-like symptoms, jaundice, bleeding, and organ failure, underscoring the importance of vaccination for prevention. Staying abreast of updated recommendations from reliable health authorities is essential for effective prevention and control of YF transmission [44-47].

Early disease detection and reporting

Early detection and prompt reporting of yellow fever (YF) cases play a pivotal role in controlling outbreaks and preventing further spread of the disease. Recognizing the symptoms of YF is crucial, as they can mimic those of other viral infections common in the region, such as dengue and malaria. Symptoms include fever, severe headache, muscle and joint pains, fatigue, nausea or vomiting. While symptoms may improve without treatment in most cases, severe forms of YF can lead to jaundice (yellowing of the skin and eyes), abdominal pain, vomiting, and bleeding, with up to 50 percent of cases resulting in shock, organ failure, and death [48].

To enhance early detection, individuals should be educated about these symptoms and encouraged to seek medical attention promptly if they experience any of them. Healthcare providers play a vital role in this process by promptly identifying and reporting suspected YF cases to local health authorities or the national public health

institute. Timely reporting is essential for initiating an effective response and containing outbreaks. Laboratory diagnosis of YF typically relies on detecting antibodies against the YF virus (YFV) in the blood, either during the acute phase or convalescence. Serological tests, such as enzyme-linked immunosorbent assays (ELISAs), are commonly used for this purpose. Additionally, molecular diagnostic techniques like polymerase chain reaction (PCR) can detect the presence of the virus in blood, tissue samples, or other bodily fluids. These tests aid in confirming a YF diagnosis in the early stages, facilitating prompt treatment and preventing the progression to severe disease and complications [1, 35].

In Nigeria, strengthening laboratory capacities and ensuring the availability of diagnostic tools are imperative for early disease detection and response. Healthcare systems should prioritize training healthcare providers on YF recognition and reporting protocols, while also investing in surveillance infrastructure to facilitate timely case identification. By enhancing early detection and reporting mechanisms, Nigeria can bolster its efforts in controlling YF outbreaks and protecting public health [1, 6].

Laboratory monitoring and tracking of the virus

Laboratory monitoring and tracking of the yellow fever virus (YFV) is essential for effective disease control [22]. One key aspect involves testing mosquitoes to detect the presence of YFV, aiding in targeted mosquito control efforts and public health warnings [19]. Gene sequencing of YFV is a pivotal tool in combating the disease. By analyzing the virus's genetic code, researchers can pinpoint specific strains causing outbreaks and track disease spread. This data informs tailored vaccine development and enhances disease surveillance and response. Additionally, gene sequencing identifies potential drug targets for YF treatment, aiding in the development of more effective therapies [25, 35]. Replacing traditional PCR, advanced techniques like metagenomic sequencing offer enhanced capabilities. Metagenomic sequencing enables comprehensive analysis of microbial communities, including viruses like YFV. This method provides detailed genetic information, facilitating precise strain identification and evolutionary analysis [12].

Moreover, Next Generation Sequencing (NGS) revolutionizes YFV genome sequencing. NGS allows rapid, high-throughput sequencing of vast genetic material. Viral RNA is extracted from samples, converted to DNA, fragmented, and sequenced using NGS platforms like Illumina or Ion Torrent. Data analysis yields full genome sequences for comparison, aiding in understanding transmission dynamics and evolution [19]. Overall, advanced laboratory techniques, such as metagenomic sequencing and NGS, are crucial for effective YFV monitoring and control. These methods empower rapid and accurate detection, supporting timely responses to outbreaks and minimizing the disease's impact [1, 6, 35, 48].

Collaborative efforts, led by organizations like the World Health Organization (WHO), further bolster global disease surveillance and prevention initiatives [8]. The WHO plays a pivotal role in monitoring the global incidence of Yellow Fever (YF) and orchestrating responses to outbreaks and vaccination campaigns. Utilizing a network of national and international partners, the WHO employs cutting-edge surveillance methods to track YF prevalence and identify emerging threats swiftly. In recent years, the WHO has intensified efforts to enhance YF surveillance through innovative approaches such as real-time data analysis and geospatial mapping. By leveraging advanced technologies and collaborative platforms, the organization can promptly detect and respond to outbreaks, thereby minimizing their impact on vulnerable populations [49, 50].

Furthermore, the WHO's engagement in vaccination campaigns is instrumental in preventing the spread of YF. Through strategic coordination with governments, healthcare agencies, and non-governmental organizations, the WHO ensures equitable access to YF vaccines in high-risk regions. Additionally, the organization advocates for the development and distribution of affordable vaccines to safeguard communities against YF transmission. Overall, the WHO's proactive monitoring of YF incidence, coupled with its commitment to vaccination campaigns and collaborative partnerships, underscores its pivotal role in combating the spread of this disease. By staying at the forefront of YF surveillance and response efforts, the WHO continues to safeguard global public health and mitigate the impact of YF outbreaks on communities worldwide [21, 40].

Public awareness and engagement

Fostering public awareness and engagement is paramount in the fight against yellow fever (YF), ensuring communities are equipped with the knowledge and resources to prevent and control

the disease effectively in Nigeria. To enhance public participation, a range of tailored approaches can be implemented [6, 7]:

Education campaigns serve as a cornerstone in disseminating accurate information about YF, its transmission, and preventive measures. Utilizing diverse mediums such as posters, leaflets, social media, radio, and TV broadcasts, communities can be educated on the risks and symptoms of YF, as well as strategies to protect against mosquito bites and the importance of vaccination. Collaboration between public health agencies, schools, and religious institutions is essential in reaching populations residing in YF-vulnerable areas [8, 9].

Vaccination campaigns are crucial for preventing YF transmission. Increasing access to YF vaccines through public health facilities and mobile clinics can expedite vaccination coverage, ensuring more individuals are protected against the disease. Community engagement initiatives involving local community groups, social clubs, and community leaders are instrumental in fostering public interest and participation in awareness and vaccination campaigns. By leveraging existing community structures, awareness of YF can be heightened, vaccine distribution facilitated, and participation in vaccination programs encouraged [35, 39, 40, 41].

Nigeria's approach to public awareness and engagement aligns with the One Health framework, emphasizing collaboration across diverse stakeholders. National and international research efforts unite scientists and health organizations to deepen understanding of YF ecology and evolution. Cross-sectoral coordination brings together health, agriculture, and environment sectors to develop integrated control strategies. Capacity-building initiatives target healthcare workers and veterinarians, strengthening overall health systems. Policy integration, led by government agencies and policymakers, is vital in formulating and implementing policies supportive of a unified approach to combat YF. By fostering public awareness, engagement, and collaboration under the One Health framework, Nigeria can enhance its capacity to prevent, detect, and respond to YF outbreaks effectively, safeguarding the health and well-being of its population [6, 7].

Challenges facing the implementation of the one health concept in Nigeria

There are many challenges bedeviling the implementation of the one health concept in Nigeria [6, 7]:

First, one of the primary challenges is the lack of robust collaboration between the human health, animal health, and environmental sectors. Yellow fever is a zoonotic disease, meaning it can be transmitted from animals to humans, and addressing it requires coordinated efforts from multiple sectors.

Second, Nigeria faces resource constraints in terms of healthcare facilities, diagnostic tools, and surveillance systems. This limitation hampers effective disease monitoring, prevention, and response efforts.

Third, there is a need for comprehensive public awareness campaigns to educate communities about yellow fever transmission, symptoms, and prevention measures. Without proper education, people may not seek vaccination or take necessary precautions against the disease.

Fourth, surveillance systems for both human and animal health are often fragmented and insufficiently resourced. This makes it challenging to detect and respond to yellow fever outbreaks promptly.

Fifth, rapid urbanization and population movement increase the risk of yellow fever spread, particularly in densely populated urban areas where mosquito breeding sites are abundant. Controlling the disease's spread in such environments poses significant challenges.

Sixth, climate change can influence the distribution and abundance of mosquitoes, the vectors responsible for transmitting yellow fever. Environmental degradation and deforestation also contribute to increased mosquito breeding habitats, exacerbating the risk of disease transmission.

The last, but not the least, policy and regulatory barriers exist. The country lacks a comprehensive policy framework that integrates OneHealth principles into disease control strategies. Existing policies might be fragmented across different sectors, hindering effective collaboration and coordination. There are regulatory gaps in enforcing measures related to disease surveillance, vaccination, and environmental management. Inconsistent enforcement of regulations could undermine efforts to control yellow fever. Some agencies or departments lack clear legal mandates or authority to enforce OneHealth interventions. This

can lead to jurisdictional conflicts and inefficiencies in implementing collaborative initiatives.

Recommendations for successful implementation of one health concept in Nigeria

Despite the challenges mentioned above, efforts are ongoing to mitigate the impact of yellow fever in Nigeria. The Nigeria Centre for Disease Control (NCDC) has taken a lead role in coordinating response activities through the National Multi-agency Yellow Fever Technical Working Group (YF TWG) [19, 22].

To this end, we therefore make the following recommendations:

1. Strengthening of Intersectoral Coordination Mechanisms: The government and the people of Nigeria must continue to strengthen platforms for collaboration between human health, animal health, environmental, and other relevant sectors at national, regional, and local levels. This includes establishing joint task forces, sharing data and resources, and conducting regular meetings to coordinate efforts.
2. Investment in Infrastructure and Capacity Building: Allocate resources to improve healthcare infrastructure, laboratory facilities, and surveillance systems. Enhance training programs for healthcare workers, veterinarians, and environmental specialists to build capacity for disease detection, prevention, and response.
3. Community Engagement and Health Education: Sustain comprehensive public awareness campaigns to educate communities about yellow fever, its transmission dynamics, and preventive measures such as vaccination and mosquito control. Engage community leaders, schools, and local organizations to disseminate information and promote behavioral change.
4. Enhanced Surveillance and Early Warning Systems: Strengthen disease surveillance networks to enhance early detection and response to yellow fever outbreaks. Implement Integrated Disease Surveillance and Response (IDSR) platform that monitor human and animal health, as well as environmental factors, to identify and mitigate potential risks.
5. Urban Planning and Environmental Management: Integrate yellow fever control measures into urban planning strategies to reduce mosquito breeding sites and mitigate environmental factors conducive to disease transmission. Implement mosquito control programs, such as insecticide spraying and habitat reduction, particularly in high-risk urban areas.
6. Climate Change Adaptation Strategies: Develop adaptation strategies to address the impact of climate change on yellow fever transmission. This includes monitoring and modeling changes in mosquito populations and implementing interventions to minimize the disease's spread in response to shifting environmental conditions.
7. Revision of current policies and regulations: The national policy framework should be review periodically. The roles, responsibilities, and mechanisms for collaboration between relevant sectors should be clearly outlined. Government must enhance regulatory oversight to ensure compliance with disease control measures and environmental regulations. This may involve revising existing laws, regulations, and enforcement mechanisms to address emerging health threats like yellow fever. Create interagency committees or task forces responsible for coordinating one health initiatives. These bodies should facilitate information sharing, joint planning, and decision-making among key stakeholders from different sectors. Provide training and capacity-building programs for regulatory agencies to enhance their ability to implement one health interventions effectively. This includes training on cross-sectoral collaboration, risk assessment, and regulatory enforcement. Engage stakeholders, including government agencies, non-governmental organizations, communities, and the private sector, in the policymaking process. Solicit input from diverse stakeholders to ensure that policies and regulations reflect the needs and

priorities of all relevant parties. Establish mechanisms for monitoring and evaluating the implementation of one health policies and regulations. Regular assessments can help identify barriers, gaps, and areas for improvement, enabling policymakers to refine strategies and enhance effectiveness over time.

Table 1. Interconnected factors contributing to yellow fever spread.

Factors	Human health	Animal health	Environmental factors
Mosquito vectors	Transmission of the virus between humans and animals	Breeding sites for mosquitoes in both human and animal habitats	Climate conditions influencing mosquito activity
Urbanization	Increased human density facilitates virus transmission	Changes in habitat and behavior of animal reservoirs	Altered ecological balance affecting disease dynamics
Globalization	Travel facilitates virus spread globally	Movement of infected animals and vectors	Changes in trade and climate patterns affecting disease spread
Deforestation	Alters habitat for both human and animal hosts	Disruption of wildlife populations	Impact on mosquito breeding grounds and virus reservoirs

Table 2. One Health Strategies for yellow fever prevention and control.

Strategies	Human health	Animal health	Environmental health
Insect vector control	Use of insecticides and bed nets for humans	Application of insecticides in animal habitats	Habitat modification and preservation
Surveillance and early detection	Early detection of human cases through healthcare systems	Monitoring of animal populations for virus presence	Environmental surveillance for mosquito breeding sites
Vaccination programs	Immunization campaigns for human populations	Vaccination of animal reservoirs	Monitoring and control of vectors in vaccination campaigns
Community engagement	Health education and awareness campaigns	Involvement of communities in animal health programs	Promoting environmental conservation and sustainable practices

Figure 1. Schematic diagram showing the morphology of YFV [18].

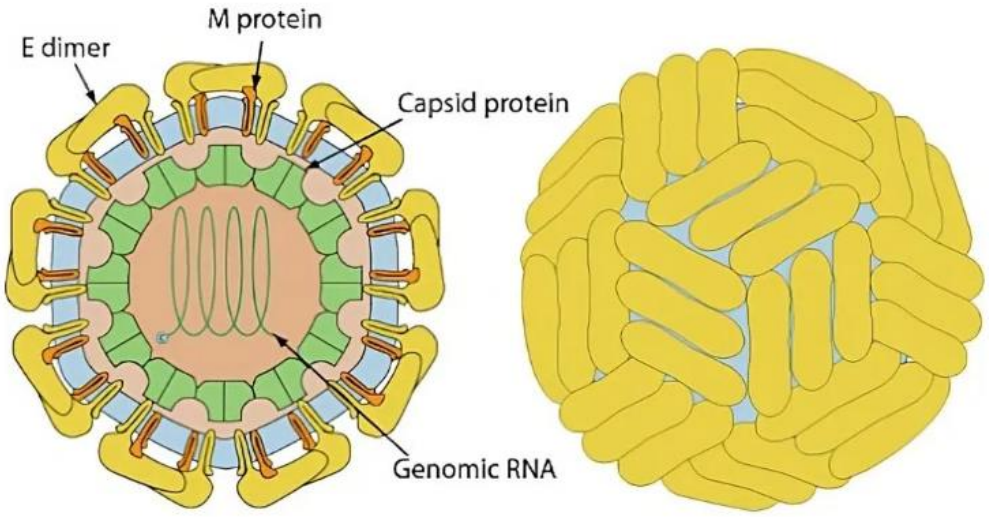


Figure 2. Map of Nigeria showing states with outbreaks of yellow fever in 2020 [20].

Figure 3. Map of Nigeria showing yellow fever outbreak in 36 states including FCT from 1st January– 31st December, 2023 [22].

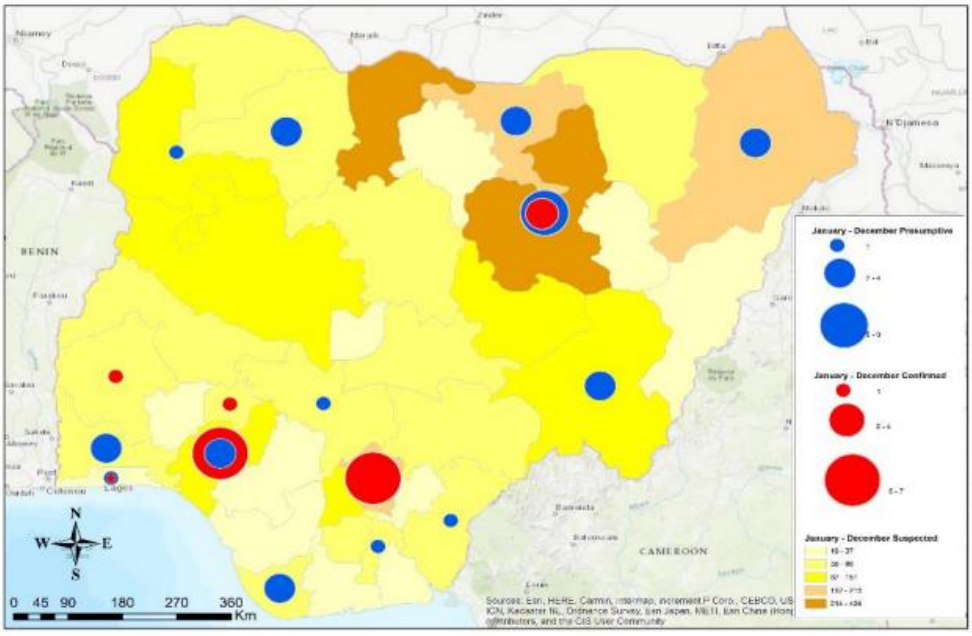
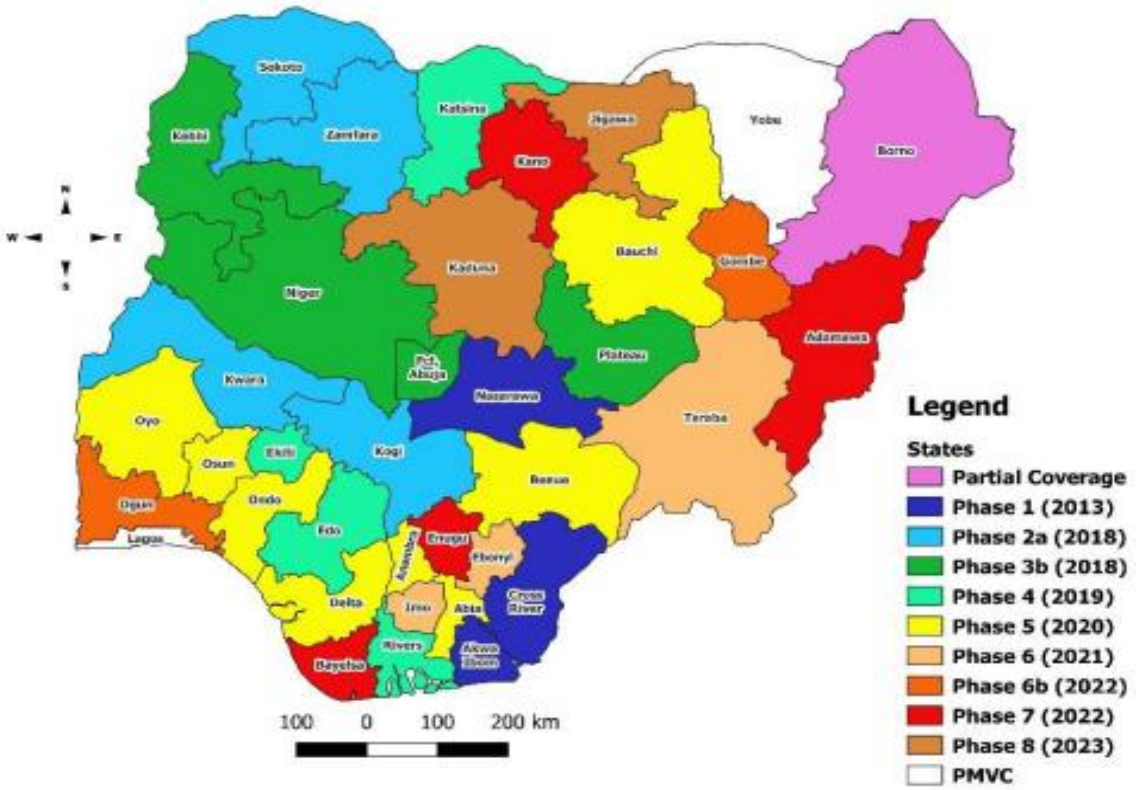


Figure 4. Illustration of One Health concept [15].

Figure 5. Map of Nigeria showing states and year of implementation of yellow fever mass vaccination campaigns from 2013 – 2023 [22].



Conclusion

In conclusion, vaccination remains the cornerstone of efforts to combat yellow fever (YF) in Nigeria. It is imperative that individuals traveling to or residing in YF-endemic regions receive the YF vaccine, ideally at least ten days before their journey. Moreover, proactive vaccination of individuals in high-risk areas is essential to prevent outbreaks within communities. Additionally, controlling the mosquito population through measures such as insecticide use, mosquito nets, and health education plays a crucial role in reducing YF transmission risks. By embracing a One Health approach tailored to Nigeria's context, integrating efforts across various sectors, we can advance towards a future free from the threat of yellow fever. Together, through comprehensive vaccination strategies and mosquito control measures, Nigeria can mitigate the burden of YF and safeguard the health and well-being of its population.

Consent and approval

Not applicable.

Competing interests

The authors have declared that there are no competing interests.

Funding

This review paper was not funded.

References

1- Ab´ılio AP, Kampango A, Armando EJ. First confirmed occurrence of the yellow fever virus and dengue virus vector Aedes (Ste-gomyia) luteocephalus (Newstead, 1907) in Mozambique. Para-sit Vectors 2020; 13:350. Available at: https://doi.org/10.1186/s13071-020-04217-9

2- Vasconcelos PF. Yellow Fever. In: Marcondes, C. (eds) Arthropod Borne Diseases. Springer, Cham 2017; 101-113. Available at: https://doi.org/10.1007/978-3-319-13884-8_8

3- Chippaux JP, and Chippaux A. Yellow fever in Africa and the Americas: a historical and epidemiological perspective. Journal of Venomous Animals and Toxins including Tropical Diseases 2018 Sep 21;24. Available at https://doi.org/10.1186/s40409-018-0162-y:

4- World Health Organization. Yellow Fever. WHO 2019. Available at: https://www.who.int/news-room/fact-sheets/detail/yellow-fever 2019 [Last accessed on January 20, 2024].

5- Moreno ES, and Barata RD. Methodology for definition of yellow fever priority areas, based on environmental variables and multiple correspondence analyses. PLoS Neglected Tropical Diseases 2012 Jul 3; 6(7):e1658. Available at: https://doi.org/10.1371/journal.pntd.0001658

6- Tomori O. Yellow fever in Africa: Public health impact and prospects for control in the 21st century. Biomedica: Revista Del Instituto Nacional De Salud 2002; 22(2): 178–210. Available at: http://www.redalyc.org/articulo.oa?id=84322213

7- Tomori O. Yellow fever: the recurring plague. Crit Rev Clin Lab Sci 2004; 41(4):391-427. Available at: https:// doi:org/10.1080/10408360490497474

8- Gianchecchi E, Cianchi V, Torelli A & Montomoli E. Yellow Fever: Origin, Epidemiology, Preventive Strategies and Future Prospects. Vaccines 2022; 10(3): 372. Available at: https://doi.org/10.3390/vaccines10030372

9- Garske T, Van Kerkhove MD, Yactayo S, Ronveaux O, Lewis RF, Staples JE, et al.. Yellow Fever in Africa: Estimating the Burden of Disease and Impact of Mass Vaccination from Outbreak and Serological Data. PLoS Medicine 2014; 11(5): e1001638. Available at: https://doi.org/10.1371/journal.pmed.1001638

10- Douam F, and Ploss A. Yellow fever virus: knowledge gaps impeding the fight against an

old foe. Trends in microbiology 2018 Nov 1; 26(11): 913-928. Available at: https://doi.org/10.1016/j.tim.2018.05.012

11- Rabinowitz PM, Pappaioanou M, Bardosh KL, Conti L. A planetary vision for one health. BMJ global health 2018; 3(5). Available at: https://doi.org/10.1136/bmjgh-2018-001137

12- Ellwanger JH, Veiga AB, Kaminski VD, Valverde-Villegas JM, Freitas AW, Chies JA. Control and prevention of infectious diseases from a One Health perspective. Genetics and Molecular Biology 2021 Jan 29;44. Available at: https://doi.org/10.1590/1678-4685-GMB-2020-0256

13- Buregyeya E, Atusingwize E, Nsamba P, Musoke D, Naigaga I, Kabasa JD, et al. Operationalizing the one health approach in Uganda: Challenges and opportunities. Journal of Epidemiology and Global Health 2020 Dec; 10(4):250. Available at: https://doi.org/10.2991/jegh.k.200825.001

14- Centers for Disease Control and Prevention. National Center for Emerging and Zoonotic Infectious Diseases (NCEZID). One Health Basics. CDC 2023. Available at: Available at: https://www.cdc.gov/onehealth/basics/index.html. [Last Reviewed: September 28, 2023].

15- One Health Trust. IndiaZooSystems – Strengthening One Health Responses to Zoonotic Diseases Available at: https://onehealthtrust.org/projects/indiazoosystems/ Last Accessed on December, 18, 2023).

16- World Health Organization. One Health. WHO 2024. Available at: https://www.who.int/health-topics/one-health#tab=tab_1 [Last Accessed January 20, 2024].

17- Erkyihun GA, and Alemayehu MB. One Health approach for the control of zoonotic diseases. Zoonoses 2022 Nov 30; 2(1). https://doi.org/10.15212/ZOONOSES-2022-0037

18- Zhao Y, Zhang X, Shu S, Sun Y, Feng X, Zhang S. Yellow Fever: A Re-Emerging Threat. Health 2018 Oct 31; 10(10):1431. Available at: https://doi:org/10.4236/health.2018.1010110

19- Haseltine W A. Promising monoclonal antibodies for the treatment of Yellow Fever Virus. 2023, Available at: https://www.forbes.com/sites/williamhaseltine/2023/04/04/promising-monoclonal-antibodies-for-the-treatment-of-yellow-fever-virus/?sh=3bea74856cff

20- Nigeria Centre for Disease Control and Prevention.Yellow Fever. NCDC 2019. Available at: https://ncdc.gov.ng/diseases/info/Y [Last updated 2019-04-15 03:49:05]

21- Centers for Disease Control and Prevention. Travelers' Health: Yellow Fever in Nigeria. CDC 2020. Available at: https://wwwnc.cdc.gov/travel/notices/level2/yellow-fever-nigeria

22- World Health Organization. Yellow Fever in Nigeria. WHO 2021. Available at: https://www.who.int/emergencies/disease-outbreak-news/item/2021-DON336

23- Nigeria Centre for Disease Control and Prevention.Yellow fever situation report. Weekly Epidemiological Report. NCDC 2023. Available at: https://ncdc.gov.ng/themes/common/files/sitreps/692a77aafd3f4bf099b127ab9507fd11.pdf

24- Agwu J, Clement I, Igbinosa I. Detection of yellow fever and dengue viruses in mosquitoes between 2014 and 2015 in Bayelsa and Benue states of Nigeria. Acta Entomologica Serbica 2019; 24:59–78. Available at: https://doi.org/10.5281/zenodo.3329978

25- Isaac C, and Ugwu EJ. Mosquito infection with dengue and yellow fever in Bayelsa and Benue

States, Nigeria. Int J Infect Dis 2016; 45: 73-74. Available at: https://doi.org/10.1016/j.ijid.2016.02.208

26- Sutherst RW. Global change and human vulnerability to vector-borne diseases. Clinical microbiology reviews 2004; Jan; 17(1): 136-173. Available at: https://doi.org/10.1128/cmr.17.1.136-173.2004

27- Benelli G, and Duggan MF. Management of arthropod vector data–Social and ecological dynamics facing the One Health perspective. Acta tropica 2018 Jun 1;182: 80-91. Available at: https://doi.org/10.1016/j.actatropica.2018.02.015

28- Auguste AJ, Lemey P, Pybus OG, Suchard MA, Salas RA, Adesiyun AA, et al. Yellow fever virus maintenance in Trinidad and its dispersal throughout the Americas. Journal of virology 2010 Oct 1;84(19):9967-9977. Available at: https://doi.org/10.1128/jvi.00588-10

29- Inziani M, Adungo F, Awando J, Kihoro R, Inoue S, Morita K, et al.,. Seroprevalence of yellow fever, dengue, West Nile and chikungunya viruses in children in Teso South Sub-County, Western Kenya. International Journal of Infectious Diseases 2020 Feb 1; 91:104-110. Available at: https://doi.org/10.1016/j.ijid.2019.11.004

30- Gaythorpe KA, Hamlet A, Cibrelus L, Garske T, Ferguson NM. The effect of climate change on yellow fever disease burden in Africa. Elife 2020 Jul 28; 9:e55619. Available at: https://doi.org/10.7554/eLife.55619

31- Zinsstag J, Crump L, Schelling E, Hattendorf J, Maidane YO, Ali KO, et al. Climate change and one health. FEMS microbiology letters 2018 Jun;365(11):fny085. Available at: https://doi.org/10.1093/femsle/fny085

32- Patz JA, Githeko AK, McCarty JP, Hussein S, Confalonieri U, De Wet N. Climate change and infectious diseases. Climate change and human health: risks and responses 2003; 2: 103-132. Available at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=0d3dc16d3c4d4b769065222930836698e789cf4a

33- McMichael AJ, and Kovats RS. Climate change and climate variability: adaptations to reduce adverse health impacts. Environmental Monitoring and Assessment 2000 Mar;61:49-64. Available at: https://doi.org/10.1023/A:1006357800521

34- Raimi MO, Vivien OT, Oluwatoyin OA. Creating the healthiest nation: Climate change and environmental health impacts in Nigeria: A narrative review. Scholink Sustainability in Environment 2021; 6(1). Available at: https://ssrn.com/abstract=3782416

35- Lashley FR. Emerging infectious diseases: vulnerabilities, contributing factors and approaches. Expert review of anti-infective therapy 2004 Apr 1;2(2):299-316. Available at: https://doi.org/10.1586/14787210.2.2.299

36- Kleinert RD, Montoya-Diaz E, Khera T, Welsch K, Tegtmeyer B, Hoehl S, et al. Yellow fever: Integrating current knowledge with technological innovations to identify strategies for controlling a re-emerging virus. Viruses 2019 Oct 17; 11(10):960. Available at: https://doi.org/10.3390/v11100960

37- Vanderslott S, and Marks T. Travel restrictions as a disease control measure: Lessons from yellow fever. Global Public Health 2021 Mar 4; 16(3): 340-353. Available at: https://doi.org/10.1080/17441692.2020.1805786

38- Ferrara P, Masuet-Aumatell C, Ramon-Torrell JM. Acceptance of yellow fever vaccine in the older traveller: A cohort study. Acta Bio

Medica : Atenei Parmensis 2021; 92(4): e2021098. Available at: https://doi.org/10.23750/abm.v92i4.11619.

39- Monath TP. Review of the risks and benefits of yellow fever vaccination including some new analyses. Expert Review of Vaccines 2012; 11(4): 427–448. Available at: https://doi.org/10.1586/erv.12.6

40- World Health Organization (WHO). Vaccines and vaccination against yellow fever: WHO position paper—June 2013. Weekly Epidemiological Record= Relevé épidémiologique hebdomadaire 2013; 88(27):269-83. Available at: https://iris.who.int/bitstream/handle/10665/242089/WER8827_269-283.PDF

41- Bifani AM, Ong EZ, de Alwis R. Vaccination and therapeutics: responding to the changing epidemiology of yellow fever. Current treatment options in infectious diseases 2020 Sep;12: 349-360. Available at: https://doi.org/10.1007/s40506-020-00232-7

42- Shearer FM, Moyes CL, Pigott DM, Brady OJ, Marinho F, Deshpande A, et al. Global yellow fever vaccination coverage from 1970 to 2016: an adjusted retrospective analysis. The Lancet infectious diseases 2017 Nov 1; 17(11):1209-1217. Available at: https://doi.org/10.1016/S1473-3099(17)30419-X

43- Jentes ES, Poumerol G, Gershman MD, Hill DR, Lemarchand, J. Lewis RF, et al. The revised global yellow fever risk map and recommendations for vaccination, 2010: Consensus of the Informal WHO Working Group on Geographic Risk for Yellow Fever. The Lancet Infectious Diseases 2011; 11(8): 622–632. Available at: https://doi.org/10.1016/S1473-3099(11)70147-5

44- Montalvo ZG, Rollier CS, Reyes-Sandoval A. Re-thinking yellow fever vaccines: fighting old foes with new generation vaccines. Human vaccines & immunotherapeutics 2022 Jan 31; 18(1):1895644. Available at: https://doi.org/10.1080/21645515.2021.1895644

45- Barrett ADT. Yellow fever vaccine: the conundrum of 2 doses, one dose, or one-fifth dose to induce and maintain protective immunity. J Infect Dis 2020; 221:1922–1924. Available at: https://doi.org/10.1093/infdis/jiz379

46- Beck AS, and Barrett AD. Current status and future prospects of yellow fever vaccines. Expert Rev Vaccines 2015;14:1479–92. Available at: https://doi.org/10.1586/14760584.2015.1083430

47- Amanna IJ, and Slifka MK. Questions regarding the safety and duration of immunity following live yellow fever vaccination. Expert Rev Vaccines 2016; 15:1519–1533. Available at: https://doi.org/10.1080/14760584.2016.1198259

48- Domingo C, Charrel RN, Schmidt-Chanasit J, Zeller H, Reusken C. Yellow fever in the diagnostics laboratory. Emerging microbes & infections 2018 Dec 1; 7(1):1-5. Available at: https://doi.org/10.1038/s41426-018-0128-8

49- Khromava AY, Eidex RB, Weld LH, Kohl KS, Bradshaw RD, Chen RT, et al. Yellow Fever Vaccine Safety Working Group. Yellow fever vaccine: an updated assessment of advanced age as a risk factor for serious adverse events. Vaccine 2005 May 9; 23(25): 3256-3263. Available at: https://doi.org/10.1016/j.vaccine.2005.01.089

50- Barrett AD, and Teuwen DE. Yellow fever vaccine—how does it work and why do rare cases of serious adverse events take place?. Current opinion in immunology 2009 Jun 1;21(3):308-13. Available at: https://doi.org/10.1016/j.coi.2009.05.018 .

Enitan SS, Gbise DS, Dogonyaro BB, Eke SS, Iduh UM, Dada MO, Adebola OA, Osareniro OE, John-Ugwuanya GA, Itodo GE, Akele RY, Edafetanure-Ibeh OM, Akinpelu RT, Oluwayemis AA, Oyewopo OE, Innocent-Sunday LA, Okuneye AO. One health approach in the fight against yellow fever in Nigeria. Microbes Infect Dis 2024; 5(3): 972-990.