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REVIEW ARTICLE

Lassa fever in Nigeria: Social and Ecological Risk Factors Exacerbating Transmission and Sustainable Management Strategies

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Abstract

With the advent of COVID-19, infectious diseases are increasingly a cause of concern to both national and international governments as well as non-governmental organizations. This review focusses on Lassa fever incidence, prevalence, and socioecological factors influencing the spread and management of the disease in Nigeria using data mined from the Nigeria Centre for Disease Control and other public databases. Lassa fever and the causative agent Lassa virus (LASV) and vector, *Mastomys natalensis* is becoming a topical issue despite the neglected tropical disease status. The primary transmission mode of LASV has not been fully comprehended but several social and environmental factors have been implicated to either play a major role in determining the rate of transmission or exacerbating transmission risks. Nonetheless, some transmission route includes faeco-oral, rodent bites, and the consumption of rodent meat. From epidemiolocal studies and surveillance, it is glaring that LASV is a West African phenomenon. In West Africa, about 100,000 to 300,000 new cases of Lassa fever have been reported with a mortality rate of 5,000 persons per year. In Nigeria, Lassa fever has occurred in several states across the six geopolitical zones and the federal capital territory. However, Edo State in the Southsouth geopolitical zone and Ondo State in the Southwest geopolitical zone is the core epicentre of the virus since December 2016 in Nigeria. Some environmental conditions that contribute to exacerbating the incidence of Lassa fever include weak environmental hygiene laws, poor housing, and regional planning, indiscriminate disposal of wastes, poor food handling, and storage, absence of a law against eating *Mastomys natalensis*, deforestation, and poor agricultural practices as well as climate change.

Keywords

Lassa fever, Neglected tropical disease, Lassa virus, *Mastomys natalensis*¸ Environmental health justice, Poor hygiene, Bushmeat consumption

List of Abbreviations

%: Percentage; COVID-19: Coronavirus disease 2019 (Illness caused by SARS-CoV-2 virus); DGP: Gross Domestic Products; DNA: Deoxyribonucleic Acid; FAO: United Nation's Food and Agricultural Organization; FCT: Nigeria's Federal Capital Territory (Abuja); LASV: Lassa Virus; *M. natalensis : Mastomys natalensis*; mm: Millimeter; NCDC: Nigeria Centre for Disease Control; NTD: Neglected Tropical Diseases; oC: Degree Celsius; UN: United Nations; UNEP: United Nations Environmental Programme; USAID: United States Agency for International Development; WHO: World Health Organization

Introduction

Globally, infectious diseases are a cause of concern to both governmental and non-governmental organizations, with the COVID-19 pandemic still fresh on the minds of people. Infectious pathogens are responsible for some diseases with a high potential for morbidity and mortality [1,2]. The United Nation developed the Sustainable development goals in 2015, a group of 17 interconnected goals, and some of the priorities are to end poverty and hunger, protection of the environment and climate, ensure healthy lives and promote well-

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being, and ensure global peace and prosperity [3,4]. To achieve these targets are met, especially in developing countries, efforts must be put in place to combat both infectious and non-infectious diseases. In Nigeria, infectious diseases are numerous but an increasingly important focal point is neglected zoonotic diseases which occur among impoverished populations and in rural regions but they receive little attention and funding, among these are Schistosomiasis [5], Lymphatic filariasis, Dracunculiasis, Leprosy, Buruli ulcer among others [6,7]. The others that are vectored by animals are Lassa fever, Ebola virus disease, etc. In the case of Lassa fever, it is an acute viral illness that was first recorded in 1969 in Lassa, Borno State, Nigeria after the death of two nurses. In the January 2022, there were over 200 cases with about 40 deaths as a result of Lassa fever [8].

Lassa fever's causative organism is the Lassa virus (LASV; Figure 1) [12] which belongs to the family Arenaviridae [13] and the order Bunyavirales [14] called Lassa mammarenavirus [15]. Lassa virus is a single-stranded enveloped RNA virus [13,16] that is bisegmented [17] (Figure 1). Lassa virus is a priority pathogen, listed by the World Health Organization as a neglected endemic zoonosis [14], that is, it is highly contagious with a short incubation period of about 2 to 21 days [13]. Transmission is through ingestion or inhalation of urine and droppings of *Mastomys* rodents or via direct contact with contaminated materials and open injuries. According to Olalekan [18]; Adewuyim, et al. [17], the infection starts with the mucous membrane, lungs, and intestines and progresses to the urinary and vascular systems with a weakened immunity of the host leading

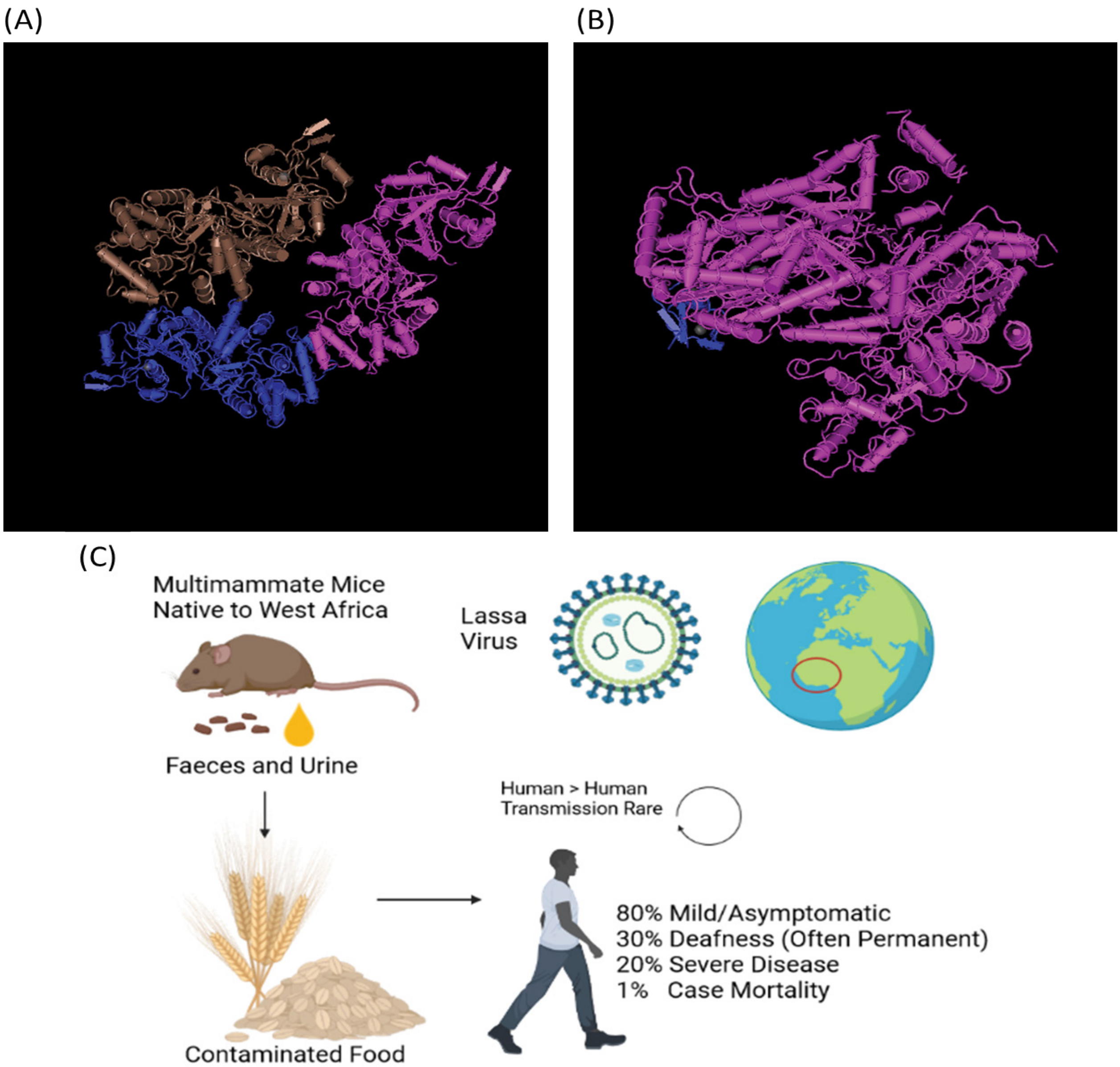

Figure 1: A) Nucleoprotein structure of Lassa virus; B) Static 3D structure of Lassa virus polymerase bound to the small zinc finger matrix protein and C) transmission path of Lassa virus and mortality rate of Lassa fever.

Source: Qi, et al. [9]; Xu, et al. [10]; Purushotham [11].

to sudden viraemia). The clinical pathomechanism as presented by Yun and Walker [19] suggests it begins as a flu that is characterized by mild to strong fever with body weakness, malaise, vascular perturbation, and gastrointestinal discomfort as well as pulmonary oedema, respiratory distress, encephalopathy, coma seizure and terminal shock in severe cases. Albeit at first presentation, it may be difficult to diagnose due to similarity with other common illnesses within the West African subregion. Recovery is likely to begin on the 8th day of infection but in severe cases, deterioration starts from the 6th day and death is likely to occur on the 12th day. However, only 20% of infected persons experience severe systems deterioration. This might be connected to the involvement of the mononuclear phagocytotic system that is associated with tissue macrophages and endothelial cells [20].

The most commonly associated vector for Lassa fever is the rodent *Mastomys natalensis* of the family Muridae [21]. This rodent is commonly called the natal multimammate rat due to the high number of mammary glands numbering between 8-12 and sometimes even 18 enabling higher fertility in the genus [14,22,23]. This rodent is synanthropic in nature and prevalent in sub-Saharan Africa [14,22,23] with a life span of about 2 years. Hansen, et al. [24] and Abdullahi, et al. [25], stated that other rodent species such as *Hylomyscus pamfi, Rattus rattus, Praomys daltoni, Mus minutoides, Crocidura* spp.*,* and *Mastomys erthrocyclus* may likely be carriers of Lassa virus although their impact in the spread of the virus. *M. natalensis* is a widespread rodent in urban and semi-urban settlements in Nigeria: where it was discovered and Sierra Leone, Liberia, and Guinea [26], the rodent has been reported in Mali, Ghana, Benin, Togo, and Ivory Coast [27-29]. LASV is transmitted mainly from rodent reservoirs to humans [14,16,17,27,29] and sometimes through person-to-person contact [12,14,15], sexual and in-utero transmission have been reported by WHO [8].

According to Amoo, et al. [13]; Adebimpe, et al. [12]; Usuwa, et al. [28] and Aigbiremolen, et al. [30], Ebonyi, Edo, and Ondo states have the highest burden of infection with occurrences reported during outbreaks and these states combined account for 74.6% of the confirmed cases between the 2017 and 2018. The distribution of the disease and the vector that transmits the virus is affected by environmental factors. These factors tend to be influenced by season. Generally, the incidence of Lassa fever is high in the dry season especially from December to April of the preceding year. With this information, it is imperative to understand the conditions enabling the transmission and incidence of the Lassa fever virus to better mitigate its spread for less morbidity and mortality indices in Nigeria. Therefore, the focus of this review is to report potential social and environmental risk factors that may exacerbate the incidence of Lassa fever in Nigeria and to outline potential sustainable management strategies with a focus on Nigeria. To effectively execute this task, data on disease incidence, prevalence, and socioecological factors influencing the spread and management of the disease in Nigeria was mined from the Nigeria Centre for Disease Control and supported with literature search from Google Scholar, PubMed and Web of Science on the subject of Lassa virus and Lassa fever. The work will contribute to understanding the factors that may increase Lassa fever incidence as well as the sustainable management of Lassa fever cases. It will assist policymakers in deciding how best to align their policies and decisions with the recommendations of the World Health Organization using an integrated management approach.

Geographical Characteristics of Nigeria

Nigeria has an area of about 923,768 square kilometers and shares its borders with Chad to the North East, Cameroon on the East, the Republic of Benin on the Western border, the Niger Republic on the North West and Northern border, and the Gulf of Guinea (the Atlantic Ocean) in the south [31,32]. Nigeria has a total of 36 states and the Federal Capital Territory, Abuja. According to the Osawaru and Ogwu [33]; Ogwu and Osawaru [34]; World Bank Group [35], the mean annual temperature is 26.9℃, with a 0.03℃ temperature increase observed between the period 1901-2016 and over 0.19 ℃ in the last 30 years, with a high degree of variability in precipitation across the country since the 1960s.

Nigeria, like the rest of West Africa, has two seasons namely; the rainy or wet season and the dry season [36-45], although it has three evident climatic regions; a tropical climate, a tropical savannah, and a Sahel climate in the south, central and northern regions respectively. The amount of rainfall in each region follows a longitudinal pattern with the Sahel having the lowest (about 500-750 mm) and shortest wet season annually usually from June to about September with the rest of the year as the dry season [46-48]. The savannah region is characterized by a distinct wet and dry season from April to October and November to March respectively, with an annual rainfall of about 1,200 mm. the southern region has the lengthiest wet season usually from March to October and the highest annual rainfall in the country with about 2,000 mm and can get up to 4,000 mm in the coastal plains. The disparities in the climate are determined by the interaction of the southwest monsoon winds and the dry and mostly dusty harmattan northeasterly winds which blow from across the Sahara [49-52].

Nigeria has an estimated population of approximately 200,000,000 people and an annual growth rate of about 2.6 %. This makes Nigeria the most populous African country. Within the last 10 years, Nigeria has experienced several recorded disease outbreaks including Lassa fever, Ebola, monkeypox, yellow fever, cerebrospinal meningitis, measles, and COVID-19.

Distribution of Lassa fever in Nigeria

Globally, West Africa is the Epicenter of Lassa fever [26] (Figure 2). In West Africa, about 100,000 to 300,000 new cases of Lassa fever have been reported with a mortality rate of 5,000 persons per annum [24,29,53,54]. In Nigeria, Lassa fever has occurred in several states across the six geopolitical zones and the federal capital territory [55] (Table 1). Since December 2016 - date (March 19, 2022), Lassa fever cases have been reported in Bauchi, Taraba, Nasarawa, Plateau, Kogi, Benue, Kaduna, Ondo, Ebonyi, Delta, Edo, and Enugu states. Within the period, Lassa fever was not reported in Bayelsa, Jigawa, Yobe, and Akwa-Ibom. In the period under review, it has been reported in Yobe state in 2022 and Ekiti state in 2018. While in the other states it occurred between 2-5 different years under the period under review. The number of states where it has been recorded thus far in 2022 (i.e., as of April 19, 2022),

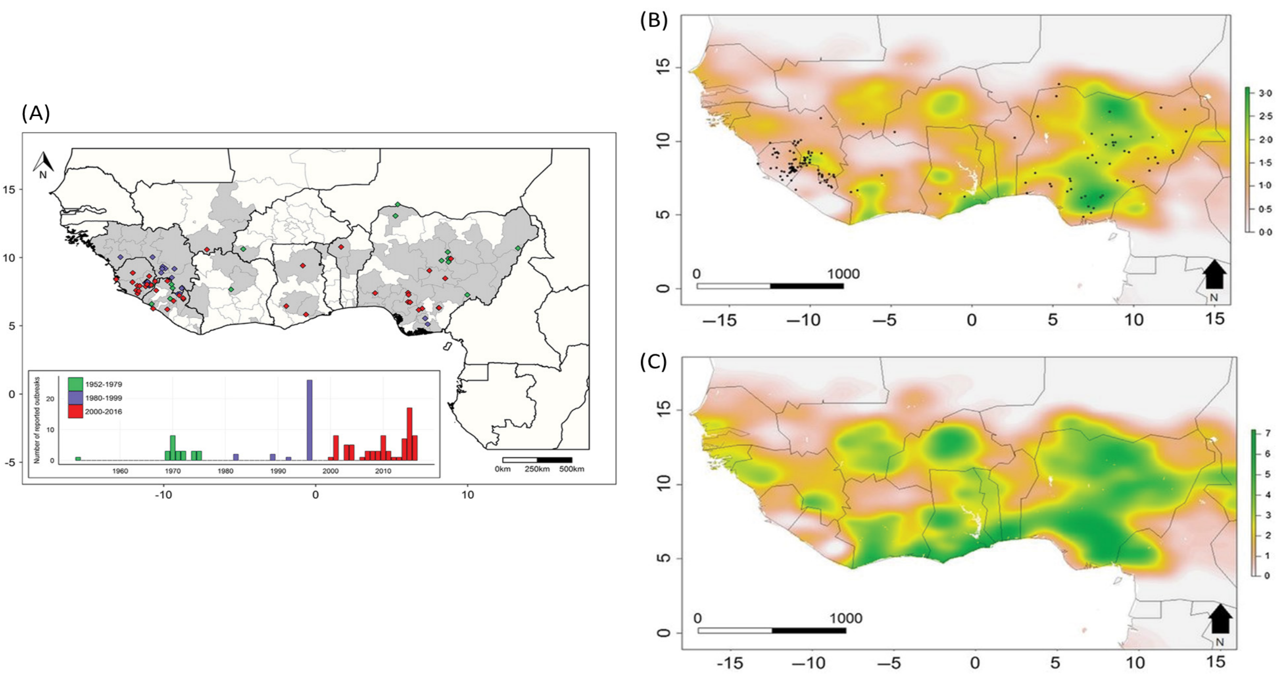

Figure 2: A) Distribution of Lassa fever in the global epicenter, West Africa; B) The present day environmental-mechanistic model of Lassa fever risk in West Africa and C) Predicted future distribution under the business as usual representative concentration pathway of climate change in West Africa.

Source: Gibb, et al. [26].

Table 1: Geographical distribution of Lassa fever by states in Nigeria (December 2016-March 19, 2022).

Geo-political zones	States	States that Lassa fever was isolated in 2022 (as of March 19)	States that Lassa fever was isolated in 2021	States that Lassa fever was isolated in 2020	States that Lassa fever was isolated in 2019	States that Lassa fever was isolated in 2018	States that Lassa fever was isolated between December 2016 to 02 December 2017
North-East	Bauchi	+	+	+	+	+	+
	Adamawa	+		+	+	+	
	Borno			+			+
	Gombe	+		+	+	+	+
	Taraba	+	+	+	+	+	+
	Yobe						
North Central	Nasarawa	+	+	+	+	+	+
	Plateau	+	+	+	+	+	+
	Kogi	+	+	+	+	+	+
	Benue	+	+	+	+	+	
	Kwara				+		+
	Niger	+					

North West	Kebbi	+		+	+		
	Sokoto			+			
	Kastina	+		+			
	Kano	+		+		+	+
	Zamfara				+		
	Kaduna	+	+	+	+	+	+
	Jigawa						
South-West	Lagos			+	+	+	+
	Oyo	+		+	+		
	Osun			+		+	
	Ogun			+			+
	Ondo	+	+	+	+	+	+
	Ekiti					+	
South-South	Edo	+	+	+	+	+	+
	Delta	+	+	+	+	+	
	Bayelsa						
	Rivers	+		+	+	+	+
	Akwa-Ibom						
	Cross Rivers	+	+		+		+
South-East	Ebonyi	+	+	+	+	+	+
	Imo		+		+	+	
	Abia		+	+	+	+	
	Anambra	+	+	+		+	+
	Enugu	+	+	+	+	+	+
Federal Capital Territory	Abuja	+	+	+		+	
	Total	23	17	27	23	23	19

Source: Adapted from NCDC [55].

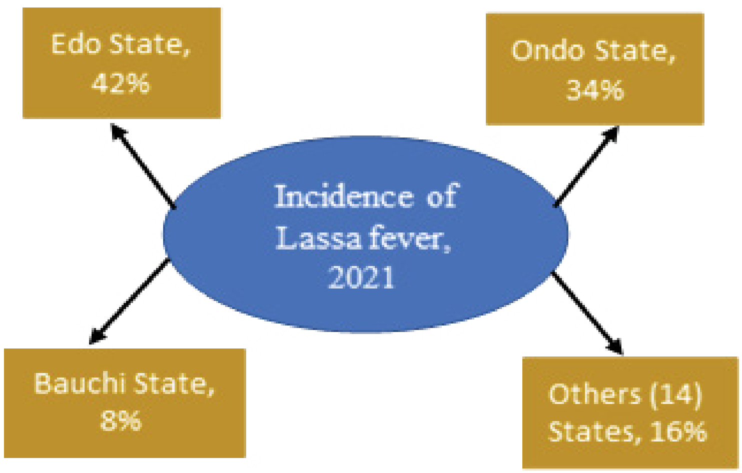

Figure 3: Incidence of Lassa fever in Nigeria by States including FCT in 2021. Adapted from NCDC [55].

2021, 2020, 2019, 2018, and December 2016/2017 is 23, 17, 27, 23, 23, and 19 respectively including the Federal Capital Territory Abuja.

Annual epidemics of Lassa fever recur throughout Nigeria's many states, causing different degrees and rates of illness and death respectively [56]. So far, the majority of casualties in Nigeria have been among young people, health care workers, and pregnant women. In 2021, three states (Edo 42%, Ondo 34%, and Bauchi 8%) accounted for 84% of total Lassa fever incidence while the rest 14 states account for 16% of Lassa fever cases (Figure 3). This indicates that Edo and Ondo states are

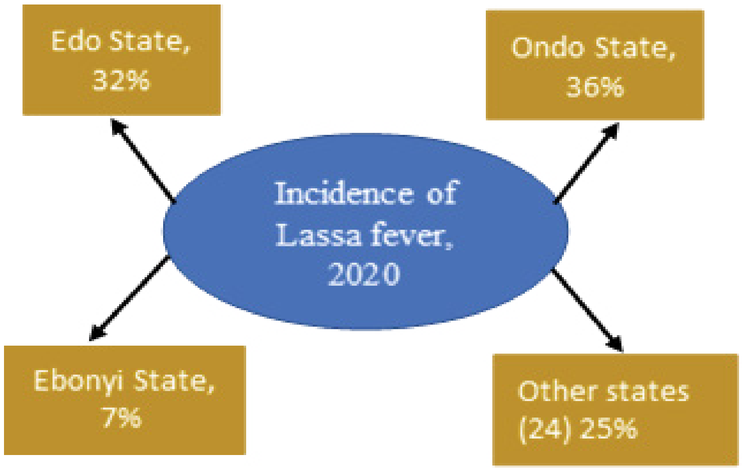

Figure 4: Incidence of Lassa fever in Nigeria by States including FCT in 2020. Adapted from NCDC [55].

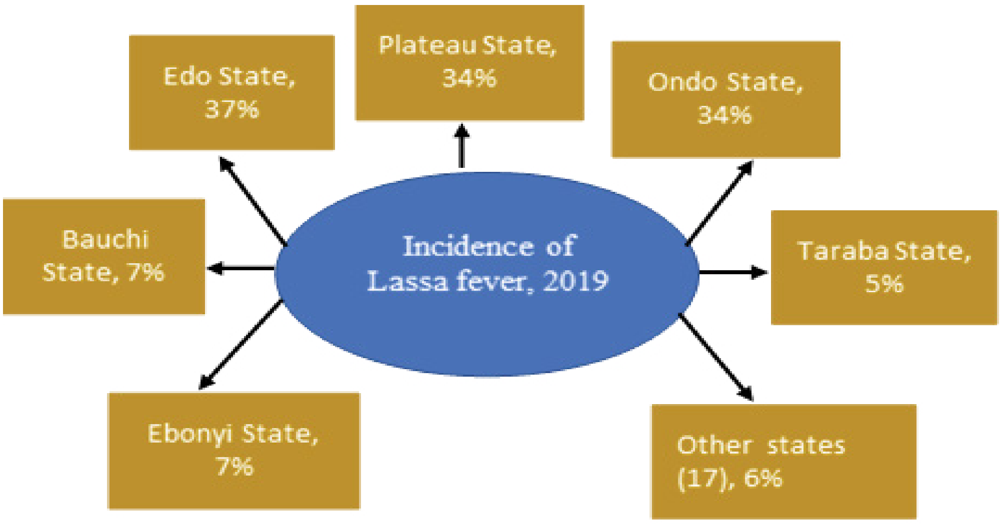

Figure 5: Incidence of Lassa fever in Nigeria by States including FCT in 2019. Adapted from NCDC [55].

the major epicentre of the virus of 2021. In 2020, three states (Edo 32%, Ondo 36 %, and Ebonyi 7%) accounted for 75 % of total Lassa fever incidence while the rest 24 states account for 25% of Lassa fever cases (Figure 4). This indicates that Edo and Ondo states are the major epicentre of the virus in 2020. In 2019, 6 states (Edo 37%, Ondo 34%, Plateau 34%, Taraba 5%, and Bauchi and Ebonyi 7% each) accounted for 94% of total Lassa fever incidence while the rest 17 states account for 6% of Lassa fever cases (Figure 5), which indicates that Edo, Plateau and Ondo states are the major epicentre of the virus at as 2019. In 2018, 3 states (Edo 44%, Ondo 25%, and Ebonyi 11% each) accounted for 80% of total Lassa fever incidence while the rest 20 states account for 20 % of Lassa fever cases (Figure 6) [57], which suggests that Edo and Ondo states are the major epicentre of the virus in 2018. As of March 19, 2022, three states (Edo 24%, Ondo 28%, and Bauchi 15% each) accounted for 77% of total Lassa fever incidence while the rest 23 states account for 23% of Lassa fever cases (Figure 7) and imply that Edo and Ondo states are the major epicentre of the virus as of March 19, 2022. Put together, Edo State in the Southsouth geopolitical zone and Ondo State in the Southwest geopolitical zone are the core epicentre of the virus since December 2016 in Nigeria. Previously, Ekechi, et al. [56] (2020) reported that Edo State is the leading hotspot State of Lassa fever in Nigeria. The state should be targeted for mitigation measures as existing data implicate an existing high Lassa fever viral transmission in these areas.

Social and Ecological Factors Contributing to the Spread of Lassa fever in Nigeria

From epidemiolocal studies and surveillance, it is glaring that LASV is a West African phenomenon [58] but it has received widespread attention due to its origin and similarity to the Ebola virus with the difference being that LASV transmission is driven by

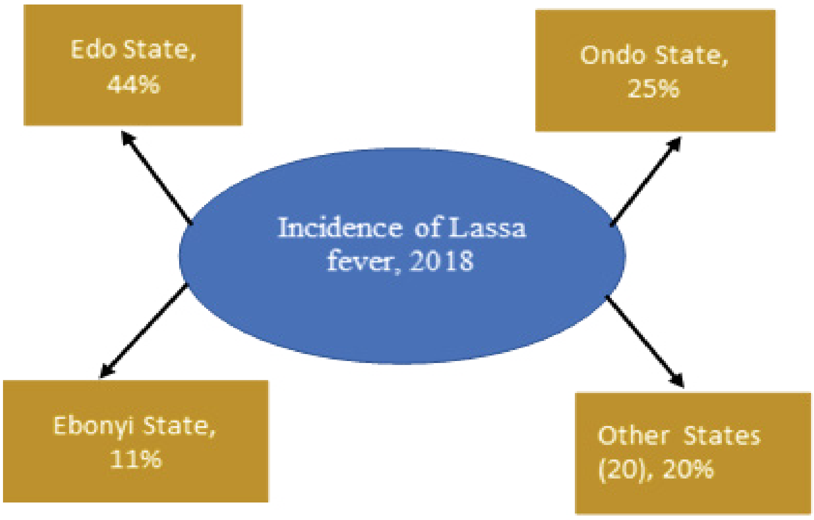

Figure 6: Incidence of Lassa fever in Nigeria by States including FCT in 2018. Adapted from NCDC [57].

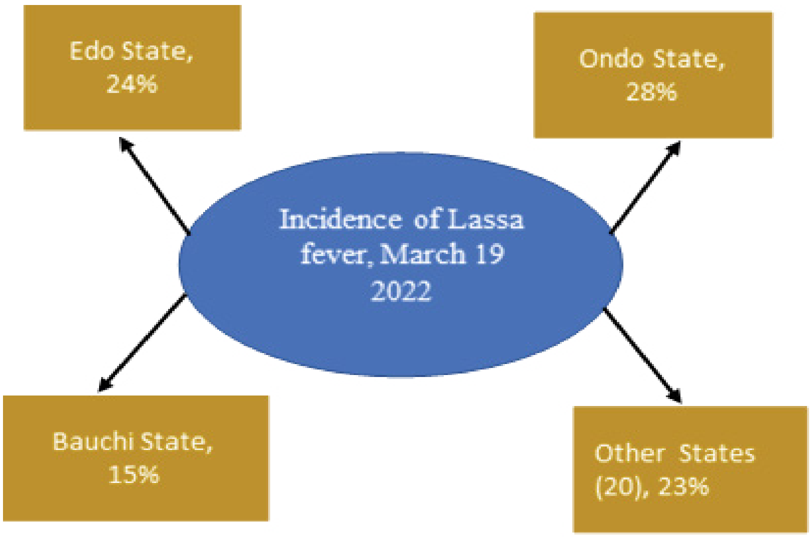

Figure 7: Incidence of Lassa fever in Nigeria by States including FCT as of March 19, 2022. Adapted from NCDC [55].

environmental exposure rather than direct human contact [16]. LASV is listed as a high-priority pathogen by WHO in 2018 due to its potential to cause epidemics through zoonotic transmission and because of its life-threatening potential to healthcare personnel, it poses a significant worldwide public health challenge [14,24,26,29]. Response to Lassa fever to date has been restricted to transdisciplinary and intergovernmental coordination, public engagement and surveillance, case management and infection prevention and control, clinical management, and vector and environmental control with Irrua Specialist Teaching Hospital Edo State spearheading efforts by the Nigeria Centre for Disease Control [8].

In the transmission of LASV, there are two distinct routes (namely primary and secondary routes). The primary zoonotic transmission from the reservoir to humans through the faeco-oral route, rodent bites and consumption of rodent meat [14,15,24,59-61] and these account for most of the cases reported of Lassa fever and is determined by the environmental conditions. The secondary transmission route is from human to human through contact and other b patterns [15,58,60]. According to published studies, when bruised skin is touched by infected blood or when copulation takes place transmission can occur, and this accounts for about 20% of cases of Lassa fever incidence [15,16,61]. These, therefore, suggest that the continual circulation of the virus in the environment may be attributed to the reservoir host [15]. It has been widely speculated that LASV is airborne and can be transmitted through aerosols. Hansen, et al. [24]; Adebimpe, et al. [12]; Abdullahi, et al. [25]; Gibb, et al. [26]; Ogbu, et al. [61] include aerosol inhalation as a route of transmission but this disagrees with Brosh-Nissimov [62] that there is a little epidemiological report showing significant levels.

The primary transmission of LASV has not been fully comprehended [25] as several environmental factors play a major role in determining the rate of transmission; as common with all emerging diseases, any increase in cases both suspected and confirmed across an endemic region must be closely monitored to establish a pattern, hence the need to study environmental factors that considerably contribute to the spread and sustenance of LASV in endemic areas. Another consideration is hygiene practices, food packaging, food storage and waste disposal practices, which have the potential to increase the disease incidence [63-70].

In humans, the burden of infectious diseases can be affected by several factors including a high probability of human exposure, a higher chance of humans being susceptible to infections and the effects, and fluctuations in the transmission, degree of virulence, and the multiplicity of the infectious agents. All these factors can be impacted by changes in the environment that could be driven by human behavioral changes, and biological and social agents [71]. Further, this section highlights the potential environmental, sanitation, and hygiene-related risk factor associated with Lassa fever transmission in Nigeria.

Climatic and weather conditions

In recent years, West Africa has seen changes in its demography, socioeconomic development, and environment [26,72]. This is at par with other developing and developed countries and regions of the world. These rapid changes are mainly due to anthropogenic activities in pursuit of the development of humans that are in turn exacerbating climate change as the average temperature has increased whereas a decrease in rainfall over time is expected [27]. Zoonotic diseases have also been predicted to increase as several forecasts indicate that higher temperatures in the sub-region and making it suitable for increased growth in the *M. natalensis* population [26]. While other regions around the world have tropical climates, *M. natalensis* is mainly found in sub-Saharan Africa and it has been established that LASV is found only in the West African region [27]. This could be the reason why the LASV like other arenaviruses has enveloped and are sensitive to high temperatures or low humidity more than its host, which may trigger the reliance of LASV transmission on rainfall and humidity in West Africa [27,71].

According to Clegg [71], climate change in recent years has modified the quantity of precipitation and the environmental distribution of LASV and this has led to subtle changes in the occurrence and distribution of the disease. Areas with a high volume of rainfall (about 3000 mm or more) had little or no recorded incidence or outbreak of Lassa fever, while areas with a moderate amount of rainfall (about 1500-3000 mm) had a higher risk of occurrence [14] when compared to areas with a lower volume of rainfall of about 1200-1500 mm had a medium risk of Lassa fever incidence. This agrees with Adebimpe [12]; Nchom, et al. [73]; Fichet Calvet, [74], and Kerneis, et al. [75] wherein a link was established between Lassa fever and the pattern of rainfall as a major abiotic factor influencing the incidence of Lassa fever. This was supported by the observation of the host rodent species ecology. The rodents in the bid for sustenance migrate from their natural habitats during the dry season to human settlements where they can find food and shelter. The human settlements make conducive breeding grounds for the rodents which remain in areas with poor sanitation even after the rains begin. Leach, et al. [76] observed in their study conducted in 2015, that the abundance of the reservoir host *M. natalensis* is at its lowest during the rainy season, Adewuyi, et al. [17] further observed that the highest cases of Lassa fever were usually during the dry season, with the rainy season having the lowest, however, they also reported that a study carried out in Sierra Leone showed a change in the infection rate as the highest number of cases reported were observed between the period of seasonal change from dry to rainy season. Redding, et al. [14] observed a link between the habitat of *M. natalensis* and rainfall as a contributing factor to the occurrence of Lassa fever. Habitat suitability varies according to the region in Nigeria. The coastal south is mostly mangrove and rainforest and this makes it unsuitable for *M. natalensis* to habit, while farther north, varying agricultural methods in response to climatic changes may contribute to the movement of rodents to human settlements thereby increasing the incidence of LASV.

Temperature, humidity, and seasonality are other environmental predictors of Lassa fever transmission, Abdullahi, et al. [25] and Hansen, et al. [24] noted that the dry season is usually the peak of Lassa fever cases in endemic areas in Nigeria and this could be as a result of the varying interaction between humans and rodents during the rainy and dry season which can impact Lassa fever transmission, and can be used to predict outbreaks in the future and identify areas suitable for interventions in public health. Furthermore, Akhmetzhanov [16] observed that LASV shows seasonality in its incidence rate as there is more often a rise in reported cases during the first few months of the year which exceeds that of the remaining months of the year, although Ogbu, et al. [61] noted that it is possible to transport the virus from one endemic region to a non-endemic one during the period of incubation, hence an outbreak of LASV can occur during the year at any time irrespective of the season. Zhao, et al. [77] in their study noted that in Nigeria, LASV outbreaks have been known to occur during the dry season between November and May, and a positive association between rainfall and the transmission of LASV was ascertained. Nchom, et al. [73] also observed that there was a hike in cases during the dry season when rainfall has significantly reduced and humidity is low, the implication of this is that the decrease in rainfall and low humidity bolsters the proliferation of LASV and hence the increase in cases.

With the unpredictability of climatic and weather conditions, it is uncertain if the current trend of *M. natalensis* population and LASV transmissibility will be maintained as seasonal rainfall in endemic areas can cause an explosion in the rodent population and the same vein drought, especially if is prolonged can lead to a decrease in the population of the rodents. Clegg [71] noted that although climate change can influence the transmission of LASV, it may likely not affect the virulence of LASV. Stephenson, et al. [78] observed in their study that during the dry season, the rate of nosocomial Lassa fever outbreak is considerably higher when compared to the wet season, on the basis that the hot weather increases the chances of the virus surviving in the environment when it has been aerosolized with *M. natalensis* urine as the source of the aerosols. When temperatures increase and the relative humidity increases during the dry season, microaerosols can be generated from dust coming from the floors when they are being swept and then the efficiency of the virus transmission will be higher.

Agricultural practices

In Nigeria, commercial agriculture is not common. A vast majority of the population that farms practice subsistent agriculture and they are found in rural areas where their practices increase the risk of massive deforestation and loss of habitat [79-81]. To clear out forests for agricultural purposes because of the lack of mechanized tools. The most common method is the slash and burns method. This method not only clears out the vegetation but also the wildlife in them thereby causing a migration of the wildlife to surrounding areas. According to Basinski, et al. [80] and Abdullahi, et al. [25], *M. natalensis* is a serious pest to farmers in rural African communities in the savanna region and surrounding shrubland. During the preparatory period (i.e., bush clearing and burning), the rodents' settlements and food sources are destroyed. Hence, making them move into or close to the human residence in search of new habitats and food sources. This may increase the risk of LASV transmission further into the human settlements.

Agricultural activities as with other types of labour intensive professions in Africa are age and gender-specific in most communities. Leach, et al. [76] noted that traditionally, the felling of trees and clearing of fallow lands fall to the men while gathering of firewood and food preparation for the men go to women and children. These activities can increase the risk of LASV transmission as there is a higher chance of contact with the multimammate rodents and their droppings. The study further observed an overlap of peak times of exposure to rodents in the planting cycle and peak times of Lassa fever in Eastern Sierra Leone where their study was done.

With climatic and weather changes, it is expected that global warming could improve agricultural yield and allow the planting of new food crops in West Africa and this, in turn, will bolster the rodent species in the region. Technological advances may also bring about an increase in commercial agriculture in the West African region. This could lead to fewer people coming in contact with the rodents in their habitats. This will also lead to less contact with rodent droppings. This could cause a reduction in LASV infections as the potential risks of contact are reduced.

Deforestation

The movement of rodents and other animal species from forested areas to human settlements is dangerous but this has been fostered by man's anthropogenic activities over time [25]. According to Adetola and Adebisi [82], the resultant effect of tree removal without any replacement leading to habitat loss for wildlife and biodiversity loss is deforestation. This process gradually encourages animals especially commensal like rodents to seek other suitable habitats for themselves in the surrounding area. Population boom mainly in developing countries, commercial agriculture, industrialization, and infrastructural development have caused the encroachment of animal habitats for exploration and exploitation through the gathering of forest commodities. This has resulted in the invasion of pests, and outbreaks of novel and reemerging diseases. In this regard, new tropical diseases like the 2013-2016 Ebola virus outbreak in West Africa, which led to the death of over 11,000 individuals, and the Zika virus outbreak in the Americas between 2015-2016 [6,25,81]. The transition of forest land into arable agricultural uses is invasive and destructive to the ecosystem, and the perpetrators of this could encounter bacteria, viruses, and other organisms which could potentially cause an outbreak when introduced into a population of humans with no previous encounters with such organisms.

Hunting/Consumption of bushmeat

Alongside deforestation, the hunting and consumption of wild animal species also referred to as "bushmeat" has increased in recent times [83-87]. According to UNEP [6], wildlife is being exploited and used for different purposes around the world including food, source of income (mostly among the poor in developing and low-income countries), medicine, ritual, and decorative purposes, recreational purposes (in zoos and recreational hunting). In the West African subregion, poverty is the motivating factor for bushmeat hunting especially the hunting of rodents [88] as poor households cannot afford to purchase beef and other types of meats thus bushmeat consumption becomes a viable alternative for them, and in a recent study of households. It was deduced that in Africa, Asia, and Latin America about 39% of the 8,000 rural households surveyed hunted and ate wild meat [6]. The study further reported that wildlife consumption has increased in the last decade. During the process of hunting and transporting wild animals, hunters come in close contact with these animals and this increases the risk of catching and transmitting diseases of zoonotic origin [6]. Hunters make use of crude methods to hunt such as the slash and burn method where the hunters set fire to previously undisturbed forests Leach, et al. [76] observed most studies are focused on the exposure to Lassa based on the interaction between rodents and humans around their homes. The study reported that rodent hunting for food is the only known risk factor that is rodent associated, in the same study it was also noted that hunting and handling of bushmeat is a role for the male gender and specific age groups and generally people preferred to consume rodents from the bush rather than those trapped around their homes. In Guinea, Duono, et al. [88] reported that rodent hunting was mainly a children's affair since it is considered meat for children as a means of compensating for the lack of protein in their households; even among children, boys are more at risk of exposure to LASV than girls as boys are responsible for the hunting (during which they have direct contact with the rodents' urine, faces and sometimes blood) and transportation of the dead rodents (in bags and where they are not available in the pockets of their clothes). This is in line with Abdullahi, et al. [25], who noted that rodent hunters have a higher exposure risk to LASV infections, and they sometimes even play with the rats before they are prepared for cooking. Girls on the other hand are exposed to LASV unintentionally when they are called to prepare and cook the rats for their brothers. They may be exposed opportunistically when preparing the meat through contact with the rodents' urine and droppings or during slaughtering when they are exposed to the rodents' blood. The hunting process is also a contributing factor to the exposure risk of hunters as they come in contact with the bodily fluids of the rodents, especially during slaughtering, some look out for rat burrows which are set on fire to force the rodents out while others including farmers set a forested area on fire during which all animals within the area are forced to leave their natural habitats thus coming in contact with humans and exposing them zoonotic diseases including LASV [82,88]. According to Amoo, et al. [13], and Duono, et al. [88], poverty is a major factor why rodent hunting is still in practice despite the outbreaks attributed to LASV.

External hygiene

Good environmental hygiene is synonymous with good health because the proliferation of vectors will decrease when the environment is devoid of waste. Bonner, et al. [60] in their study observed the LASV vector is a semi-domesticated scavenger pest that moves from agricultural areas, open grasslands, and human settlements. These environments where rodents have access to food and shelter are associated with the risk of infection and the presence of rat burrows and the quality of material used to build the house contributes poses a potential risk to the number of infections recorded. According to UNEP [6], Gakeji, et al. [89], the rise in human population has led to an increase in agricultural activities to sustain the population, and also there is a need for settlement with the high birth rate and the migration of individuals from rural to urban settings. These have led to a high generation of waste and poor disposal methods. In many regions in Nigeria, waste dumpsites are close to people, and this has led to the increase in vector populations and increase the incidence of zoonotic diseases are on the increase. In rural areas, certain practices like the storing of firewood in heaps behind households and disposing of organic household wastes in certain areas for composting usually close to the house encourage vectors like flies and rodents to inhabit such places. Surrounding shrubs, home gardens, and the presence of fruit trees especially when they are in season provide shelter for rodent species. Thus, poor sanitation and hygiene may potentially be a risk factor for infestation by rats thereby transmitting the Lassa fever virus to individuals whose homes have been infested and also in the surrounding environment.

Food handling and storage

Behind oil and gas, agriculture is the main contributor to the country's GDP. According to Akinyele [90], 90% of all Nigeria's agricultural produce is from rural dwellers and a lot of the agricultural produce becomes waste due to spoilage during transportation. Storage of food is a major problem faced by farmers, and those in rural settlements are more affected because they do not have the knowledge and access to certain handling and storage processes. According to Abdullahi, et al. [25]; Osawaru and Ogwu [52]; Ogwu [91] in most rural settlements in West Africa, food products are sun-dried in the open along the roads (a typical example is the sun drying of cocoa seeds) as a means of increasing the food and food product shelf life and also for the transformation of the produce (an example is sun drying of yams and plantains chips for yam flour and cassava flour respectively). This practice encourages contamination of food as they are exposed to environmental elements and increases the chances of rodent infestation thereby increasing the chances of Lassa fever transmission. Poor storage of foods is also a major concern in the transmission of Lassa fever; rodent-proof containers are generally not available for the storage of local farmers. This tends to make use of baskets and other containers without proper lids and coverings for the storage of food [64,67,69] making the containers easy targets for rat populations foraging for food and increasing the risk of LASV infections. This is not just peculiar to farmers but also in rat-infested households where food is left exposed, undercooked, or not reheated properly when the food has been left open and is cold. An association between poor food handling practices, especially in non-airtight containers, and the incidence of LASV, has been reported in the literature [30,92]. Ben-Enukura, et al. [93] reported from a study carried out in Edo state noted that high-risk practices like consuming foods half-eaten by rodents after removing the portions that were contaminated. Poor knowledge of the risk factors associated with LASV transmission is also very poor among rural and slum dwellers.

Waste disposal

According to Gakeji, et al. [89]; Ogwu [94], most household wastes comprise leftovers and spoilt food items generated in the kitchen and when appropriate means of adequate disposal are not available, these wastes become food sources for vectors, especially rats. Rats are vectors that are responsible for the highest number of disease fatalities, hence it is important for adequate waste disposal means using bins and prompt clearing for a reduction in vector growth. According to the WHO [8], Gakeji, et al. [89], maintaining a clean household, disposing of wastes far away from the home and if possible, keeping a cat as a pet would discourage rodents from entering households as opposed to poor housekeeping which attracts the invasion of rodents.

Wastes generated in hospitals and diagnostic centers also pose a serious risk factor in the spread of LASV. Infectious wastes from clinical consumables and equipment according to Onoh, et al. [95] may carry microorganisms when they come in contact with bodily fluids or tissues from patients and chemical or radioactive wastes also can potentially transmit nosocomial infections among personnel and also people they come in contact with especially patients, caregivers, and the environment. The disposal of medically generated wastes if not segregated and properly disposed of may cause outbreaks of epidemics, LASV in particular; by proper management and disposal of medical wastes the transmission of LASV in a clinical setting can be minimized.

Housing quality/regional planning

Mass migration of humans from rural to urban and semi-urban regions has been on the increase over the last century. This large-scale migration leaves little or no room for regional planning and with the high poverty rate in the West African region; migrants are conditioned to live in areas with low-quality housing, poor access to potable water and sanitation, and poor management of wastes. Houses with defects in their structures such as burrows in the walls and surrounding areas, housing amenities, loosely fitted doors, ceilings, and windows are risk factors for the invasion of vectors including rodents, flies, cockroaches, and even reptiles [89,60]. In addition, improper home garden practices [66] can contribute bring the vector closer to human residence.

Sustainable Management Strategies for Lassa fever in Nigeria

Clinical management of Lassa fever should by extension include key environmental considerations. As with all evolutionary processes, it is expected that some people in endemic areas might develop some form of immunological response that may trigger resistance with time. Tewogbola and Aung [96] suggest that the Yoruba ethnic group of Nigeria to some extent has formed resistance to LASV when compared to other endemic areas. Klitting, et al. [27] also predict that in the next few decades, LASV may extend beyond its current geographical borders as its predecessor Ebola virus if it is introduced to a new habitat that is fitting for its needs.

Achieving the sustainable development goals requires a healthy environment, which is also tied to sustainable governance models that will engage multiple intersectoral links [97]. This point was further emphasized by Grace, et al. [98] wherein they suggest that effective management of Lassa fever should focus on the implementation of preventative methods, prompt diagnosis, and treatment, ensuring the availability of personal protective equipment, contact tracing, community awareness, and cross border monitoring and surveillance. In addition, the characterization of the epidemiological profiles of Lassa fever should be ongoing and made a priority even outside the West Africa sub-region [99]. This will contribute to the monitoring and early detection of emerging outbreaks as well as in the diagnostic evaluation and treatment of the disease in patients.

Merson, et al. [100] presented the need for greater levels of coordination in Lassa fever research methodology and reporting to foster confidence and better integration. This can be done through unifying molecular biology techniques used in the characterization, diagnosing, and treatment of Lassa fever like recombinant DNA technology, genomic sequencing, and next-generation sequencing [101]. Besides research coordination, sustainable management of Lassa fever incidence should harmonize environmental management strategies that are focused on stronger environmental hygiene laws, improved housing and regional planning, stemming the indiscriminate disposal of wastes, improving food handling and storage, creation and implementation of new laws against the consumption of *Mastomys natalensis*, promote afforestation and prevent deforestation and encourage better agricultural practices. Even though there is sufficient evidence that land-use practices like soil disturbance and agricultural practices bring people more in contact with the Lassa fever vector, environmental considerations are largely ignored in the management of the disease. These environmental shifts are capable of causing a shift in the habit, density, and distribution of the vector.

The establishment of an emergency threshold and standardized guidelines for Lassa fever management that were suggested in Dan-Nwafor, et al. [102] will improve the surveillance system for the disease. A One Health surveillance approach was recommended by Tambo, et al. [103]. To improve the efficiency in line with their suggestion, we propose an Eco Health surveillance method for Lassa fever. This will focus on environmental issues that may exacerbate Lassa fever incidence along with health and sustainability. For instance, integrated rodent management and rapid testing or conscious effort to understand human-animal vector interaction as a surveillance approach for Lassa fever. The Eco Health approach coupled with developing an integrated data-based and timely risk communication and reporting will go a long way in sustainably managing Lassa fever outbreaks. Another consideration is the evolution of a cost-effective approach from existing management systems through pragmatic actions [104]. In all of these, there is a need to integrate efficient and effective public policy into Lassa fever detection, testing, treatment, and control [26]. Gibb, et al. [26] further mentioned the need to reduce environmental knowledge and practice gaps to avoid super-spreading Lassa fever events at the community levels.

Conclusion

To halt the environmental health justice issue associated with Lassa fever, there is a need for international support to stem the current spread and ensure the availability of Ribavirin, which is considered the choice drug for treating Lassa fever. At the moment, the virus may be considered neglected and endemic to West Africa but if lessons from COVID-19 are anything to go by, then we are uncertain of the future spread of this zoonotic disease. Increasing international travel and globalization have been discussed as ways to weaponize the disease. Hence, all hands need to be on deck. Moreover, within the West African sub-region, so much is unknown about the environmental connection to the transmission of this virus. Therefore, public sensitization program should be put in place to inform the populace about the actual and potential risks associated with the virus. This can include community, state, regional, zonal, and national-focused workshops and training programs to improve local capacity and enhance awareness. After all, Abdulkarim, et al. [105] mentioned the lack of adequately trained personnel in addition to the absence of essential resources necessary to manage clinical complications as a reason why cases escalated during an outbreak of Lassa fever in Bauchi State, Northeast, Nigeria. A greater level of coordination is required among key stakeholders within Nigeria, West Africa, and globally. For instance, harmonizing transdisciplinary research methods used in building resilience is required to stem the disease and build confidence [100]. As a part of the coordination, the distributional logistics pertaining to the supplies may be emphasized especially when there is an outbreak being managed.

Besides potential exacerbation of the incidence of Lassa fever, there is also a social consequence attached to the transmission of the virus, which was reported by Richmond and Baglole [106]. On a small scale, it can be social exclusion, and at a large scale as a potential biological weapon. Lassa fever treatment facilities should be separated from centralized facilities like teaching hospitals to enable a focused management system.

Declarations

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