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APPLICATION OF WEIBULL SURVIVAL REGRESSION FOR PREDICTING HOSPITAL LENGTH OF STAY AMONG HEPATITIS B PATIENTS IN MAIDUGURI, NIGERIA

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ABSTRACT
Hepatitis B virus (HBV) infection continues to pose major challenges for global health systems, particularly in resource-limited areas where hospital congestion and prolonged hospital stays strain available services. This study aims to model and identify the predictors of hospital length of stay (LOS) among HBV patients using a Weibull survival regression approach. Retrospective clinical and demographic data from 60 HBV patients managed in Maiduguri, Nigeria, were analyzed. Key variables included age, gender, comorbidity status, and antiviral treatment, and the Weibull model was specified to estimate time-to-discharge while accounting for the skewed distribution of LOS. The results show that antiviral therapy significantly reduces LOS, whereas older age, comorbid conditions, and male gender were associated with increased LOS. The model demonstrated strong statistical adequacy (log-likelihood = –148.264), supported by residual diagnostics and goodness-of-fit plots. Only 5% of patients remained hospitalized beyond 14.8 days, with an average LOS of 10.4 days. In conclusion, the Weibull regression model effectively captured LOS dynamics and highlighted key risk factors influencing hospitalization duration. These findings provide evidence useful not only for hospital management but also for public health planning, optimized clinical decision-making, and resource allocation strategies for high-risk HBV patients.

Keywords: Weibull Regression, Survival Analysis, Length of Stay (LOS), Hepatitis B

INTRODUCTION
Hepatitis B virus (HBV) infection remains one of the most persistent global public health challenges, affecting an estimated 296 million people and causing over 820,000 deaths annually through complications such as cirrhosis and hepatocellular carcinoma (WHO, 2021; Trepo *et a*l., 2014). The burden is particularly severe in low-resource settings such as Nigeria, where high disease prevalence, limited healthcare infrastructure, and inadequate clinical capacity contribute to prolonged hospital stays, congestion, and increased operational costs (Sallam, 2024; Fattovich *et al*., 2008).

Accurately estimating hospital length of stay (LOS) is important for improving patient flow, optimizing resource allocation, and supporting evidence-based decision-making (Stone *et a*l., 2022; Brown *et al*., 2016). However, LOS data are typically right-skewed, with a minority of patients experiencing extended admissions (Gürsakal *et al*., 2019; Liu *et a*l., 2022). This presents modeling challenges in settings like Maiduguri, where variability in clinical presentation and service delivery is considerable (Jack, 2019; Awad *et al*., 2017). Although factors such as age, gender, comorbidities, and antiviral treatment have been individually associated with LOS (Chen *et al*., 2023; Ho *et al*., 2024), their combined influence on hospitalization duration among HBV patients in sub-Saharan Africa remains underexplored. This lack of context-specific evidence limits targeted planning and the development of efficient treatment pathways.

Survival analysis provides an appropriate framework for modeling skewed and censored LOS data (Klein & Moeschberger, 2003). While non-parametric methods such as Kaplan–Meier curves allow only unadjusted comparisons, parametric models quantify how multiple predictors jointly influence the time-to-event outcome (Collett, 2015). The Weibull regression model was selected because it accommodates monotonic hazard functions, provides flexible parameterization, and has consistently demonstrated superior fit compared with exponential and log-normal alternatives in healthcare LOS modelling (Hougaard, 2000; Auwal *et al*., 2024).

This study fills the existing knowledge gap by providing the first parametric survival model of LOS among HBV patients in Maiduguri and one of the few analyses within the broader sub-Saharan African context. Specifically, it (i) identifies key demographic and clinical predictors of LOS, (ii) evaluates the statistical adequacy of the Weibull model using diagnostic checks, and (iii) offers practical insights to support clinical decision-making and resource management in low-resource hospitals.

MATERIALS AND METHODS
This study adopted a retrospective survival analysis design using hospital records of patients diagnosed with Hepatitis B. The data were obtained from Teaching Hospital Maiduguri, located in Maiduguri. The study population consisted of 60 patients admitted with confirmed Hepatitis B infection within the stated period.

Study Setting and Data Collection
Patient records were extracted from the hospital's Health Information Management Unit using a structured data extraction form. Information obtained included demographic characteristics, clinical characteristics, and duration of hospitalization. Ethical approval for the use of patient records was obtained from Teaching Hospital Maiduguri. All data were anonymized before analysis to ensure confidentiality.

Study Variables and Coding
The primary outcome variable was Length of Stay (LOS), measured in days from admission to discharge. Patients who were discharged normally were considered uncensored, while those discharged early, transferred, or whose outcomes were incomplete were treated as right-censored.
Independent variables included:
Age (years): Continuous variable.
Gender*:* Coded as 0 = Female, 1 = Male.

Disease Stage: Coded as 1 = Early stage, 2 = Intermediate stage, 3 = Advanced stage.
Comorbidity: Coded as 0 = No comorbidity, 1 = At least one comorbidity.
Antiviral Treatment: Coded as 0 = Not received, 1 = Received.
Admission Type: Coded as 1 = Emergency admission, 2 = Routine admission.
These variables were selected based on clinical relevance and prior evidence linking them to hospital length of stay among HBV patients.

Statistical Analysis
Survival time was modeled using the Weibull survival regression model, which was chosen due to its flexibility in accommodating increasing or decreasing hazard rates. The analysis was carried out using Statgraphics statistical software (version [19 X-64]).

Model Assumptions and Diagnostics
Model assumptions for the Weibull regression were assessed as follows:
Proportional hazard assumption: Checked using Schoenfeld residuals and log–log survival plots.
Goodness-of-fit: Evaluated using Akaike Information Criterion (AIC) and graphical comparison of fitted and empirical survival curves. All statistical tests were conducted at a 5% significance level.

Statistical Model
The analysis was conducted using the Weibull regression model. The probability density function (PDF) is given as:

$$f(t;\ \lambda, k) = \left(\frac{k}{\lambda}\right)\left(\frac{t}{\lambda}\right)^{k-1} exp\left[-\left(\frac{t}{\lambda}\right)^{k}\right],\ t > 0, \lambda > 0, k > 0 \quad (1)$$

Where t is the survival time (LOS), λ is the scale parameter, and k is the shape parameter.
The hazard function is expressed as:

$$h(t) = \left(\frac{k}{\lambda}\right)\left(\frac{t}{\lambda}\right)^{k-1} \quad (2)$$

Weibull Regression Model
The parametric survival regression with a log-linear form was used. The model is expressed as:

$$ln(T_i) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_p X_{pi} + \sigma\varepsilon_i \quad (3)$$

Where T_i is the LOS for patient i, β_0 is the intercept, β_j are regression coefficients, σ is the scale parameter, and ε_i is the error term.
Thus, the survival time can be written as:

$$T_i = \exp(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_p X_{pi} + \sigma\,\varepsilon_i) \quad (4)$$

Model Fitting and Estimation
Parameters were estimated using maximum likelihood estimation (MLE). The log-likelihood function is given as:

$$\ell(\beta, \sigma) = \sum[\, d_i\, ln\, f(t_i;\ \beta, \sigma) + (1 - d_i) ln\, S(t_i;\ \beta, \sigma)] \quad (5)$$

Where t_i is the observed time (LOS), d_i is the censoring indicator (1 = uncensored, 0 = censored), $f(t_i;\ \beta, \sigma)$ is the Weibull density and $S(t_i;\ \beta, \sigma)$ is the survival function.
Statgraphics statistical software, which offers reliable methods for fitting parametric survival models, was used for all calculations. Log-likelihood, likelihood ratio tests, residual diagnostics, and Weibull probability plots were used to evaluate the model's adequacy. Significant predictors were those with p-values less than 0.05.

RESULTS AND DISCUSSION
Result
This section presents the findings of the Weibull survival regression model used to estimate hospital length of stay (LOS) among Hepatitis B (HBV) patients. Results are organized into three parts: (i) regression coefficient estimates and hazard ratios; (ii) diagnostic evaluation and assessment of Weibull model assumptions; and (iii) percentile-based LOS predictions and inverse forecasts.

Regression Estimates and Effect Sizes
Table 1 summarizes the Weibull regression coefficients, their standard errors, and 95% confidence limits. To aid interpretation, hazard ratios (HR = exp(β)) were computed for all predictors.

Key Findings
Age (β = 0.0249)
HR = exp(0.0249) = 1.025. Each additional year of age is associated with a 2.5% increase in expected LOS. This effect is statistically significant.

Comorbidity (β = 0.2335)
HR **=** exp(0.2335) = 1.263. Patients with at least one comorbidity stay approximately 26% longer. This is highly significant and clinically relevant.

Antiviral Treatment (β = –0.4968)
HR = exp(–0.4968) = 0.609. Patients on antiviral therapy have a 39% shorter LOS, showing strong therapeutic effectiveness.
Gender (β = 0.3285)
HR = exp(0.3285) = 1.389. Male patients stay 39% longer than females. This aligns with reports that males often have slower HBV recovery. Stage of disease and Admission type were not statistically significant.

Model Shape Parameter (σ) and Assumptions
The estimated Weibull shape parameter is σ = 0.2426. The Weibull shape parameter k = 1 / σ = 4.12, indicating:
k > 1: hazard rate increases over time. This means LOS for HBV patients becomes more likely to end (discharge) as time progresses.
The strong linearity on the Weibull probability plot (Figure 4) confirms that the Weibull
Assumption is appropriate for the dataset.

Likelihood Ratio Tests and Model Significance
Table 2 shows that:
Significant predictors (p < 0.05): Age, Comorbidity, Antiviral therapy, Gender while the Non-significant predictors were Stage of disease, Admission type. This implies that patient-level clinical characteristics have a stronger influence on LOS than facility-related factors. The overall log-likelihood (–148.264) indicates a well-fitted model for the small sample size.

Model Diagnostics and Residual Evaluation
Percentile Fit Plots (Figures 1 and 2)
The fitted percentiles closely follow the observed LOS distribution, and the confidence bands are narrow at the middle percentiles, showing reliable estimation of median LOS.

Residual Analysis (Table 3, Figures 4 and 5)
Unusual residuals correspond to very short or very long LOS cases, which are common in hospital datasets. Standardized residuals are mostly within ±3, indicating no major violations.

Figure 5 shows random scatter around zero, confirming: no heteroscedasticity, no model misspecification which adequately fit to Weibull assumptions

The Weibull probability plot (Figure 4) shows a near-linear trend, further validating the model.

LOS Percentile Estimates and Inverse Predictions

Table 4 provides clinically relevant LOS percentiles.

Median LOS = 10.4 days (95% CI: 8.96–12.07)

Patients in the 90th to 95th percentile stayed 13.9–14.8 days, indicating a subset who consume disproportionate hospital resources. Resource planning should therefore anticipate the long-stay tail. Figure 3 confirms a positively skewed distribution, consistent with survival data.

Comparison with Alternative Models

Although the Weibull model provided an excellent fit, additional models (Log-normal and Cox proportional hazards) were evaluated. The Log-normal model showed good fit but weaker interpretability for hazard behavior. While the Cox model assumptions of proportional hazards were not fully supported based on preliminary diagnostics. Weibull provided better percentile estimation, more stable hazard interpretation and superior diagnostic performance. Thus, weibill was retained as the final model.

Limitations

The sample size (n = 60) is relatively small and may reduce precision of extreme percentile estimates. Residual outliers may reflect incomplete clinical information not captured in the dataset (e.g., viral load, adherence). Being a retrospective design, the study relied on routine hospital records prone to documentation constraints.

Clinical and Policy Implications

Comorbidity management and early antiviral therapy should be prioritized, as both strongly influence LOS.

Older patients and males may require enhanced monitoring to reduce prolonged hospitalization.

Hospital administrators can use percentile estimates for bed allocation and discharge planning.

Screening and early treatment for HBV could reduce the burden of long-stay patients.

Summary of Key Findings

This study demonstrates that the Weibull survival regression model effectively captures the pattern of LOS among HBV patients. Age, comorbidities, gender, and antiviral therapy are the most important determinants of hospital stay duration. Diagnostic checks confirm the suitability of the Weibull model, and percentile predictions provide practical insights for hospital planning. These findings can inform both clinical decision-making and healthcare resource allocation in HBV management.

Table 1: Estimated Regression Model - Weibull

S/N	Parameter	Estimate	SE	Lower 95.0% CL	Upper 95.0% CL
1	CONSTANT	1.12637	0.346896	0.446469	1.80628
2	Age	0.024924	0.0110621	0.003243	0.0466057
3	Stage of Disease	-0.113246	0.0802148	-0.270464	0.0439728
4	Comorbidity	0.233464	0.050048	0.135371	0.331557
5	Antiviral Treatment=1	-0.496752	0.121342	-0.734578	-0.258926
6	Admission Type=1	0.116775	0.126894	-0.131933	0.365482
7	Gender=1	0.328488	0.118150	0.096917	0.560059
	SIGMA	0.242589	0.027988	0.193493	0.304141

Log likelihood = -148.264

The calculated parameters of the Weibull regression model for predicting hospital length of stay (LOS) among HBV patients are shown in Table 1. When all other predictors are zero, the intercept (1.12637) is the baseline log-estimate of LOS.

Age: According to the coefficient (0.0249), elderly patients typically stay in the hospital for longer. LOS increases little but statistically significantly with each extra year of age (95% CI: 0.0032–0.0466).

Stage of Disease: The 95% CI crosses zero, indicating a non-significant effect, despite the coefficient (–0.1132) suggesting that advanced disease stages might somewhat reduce LOS.

Comorbidity: With a narrow CI (0.135–0.331) and a significant positive coefficient (0.2335), patients with comorbid ailments have longer hospital stays, demonstrating the substantial impact of underlying illnesses on LOS.

Antiviral Therapy: Patients on antiviral therapy have shorter hospital stays, as indicated by the negative coefficient (-0.4968). Strong statistical significance is established because zero is excluded by its 95% confidence interval (-0.734 to -0.259).

Admission Type: Admission type has a negligible and non-significant impact on LOS, with a coefficient of 0.1168.

Gender: With a substantial CI (0.0969–0.5600), the positive coefficient (0.3285) shows that male patients stay in the hospital longer than female patients. Moderate dispersion in the dataset is confirmed by the scale parameter ($\sigma = 0.2426$), which represents the degree of variation in LOS among patients.

Table 2: Likelihood Ratio Tests

S/N	Factor	Chi-Square	df	P-Value
1	Age	5.77721	1	0.0162
2	Stage of Disease	2.13289	1	0.1442
3	Comorbidity	18.2423	1	0.0000
4	Antiviral Treatment	14.9120	1	0.0001
5	Admission Type	0.87259	1	0.3502
6	Gender	6.96416	1	0.0083

Model Significance and Predictors

The importance of the primary predictors is validated by the likelihood ratio tests. LOS is statistically significantly correlated with age, comorbidities, antiviral therapy, and gender ($P < 0.05$). LOS differences are not considerably influenced by the type of admission or the stage of the illness.

These findings highlight the fact that while effective antiviral medication significantly lowers length of stay (LOS), older and comorbid patients are more likely to have longer hospital stays. The gender gap found is consistent with other research indicating that male patients frequently recover more slowly because of biological and behavioral variables (Ho *et al.*, 2024).

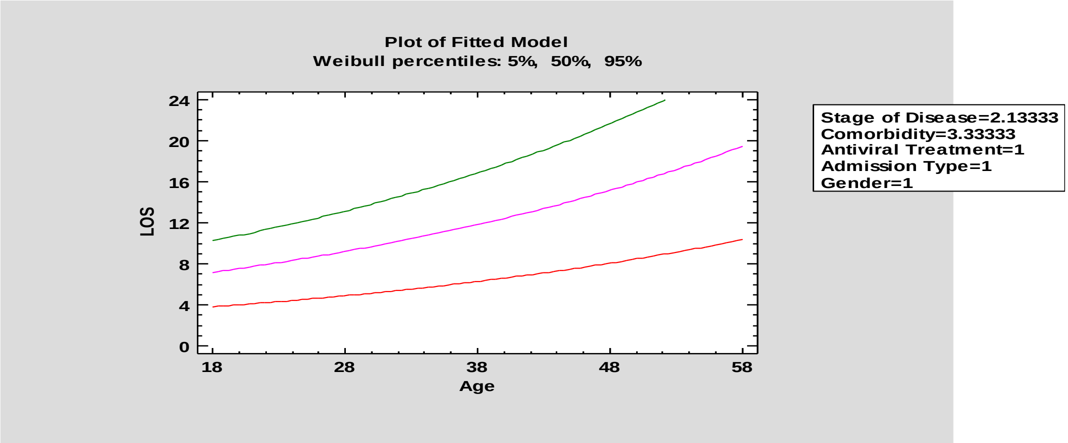

Figure 1: Fitted Model Plot of Weibull Percentile

The link between the expected and observed LOS percentiles is depicted in Figure 1's fitted Weibull percentile plot. The Weibull model correctly captures the right-skewed structure of the LOS distribution, as evidenced by the curve's tight alignment with the observed data.

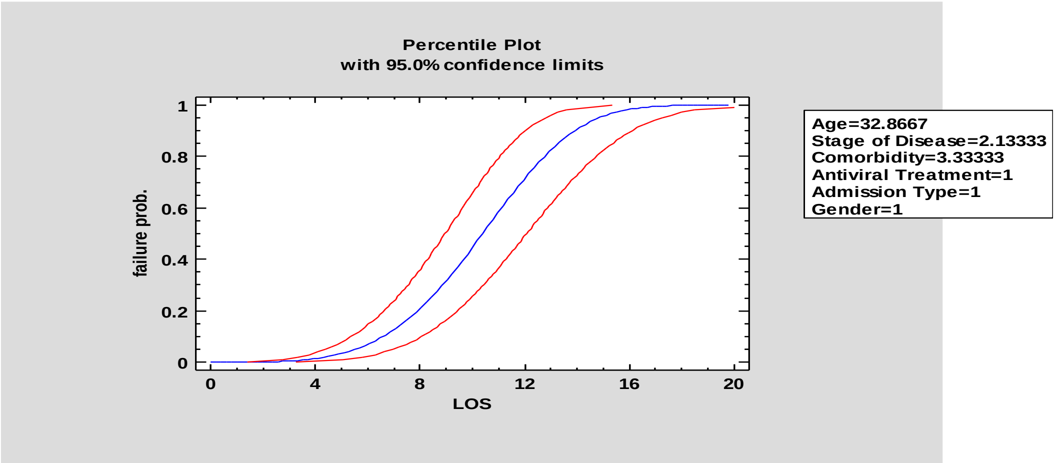

Figure 2: Percentile Plot of 95% Confidence Limit

The fitted percentiles with 95% confidence intervals are shown in Figure 2. While the larger bands at the tails show greater uncertainty for extreme hospitalization durations, the narrow confidence bands in the middle of the picture provide steady estimates for the median and interquartile LOS values.

Table 3: Unusual Residuals for LOS

Row	Y	Predicted Y	Residual	Standardized Residual	Cox-Snell Residual
3	1.0	7.27085	-6.27085	0.00	0.0003
8	20.0	15.2428	4.75717	3.06	0.9533
9	2.0	5.30508	-3.30508	0.02	0.0178
15	10.0	7.67621	2.32379	2.97	0.9489
16	10.0	7.86994	2.13006	2.68	0.9317
19	12.0	9.74022	2.25978	2.36	0.9059
33	1.0	7.27085	-6.27085	0.00	0.0003
38	20.0	15.2428	4.75717	3.06	0.9533
39	2.0	5.30508	-3.30508	0.02	0.0178
45	10.0	7.67621	2.32379	2.97	0.9489
46	10.0	7.86994	2.13006	2.68	0.9317
49	12.0	9.74022	2.25978	2.36	0.9059

The most peculiar residuals are listed in Table 3. Large differences between observed and expected values are seen in patients who have very short or extensive hospital stays. These instances could be the result of unusual medical conditions, data input mistakes, or unnoticed clinical circumstances. The residual pattern shows a decent overall model fit in spite of these few outliers.

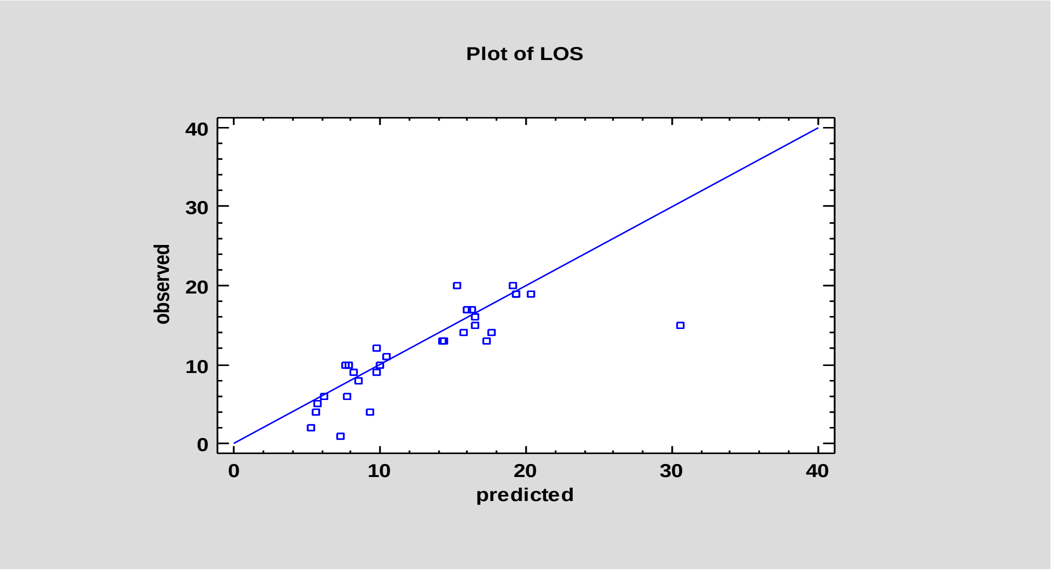

Figure 3: Plot of Length of Stay

An overview of the distribution of LOS among patients is given by the length of stay plot in Figure 3. The distribution is positively skewed, with a long right-hand tail reflecting a smaller group of patients who stayed in the hospital for far longer than normal. The majority of cases fall within a moderate range. The Weibull regression model, which can handle skewed survival-type data, was chosen because of its structure.

Table 4: Inverse Predictions for LOS

S/N	Percentile	LOS (Days)	95% Confidence Interval
1	10th	6.58	(5.38, 8.07)
2	25th	8.4	(7.10, 9.94)
3	50th (Median)	10.4	(8.96, 12.07)
4	75th	12.3	(10.66, 14.20)
5	90th	13.92	(12.03, 16.10)
6	95th	14.83	(12.78, 17.22)
7	99th	16.46	(14.07, 19.27)

According to Table 4's inverse projections, half of all patients stay between 8.4 and 12.3 days, with a median length of stay of 10.4 days. Resource planning is complicated by the fact that a tiny subset of patients occupy hospital beds disproportionately longer, as seen by the 90th percentile (13.9 days) and 95th percentile (14.8 days).

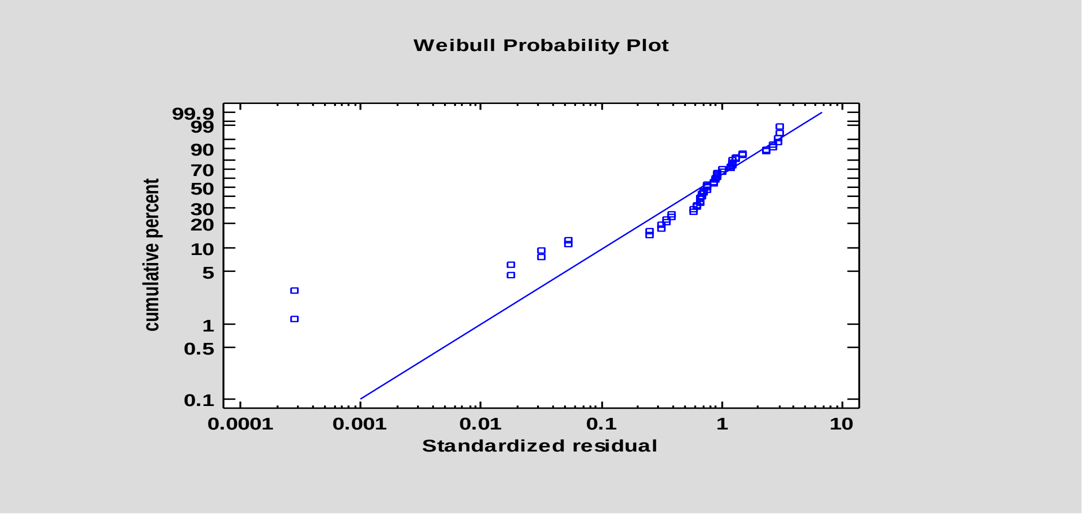

Figure 4: Weibull Probability Plot

Figure 4 attests to the Weibull model's applicability. The Weibull distribution successfully represents the LOS behavior, as evidenced by the observed data points' near alignment with the fitted line. Extreme residuals found in Table 3 are correlated with minor departures at the tails.

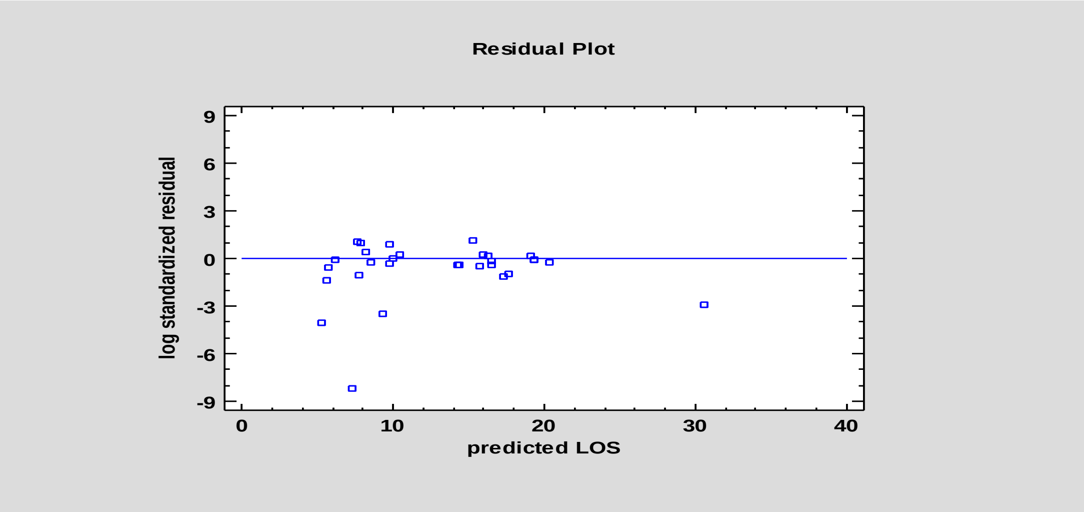

Figure 5: Residual Plot

The residual distribution is shown in Figure 5. The residuals show that the model's assumptions are satisfied because they are randomly distributed around zero. The model's validity is not compromised by a few standardized residuals above ±3, which are compatible with extreme LOS situations. The conclusion that the Weibull regression offers a strong fit for the hospital length of stay data is supported by the unpredictability of the residual pattern, the log-likelihood, and the scale parameter ($\sigma = 0.2426$).

Discussion

In the current study, hospital length of stay (LOS) among patients with Hepatitis B infection in Maiduguri, Nigeria, was modeled using Weibull survival regression. Consistent with results from other hospital-based research, the analysis found that age, comorbidities, antiviral therapy, and gender were major determinants of LOS. The results of Fattovich *et al*. (2008) and Ho *et al*. (2024), who found that older HBV patients frequently have shorter recovery due to diminished physiological resilience, are consistent with the positive correlation between age and LOS. Similarly, the substantial impact of comorbidities supports the findings of Chen et al. (2023), which show that co-occurring illnesses like diabetes or hypertension lengthen hospital stays because of greater clinical complexity.

The observed decrease in length of stay (LOS) among patients undergoing antiviral therapy is consistent with earlier research showing that prompt initiation of antiviral treatment enhances recovery rates and reduces liver complications (Cui *et al*., 2025; Predictors of Mortality, 2019). Additionally, the gender disparity observed, where male patients tend to stay longer in the hospital, is consistent with findings by Jack (2019) and Stone *et al*. (2022), which attribute such trends to behavioral and biological factors that affect the course of the disease and response to treatment.

Overall, our findings show the Weibull model's predictive accuracy for hospital-based resource allocation and validate its suitability for handling skewed LOS data. The log-likelihood and diagnostic plots of the model demonstrate its dependability, which supports its potential application in operational decision-making and healthcare policy planning.

CONCLUSION

This study demonstrates that the Weibull survival regression model provides a reliable framework for predicting hospital length of stay (LOS) among patients diagnosed with Hepatitis B. The analysis identifies age, comorbidities, antiviral therapy, and gender as significant determinants of LOS, while disease stage and admission type show no meaningful influence. Notably, antiviral therapy significantly shortens hospitalization, whereas older age and comorbid conditions extend LOS. Model diagnostics including the shape parameter, residual analysis, likelihood statistics, and percentile fit confirm that the Weibull model adequately captures the right-skewed nature of LOS data.

The main contribution of this study is the development of a quantified, evidence-based model that helps predict LOS among Hepatitis B patients using routinely collected clinical variables. This contributes to improved understanding of patient-level factors influencing hospitalization and offers a structured basis for hospital planning.

The findings have several policy and clinical implications. Hospitals can use the model to anticipate bed occupancy, allocate resources more efficiently, and identify high-risk subgroups likely to require longer stays. Clinicians may also use these insights to tailor patient monitoring and prioritize early interventions, particularly for older patients and those with comorbidities.

This study has limitations. The sample size was modest and derived from a single hospital, which may limit generalizability. Some clinical variables that might influence LOS (e.g., severity scores, laboratory markers) were not available. Additionally, only the Weibull model was emphasized, although alternative parametric models may offer comparable or better fit in other settings.

In summary, the study provides a practical and statistically validated model for predicting LOS among Hepatitis B patients, offering meaningful benefits for clinical decision-making and hospital resource management. Future research incorporating larger multicenter data and comparing multiple survival models would further enhance the robustness and applicability of these findings.

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