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Monitoring Lassa Virus Prevalence in Nigeria Using Control Charts: A Public Health Surveillance Approach

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Abstract **Original Research Article**

In this study, Modified Exponentially Weighted Moving Average (MEWMA) chart is applied to monitor changes in the number of Lassa fever outbreak in Nigeria using the observed Lassa fever data obtained from Nigeria Centre for Disease Control (NCDC) website (https://ncdc.gov.ng/diseases/sitreps). The designed structure is apply to demonstrate the application of the chart in the non-manufacturing area. From the evaluation, the chart has a good potential as a SPC tool for monitoring changes in the number of infectious diseases in Nigeria. The severity of each year considered was measured by the percentage number of points plotted outside of the upper control limit, 2023 (17.31%) > 2024 (2024) > 2025 (13.46%) > 2022 (9.62%) > 2021(7.69%). This severity, particularly pronounced around early weeks of the years, suggest that the occurrence of Lassa fever is influenced by seasonal or environmental factors, such as variations in rodent activity and climatic conditions favorable to virus spread. The observed periodicity highlights the disease's cyclical nature and reinforces the need for sustained surveillance, preventive health education, and rapid response strategies during high-risk seasons to minimize the impact of recurrent outbreaks. The control charts enable early detection of weekly Lassa fever outbreaks, providing a systematic strategy for government and medical staff. Integrating the MEWMA chart for monitoring Lassa cases is recommended.

Keywords: Lassa fever, Outbreak, MEWMA, Control Chart and Monitoring.

1. INTRODUCTION

Lassa fever is a viral hemorrhagic illness caused by the Lassa virus (LASV), a member of the Arenaviridae family, and it remains a significant public health concern in Nigeria and other West African countries. The disease was first identified in 1969 in the town of Lassa, Borno

State, Nigeria, during an outbreak that led to the deaths of two missionary nurses (Richmond et al., 2003, Bond et al., 2010). Since then, it has been recognized as an endemic threat across several West African nations, including Nigeria, Sierra Leone, Liberia, and Guinea.

The natural reservoir of the Lassa virus is the multimammate rat (*Mastomys natalensis*), which carries the virus without symptoms and sheds it in urine and feces. Human infection typically occurs through contact with contaminated surfaces, consumption of food contaminated with rodent excreta, or direct contact with the rodents themselves. In addition to zoonotic transmission, person-to-person spread is also common, particularly through contact with the blood or bodily fluids of infected individuals (Richmond et al., 2003). Laboratory-acquired infections can occur as well, especially in healthcare facilities where infection prevention and control measures are inadequate (Parning et al., 2010).

The clinical presentation of Lassa fever varies widely among patients. Symptoms generally appear within one to three weeks after exposure, although the incubation period and severity differ across individuals (Ijarotimi et al., 2018). About 80% of infected individuals experience mild or no symptoms, while approximately 20% develop severe illness. Severe cases may present with bleeding from the nose, eyes, or gums, respiratory difficulties, persistent vomiting, facial swelling, chest pain, abdominal pain, and back pain (Richmond et al., 2003, Lupi & Tyring).

Lassa fever is notable for its seasonal outbreaks, which pose a serious risk to human health and can result in large-scale infections and high mortality if not effectively controlled. Understanding the seasonal dynamics of the disease is therefore critical for developing targeted intervention strategies and strengthening healthcare preparedness in affected regions.

Control chart is widely used in manufacturing industry to detect a change in the quality of a manufactured product but their application in non-manufacturing concerns have not been very wide. Shewhart control charts have been successfully applied in diverse fields such as healthcare, manufacturing, education, and human well-being (Mohammed et al., 2001). Although their use in epidemics is limited (Tennant et al., 2007), the exponentially weighted moving average (EWMA) chart has proven useful for estimating outcomes and controlling risk factors (Grigg & Spiegelhalter, 2007).

In public health, control charts enable early outbreak detection (Mohammed et al., 2008), with applications in seasonal disease monitoring (Dong et al., 2008; Spark et al., 2010) and influenza surveillance (Stainer et al., 2010). EWMA charts have also supported cardiac surgery monitoring (Smith et al., 2013), while c-charts improved medical record assembly times (Canel et al., 2010) and tracked early death reports. Run charts have been used to reduce ventilator-associated pneumonia (Alsader et al., 2012).

Adeoti (2009) provides overview of SPC and its primary tool- the control charts highlighting the challenges and benefits of the control chart as a tool for health care improvement. Adeoti (2013) applied CUSUM chart to monitor increase (changes) in the number of HIV/AIDS incidences in Nigeria using the screening result of HIV/AIDS data in Oyo state.

During the COVID-19 pandemic, control charts provided early-warning signals for deaths and supported organizational responses (Staines et al., 2020), with unique Shewhart graphics highlighting death heterogeneity (Perla et al., 2021). EWMA charts were further applied to monitor COVID-19 case growth and define alert levels (Yupaporn & Rapin, 2021), while c- and EWMA charts tracked COVID-19 deaths in Pakistan (Mahmood et al., 2021). Recent evaluations emphasize the importance of selecting appropriate charts to avoid misleading conclusions. In this regard, Waqas et al. (2023) found EWMA charts superior for epidemiological monitoring due to their strong detection capabilities.

This study describes the application of a Modified EWMA chart to provide an overview of the changes in the incidences of Lassa fever using weekly situational reports compiled by the Nigeria Centre for Disease Control (NCDC) from 2021 to 2025. Lassa fever is one of the deadly diseases in Nigeria and many research have been carried out by different authors on the causative factors, however the need to monitor changes in the rate of infection is desirable so that factors responsible for the high number of patients testing positive to the disease can be quickly identified and urgent and necessary action taken to curb its spread

2. MATERIALS AND METHODS

2.1 Study Design and Data Sources

This study investigates the implementation of modified EWMA (MEWMA) control charts in monitoring variations in the number of cases for different phases of Lassa fever in Nigeria. The study employed a retrospective cohort analysis of weekly epidemiological situation reports on suspected, confirmed, and probable cases, as well as case facility ratio related to Lassa fever outbreaks. The data were sourced from the publicly accessible Nigeria Centre for Disease Control (NCDC) website (https://ncdc.gov.ng/diseases/ sitreps). Over 244 data points were extracted, covering a five-year period from January 2021 to September 2025. The data were compiled in Excel, cleaned, and validated for subsequent analysis

2.2 Histogram and Density Curve

The histogram and overlaid density curve are used to show the distribution of Lassa fever outbreak during the study period.

2.3 Time Plot

Growth occurs progressively over time, and to determine whether such growth is sustained, it is essential to analyze trends over a period. The time plot serves as an effective tool for examining variations. In this study, time plot was used to observe temporal variations and seasonal outbreak patterns

2.5 Modified EWMA (MEWMA) Control Chart

Modified exponentially weighted moving average (MEWMA) chart was introduced by Khan et al., (2017). If X_i represents the number of Lassa fever cases per week, then the MEWMA statistic is defined as

$$Z_i = (1-\lambda)Z_{i-1} + \lambda X_i + k(X_i - X_{i-1}) \qquad (1)$$

where k is a constant and $0 < \lambda \leq 1$ is a smoothing parameter. The initial value Z_0 is the process target so that $Z_0 = \mu_0$ but sometimes, the average of preliminary data may be considered as the starting value, i.e. $Z_0 = \bar{X}$. The MEWMA chart depends on two constants λ and k, where a smaller value of λ leads to quicker detection of small shifts. The MEWMA statistic can be regarded as a weighted average of all past and recent observations, so it is insensitive to the normality assumption. Therefore, the MEWMA chart is ideal to use with individual observations Montgomery (2019). The MEWMA chart is the extension to the existing control charts. This control chart reduces to the EWMA chart by Roberts (1959) and modified EWMA by Patel (2011) when $k = 0$ and $k = 1$, respectively.

The process mean and variance of MEWMA statistic are given by

$$E(Z_t) = \mu \text{ and } V(Z_t) = \left[\frac{\lambda + 2\lambda k + 2k^2}{(2-\lambda)}\right]\frac{\sigma^2}{n} \qquad (2)$$

The upper and lower control limits of Modified EWMA chart are given by

$$\begin{cases} UCL = \mu_0 + L\sigma\sqrt{\frac{\lambda+2\lambda k+2k^2}{n(2-\lambda)}} \\ CL = \mu_0 \\ LCL = \mu_0 - L\sigma\sqrt{\frac{\lambda+2\lambda k+2k^2}{n(2-\lambda)}} \end{cases} \quad (3)$$

where L is a control chart coefficient to be determined. The value of k may be chosen independently of λ, but in this study we choose $k = -\frac{\lambda}{2}$ as it was derived by khan et al., (2017) to minimize the variance. We declare the process as in-control if $LCL \leq Z_t \leq UCL$. Otherwise, the process is out-of-control.

3 RESULTS AND DISCUSSION

3.1 Curve, Histogram and Time plot

The histogram and accompanying density curve illustrate the distribution of Lassa fever occurrences over the study period. The data exhibit a positively skewed pattern, indicating that most reported cases occurred at low frequencies, while high case numbers were relatively rare. The peak density around 10–20 cases suggests that minor outbreaks are the most common. The long right tail represents infrequent but severe outbreaks with substantially higher case counts. This distribution implies that while Lassa fever is generally contained, it retains the potential for sporadic high-impact epidemics. Continuous monitoring and early intervention are therefore vital in controlling such occasional surges in transmission. Similarly, the time plot illustrates the temporal trend of Lassa fever cases across a five-year period. The pattern reveals a clear annual cycle, with distinct peaks corresponding to outbreak periods and troughs representing times of low transmission.

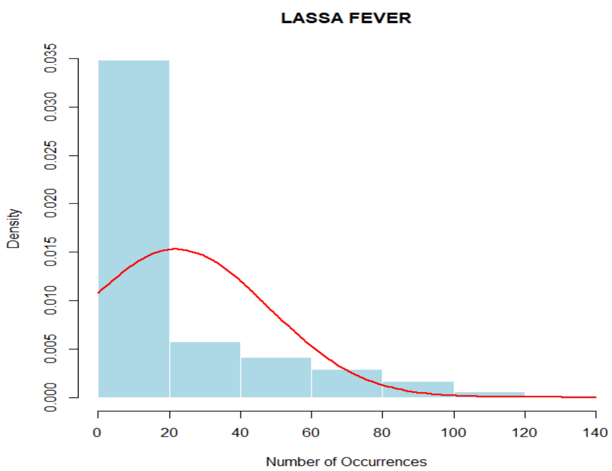

Figure 1: Curve and Histogram of weekly Lassa fever outbreak (2021-2025)

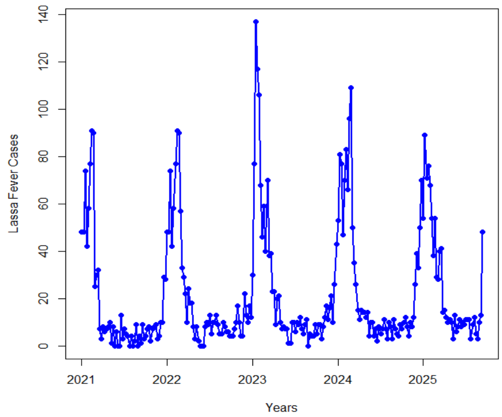

Figure 2: Time plot of weekly Lassa fever outbreak

3.2 Calculations for the MEWMA chart

In this section, the MEWMA statistic Z_t is computed using Equation (2), and the upper control limit (UCL) of the MEWMA chart is determined using Equation (3), since the focus is on detecting an upward shift. A tabular MEWMA data scheme was developed to monitor and detect any increase or change in the number of Lassa fever outbreaks using screening data obtained from the Nigeria Centre for Disease Control (NCDC) between January 2021 and June 2025 (a total of 244 weeks).

For this study, the out-of-control Average Run Length (ARL_0) is assumed to be 370, and the chart coefficient L and smoothing constant λ are set to 3 and 0.20, respectively. The observed data and the corresponding values of the MEWMA statistic Z_t are presented in Table 1. The calculated upper control limit (UCL) is 51.6243. The computed values are plotted on the MEWMA control chart. The MEWMA chart designed for detecting upward shifts will indicate an out-of-control signal whenever $Z_t >$ UCL.

Table 1: **Observed Lassa fever occurrence X_i and MEWMA statistic Z_t**

2021 (week 1-52)			2022 (week 1-52)			2023 (week 1-52)			2024 (week 1-52)			2025 (week 1-52)		
Wk	X_i	Z_i	Wk	X_i	Z_i	Wk	X_i	Z_i	Wk	X_i	Z_i	Wk	X_i	Z_i
1	48	31.920	53	48	24.713	105	30	17.337	157	53	30.415	209	54	40.862
2	48	35.136	54	48	29.370	106	77	33.970	158	81	43.332	210	89	**53.989**
3	74	45.509	55	74	40.896	107	137	**60.576**	159	77	49.665	211	71	**55.591**
4	42	41.607	56	42	37.917	108	117	**69.861**	160	47	46.132	212	76	**60.173**
5	58	46.486	57	58	43.534	109	106	**75.988**	161	70	**53.206**	213	68	**60.939**
6	77	**54.489**	58	77	**52.127**	110	68	**70.591**	162	83	**60.465**	214	54	**58.151**
7	91	**63.191**	59	91	**61.301**	111	46	**63.473**	163	66	**59.872**	215	38	**52.521**
8	90	**68.453**	60	90	**66.941**	112	59	**63.878**	164	96	**70.097**	216	54	**54.417**
9	25	**53.262**	61	57	**61.653**	113	40	**57.202**	165	109	**79.178**	217	29	46.833
10	30	49.110	62	33	**53.522**	114	70	**62.762**	166	50	**67.442**	218	28	42.967
11	32	45.888	63	29	48.218	115	38	**54.610**	167	35	**59.454**	219	40	43.573

12	7	35.610	64	22	42.274	116	39	51.588	168	26	51.863	220	41	43.159
13	3	28.688	65	10	34.619	117	23	44.270	169	15	43.390	221	14	34.627
14	8	25.051	66	24	33.896	118	23	40.016	170	11	36.512	222	15	30.802
15	6	21.040	67	18	30.116	119	9	32.413	171	15	32.610	223	12	26.741
16	7	18.332	68	18	27.693	120	20	31.030	172	14	28.788	224	10	23.193
17	8	16.366	69	8	22.755	121	21	29.124	173	14	25.830	225	11	20.854
18	10	15.293	70	3	18.304	122	10	24.199	174	12	22.864	226	10	18.583
19	1	11.534	71	8	16.743	123	7	20.460	175	14	21.291	227	3	14.767
20	8	11.527	72	2	13.194	124	8	18.068	176	4	16.833	228	13	15.413
21	0	8.422	73	0	10.355	125	7	15.754	177	10	16.067	229	6	12.831
22	6	8.537	74	0	8.284	126	7	14.003	178	10	14.853	230	8	12.065
23	0	6.230	75	0	6.627	127	1	10.803	179	4	12.083	231	11	12.152
24	0	4.984	76	8	7.702	128	1	8.842	180	7	11.366	232	8	11.021
25	13	7.887	77	10	8.362	129	10	9.974	181	2	8.993	233	10	11.017
26	3	5.910	78	9	8.389	130	10	9.979	182	8	9.394	234	9	10.514
27	7	6.528	79	13	9.711	131	6	8.783	183	5	8.215	235	11	10.811
28	5	6.022	80	5	7.969	132	10	9.427	184	7	8.172	236	11	10.849
29	4	5.518	81	10	8.875	133	9	9.241	185	11	9.138	237	11	10.879
30	0	4.014	82	10	9.100	134	12	10.093	186	7	8.310	238	3	8.503
31	4	4.411	83	13	10.180	135	7	8.974	187	3	6.848	239	9	9.203
32	0	3.129	84	9	9.544	136	5	7.980	188	10	8.179	240	12	10.062
33	2	3.103	85	5	8.235	137	9	8.584	189	8	7.943	241	5	8.350
34	9	4.983	86	5	7.588	138	11	9.267	190	3	6.454	242	3	7.080
35	0	3.086	87	10	8.571	139	0	6.314	191	11	8.163	243	10	8.364
36	4	3.669	88	8	8.256	140	5	6.551	192	7	7.531	244	13	9.591
37	1	2.835	89	6	7.605	141	4	5.941	193	5	6.825			
38	9	4.868	90	6	7.284	142	4	5.553	194	4	6.160			
39	3	3.894	91	4	6.427	143	9	6.742	195	9	7.228			
40	4	4.016	92	4	5.942	144	5	5.994	196	7	6.982			
41	7	4.912	93	4	5.553	145	9	6.995	197	10	7.886			
42	8	5.630	94	7	6.143	146	9	7.396	198	12	8.909			
43	2	4.304	95	10	7.214	147	3	5.917	199	8	8.327			
44	7	5.343	96	17	9.871	148	8	6.833	200	4	7.062			
45	8	5.975	97	10	9.197	149	12	8.267	201	10	8.249			
46	9	6.680	98	4	7.558	150	17	10.513	202	8	7.999			
47	3	5.344	99	4	6.846	151	11	10.011	203	12	9.199			
48	4	5.175	100	22	11.677	152	16	11.709	204	26	13.960			
49	10	6.740	101	13	11.042	153	21	14.067	205	39	20.268			
50	10	7.392	102	10	10.533	154	10	12.153	206	33	22.214			
51	29	13.614	103	17	12.527	155	26	16.523	207	50	29.471			
52	28	16.391	104	12	11.921	156	43	23.518	208	70	39.577			

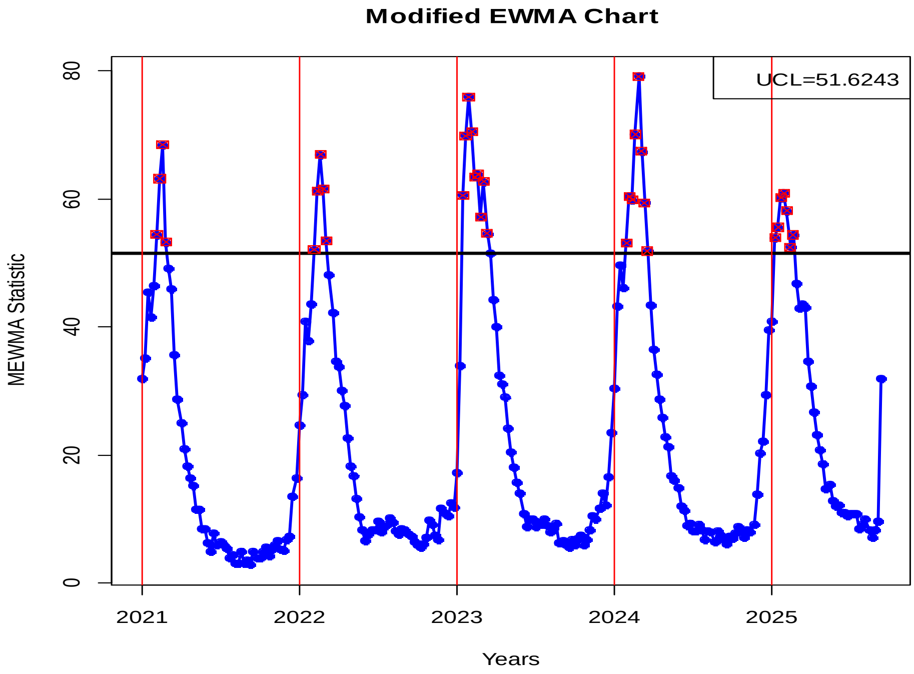

Figure 3: Modified EWMA Chart of Lassa fever outbreak

Figure 3 presents a Modified Exponentially Weighted Moving Average (EWMA) chart used to monitor the weekly Lassa fever outbreak from January 2021 to June 2025 in Nigeria. Each plotted point corresponds to the number of individuals infected in a given week, while the chart's control structure includes an Upper Control Limit (UCL) of 51.6243, serving as a threshold for detecting unusual or excessive increases in infection rates.

The chart reveals a repetitive cyclical pattern across the five-year period, characterized by sharp peaks followed by gradual declines. These peaks occur roughly once each year, indicating a seasonal or periodic trend in the occurrence of Lassa fever outbreaks. During each peak, the Modified EWMA statistic surpasses the UCL, signifying periods when the infection rate was significantly higher than expected, and the process was out of statistical control. The MEWMA chart detected several out-of-control (OC) signals each year. Severity levels were computed as the percentage of weeks above the upper control limit (cf. Table 2). These results show 2023 as the most severe outbreak year, followed by 2024. All years exhibit a cyclical pattern driven by environmental and ecological factors.

Table 2: Points above UCL for each year

Years	Period	Weeks	OC Points	%
2021	Feb-7 to Mar-7	6-9	4	7.69
2022	Jan-31 to Mar-13	6-10	5	9.62
2023	Jan-6 to Mar-13	3-11	9	17.31
2024	Jan-29 to Mar-24	5-12	8	15.38

2025	Jan-6 to Mar-23	2-8	7	13.46

Between the peaks, the MEWMA values drop substantially, indicating weeks with very low or minimal infection cases. This alternating pattern of high and low infection levels suggests a recurring outbreak cycle, likely associated with seasonal environmental conditions, rodent population dynamics, or other epidemiological factors influencing the transmission of Lassa fever.

3.3 Justification of MEWMA parameters and average run length used in the study

The choice of smoothing parameter (λ) and the control limit coefficient (L) in the MEWMA charts is very important as they are used to check how sensitive the chart would be to the variations occurring in the process under observation. In the research, λ was defined as 0.20, and $L = 3$, which aligns with the literature on control charts (Montgomery, 2009) and with the applications of the control chart in surveillance used by the public health (Mohammed et al., 2008; Dong et al., 2008). A smaller value of λ ($0.1 < \lambda < 0.30$) tends to be suggested when it is desired to identify small and moderate changing of the process mean, especially in epidemiological data where sudden changes can be interpreted as an outbreak rather than as a mere fluctuation. It has been demonstrated before that λ values in the range of 0.10 to 0.30 offer an acceptable tradeoff between reduction of noise and sensitivity to slow variations in the disease incidence. Since the weekly Lassa fever prevalence data are observed to have fluctuations, as a result of reporting delays and seasonal influences, $\lambda = 0.2$ was selected in order to eliminate short term noise, but leave the data sensitive to any long term increases in cases.

The control limit coefficient of $L = 3$ is the same as the conventional $\pm 3\sigma$ limits employed in statistical process control. This option reduces the number of false alarms with a low sensitivity to detect outbreaks. In surveillance of health in the community, there is a possibility of false signals that will cause panic or a waste of scarce health facilities. Thus, it can be observed that the selected $L = 3$provides a conservative yet reliable monitoring model that can be applied to the national disease surveillance systems like the Nigeria Centre for Disease Control (NCDC).

The average Run Length (ARL): This is a basic performance measure of control charts that gives the average number of observations performed before the out-of-control signal is triggered. A 370 in-control ARL was assumed in this study. Practically, since weekly Lassa fever surveillance data is to be monitored, an ARL of 370 suggests that given that the disease process is stable (no unusual outbreak) the MEWMA chart will yield a false alarm approximately once per weeks (approximately 7 years). This long ARL is desired in the use of public health where it eliminates the chance of false outbreak signals that would overload the surveillance and response framework. On the other hand, once the process runs out of control, e.g., when the Lassa fever becomes more frequent in reality, the ARL is lower, i.e., the chart shows the change at a much earlier point in time. Therefore, ARL is a tradeoff between timely detection of outbreak (sensitivity) and control of false alarms (specificity). In the Lassa fever case, where the disease has major impacts on the population and economy, having high in-control ARL would mean that the alerts are based on meaningful changes in the epidemiology and not on random events.

4. **CONCLUSIONS AND RECOMMENDATIONS**

The uniqueness of the EWMA chart for process characteristics monitoring lies in its ability to adjust for seasonality and other time varying factors. Using a weighted average of past observations, EWMA chart can account for fluctuations in observation due to factors associated to such observation. Therefore, this study employed modified EWMA control chart to monitor weekly Lass fever outbreak in Nigeria between January 2021 and June 2025. The chart provided more responsive and accurate monitoring of changes in Lassa fever occurrence over time. It detected peaks at the early time of the years and a pattern of outbreak during each year. The modified EWMA chart effectively identified maximum Lassa fever occurrences above the upper control limit and nearly all the early weeks of the years under study are out-of-control. Such that 7.69%, 9,62%, 17.31%, 15.38% and 13.46% of the plotted points in 2021, 2022, 2023, 2024 and 2025, respectively. 2023 and 2024 remained the years that have the highest out-of-control points among the years considered.

The Modified EWMA chart demonstrates that the Lassa fever infection process is not stable over time, as evidenced by the repeated exceedance of the control limit. However, the regular nature of these fluctuations implies a systematic, predictable pattern rather than random variation. Consequently, health authorities can use this information to anticipate outbreak periods, strengthen preventive measures during high-risk week/months, especially from January to March each year and reduce infection rates through proactive intervention and surveillance programs.

Effective monitoring of Lassa fever outbreak in Nigeria can provide valuable insights into the efficacy of control policies, sensitization programs and enable evidence-based decision-making for the future. By leveraging the knowledge gained in managing this pandemic, healthcare officials can help safeguard the well-being of society. The public must also comply with government and healthcare directives. Moreover, governments and research institutes should collaborate with global organizations to explore the causes of the pandemic and share the latest research findings to overcome it. Therefore, top management must commit to quality initiatives and incorporate them into their business strategy to improve healthcare quality.

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