ACTUARIAL MODELING OF MORTALITY IN NIGERIA: PROJECTIONS AND IMPLICATIONS FOR TERM-LIFE ANNUITIES

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ABSTRACT
This study investigates the actuarial modeling of mortality in Nigeria, leveraging data from the World Health Organization's Abridged Life Table for the years 2000 to 2019. Given the critical role mortality projections play in the financial stability of insurance and pension industries, this research explores the Expected Present Value (EPV) of term-life annuities due under varying conditions. Missing data were addressed using linear interpolation, while projections for 2020 to 2024 employed double exponential smoothing. The analysis considers demographic characteristics such as gender and age, focusing on four policyholder age groups (15, 40, 60, and 80 years) across a five-year term. Results reveal declining mortality rates over time, with females consistently exhibiting lower probabilities of death than males. The EPV of annuities shows notable variations based on age, gender, and term duration, underscoring the importance of accurate demographic-specific mortality data for actuarial applications. This research provides actionable insights for the insurance industry and policymakers to address longevity risks and design equitable financial products tailored to Nigeria's demographic realities.

Keywords: Mortality modeling, life annuities, Expected Present Value, longevity risk, Nigeria, actuarial science, probabilities.

JEL Classification: C53, C18, G11.

1. INTRODUCTION
In actuarial science, mortality and longevity risks play a crucial role in calculating premiums and reserving benefits. If these calculations are inaccurate, insurance companies may face financial losses and fail to meet their obligations to policyholders. Furthermore, comprehensive information on a country's population dynamics and mortality rates is vital for governments to design effective and evidence-based policies(Unfpa & Un-Habitat, 2013). This is particularly relevant in Nigeria, where the rapid growth of the insurance industry and changing demographic trends underscore the importance of accurate mortality data for both corporate and public decision-making.

Currently, Nigeria lacks an updated and standardized mortality table that captures the population's demographic and mortality characteristics. The use of mortality tables based on insured populations, as is common in many countries, may not accurately reflect the broader Nigerian population. For instance, data from the insured demographic often excludes the informal workforce, which constitutes a significant portion of Nigeria's population. If the government aims to formulate policies using mortality rates reflective of the entire population, demographic data that represent the general populace must be utilized. Accurate mortality projections can inform insurance practices and public policies, particularly in addressing longevity risks and designing retirement benefits(Ayuso, Bravo, & Holzmann, 2021; Ernest & Partial, 2016).

Mortality projection is an essential tool in actuarial science and public policy, providing insights into future trends in death rates. By forecasting mortality rates in Nigeria, insurance companies and the government can better predict and mitigate potential losses associated with longevity risks. These projections can also guide the design of long-term financial instruments such as life annuities and pension schemes. Studies have shown that statistical forecasting methods, such as Double exponential smoothing, can effectively project mortality trends, offering a data-driven approach to tackling uncertainties in population dynamics(Booth & Tickle, 2008; Singh et al., 2019).

The UDD approach offers a reliable and straightforward framework for estimating the EPV of annuities, making it suitable for the Nigerian context, where data availability and quality may be limited(Gerber & Shiu, 2024; Siswono, Azmi, & Syaifudin, 2021). By producing mortality projections and evaluating term annuities that align more closely with Nigeria's demographic realities, this study provides actionable insights for the insurance industry and policymakers. These findings can help minimize risks, design equitable insurance products, and develop informed government policies to address longevity challenges and population aging in Nigeria(Hamadu & Mojekwu, 2014; Mbam, Halvorsen, & Okoye, 2022).

This study offers a comprehensive actuarial analysis of mortality in Nigeria by leveraging the World Health Organization's Abridged Life Table data from 2000 to 2019. It addresses the critical gap in localized mortality models and provides forward-looking projections using d

Double exponential smoothing for 2020–2024. Unlike existing models primarily based on insured populations, this research incorporates demographic characteristics reflective of Nigeria's broader populace. The findings reveal gender-specific mortality patterns, with females consistently exhibiting lower death probabilities than males. By calculating the Expected Present Value (EPV) of term-life annuities across various age groups, this study underscores the significant demographic and temporal variations in EPVs, highlighting the pressing need for accurate mortality data to manage longevity risk and develop equitable financial products.

In this research, we aim to calculate the Expected Present Value (EPV) of a term-life annuity due. A term-life annuity due is a financial product that makes fixed payments to the annuitant at the beginning of each payment period, provided the policyholder is still alive. Specifically, we consider an annuity that pays one unit of money per year to a person currently aged x, with the payments lasting for n years. These payments are contingent on the survival of the policyholder and are discontinued upon their death. The calculation of the EPV incorporates actuarial principles, including survival probabilities and discount factors, to determine the present value of future payments. This approach not only highlights the financial planning benefits of annuities but also underscores their role in risk management. Annuities, like other insurance products, provide a mechanism for transferring risk and ensuring financial stability over time(Adereti & Oladoyin, 2021; and Aduloju, 2021). The effectiveness of such financial instruments is rooted in the insurers' extensive experience and actuarial expertise, which enable them to design products that balance risk and reward effectively.

This study utilizes Nigerian mortality data, specifically the probability of a person aged x dying before reaching age $x + n$, obtained from the World Health Organization (WHO) repository for the period 2000 to 2019. These data are projected using a simple forecasting method, double exponential smoothing, to estimate future mortality trends. The projected results are then applied to analyze the distribution of life expectancy and to determine the value of the term annuity. The study is structured in the following sequence: introduction, literature review, methodology, results and discussion, and conclusion.

2. LITERATURE REVIEW

The literature on life insurance and life annuities explores the intersection between insurance contracts and financial markets. Artzner et al. (2024) and Artzner et al. (2020) discussed the concept of insurance-finance arbitrage (IFA), highlighting the consistency of insurance contracts with financial trading strategies. They emphasized the connection between insurance contracts and financial markets, including interest rates and hybrid products like equity-linked life insurance and variable annuities. The focus on life insurance companies' investments abroad and the internal rate of return on Chilean annuities sheds light on the international aspects of life insurance(Escudero & Ruiz, 2021; Escudero Navarrete & Ruiz Vergara, 2020). Registered index-linked annuities (RILAs) are introduced as popular equity-based retirement savings products offered by U.S. life insurance companies, providing insights into pricing models and hedging strategies (Moenig, 2022).

Mortality projection plays a critical role in determining the Expected Present Value (EPV) of term annuities in various countries. Siswono et al. (2021) conducted a study using Indonesia's Abridged Life Table to project mortality rates for both male and female populations in Indonesia. This research highlights the importance of accurate mortality projections in the context of determining the EPV of term annuities. The use of mortality rates and discount rates plays a significant role in determining the present value of future benefits and payments(Rackwitz, 2006). Additionally, the actuarial present value of future benefits is essential in understanding the financial impact of longevity risk (Nantwi, Lotsi, & Debrah, 2022). In the context of Nigeria, developing a life table specific to the region is essential for accurate estimations. While existing mortality tables such as the Annuity Mortality Table provide valuable insights, tailoring the models to the Nigerian population is crucial for precise calculations(Okoro & Nwogu, 2020). The present value of expected future payments is a key component in determining the financial stability of pension plans and annuity contracts(Sogunro, Adeleke, & Ayorinde, 2019; Sogunro & Oke, 2022). Financial assumptions, including discount rates and future benefit levels, play a critical role in measuring plan obligations and assessing the long-term impact of longevity risk(Ibiwoye, 2008; Ibiwoye & Ajijola, 2012; Paul & Margret, 2024). Understanding the expected number of deaths and the present annuity value is essential for effectively managing portfolios and ensuring financial stability (Bütler & Teppa, 2007; Duxbury, Summers, Hudson, & Keasey, 2013). Hence, actuarial modeling of mortality in Nigeria's life table is vital for estimating the expected present value of a term annuity. By incorporating specific demographic data and financial assumptions, reliable assessments of longevity risk and future benefit payments can be made to ensure financial stability and security.

3. METHODOLOGY

3.1 Data

This study utilized data from the World Health Organization (WHO) specifically for Nigeria's population. The data, however, was incomplete and presented as an Abridged Life Table instead of a Complete Life Table. Additionally, it spanned five-year intervals from 2000 to 2019. To address the gaps, such as missing data for the period between 2020 and 2024, a linear interpolation technique was applied. First, for the linear interpolation, the data from the **WHO** were disaggregated into one-year intervals instead of the original five-year intervals in which they were provided. This step was necessary to enhance the accuracy of the interpolation and ensure a more granular representation of mortality trends over time. Secondly, mortality projections for the years 2020 to 2024 were generated using a two-step approach. The Matlab function "interp1" was employed to perform linear interpolation, filling in gaps between data points and ensuring a continuous mortality trend. Additionally, the Double exponential smoothing method was applied to account for trends and fluctuations, effectively smoothing the data while capturing both level and trend components. This method is particularly useful for time series forecasting as it assigns exponentially decreasing weights to past observations, reducing noise and improving predictive accuracy(Siswono et al., 2021).

3.2 Expected Present Value

The timeline of the payments is critical to understanding the structure of annuity. If the policyholder survives to age $x + t$, the payments will occur at $t = 0,1,2, \dots . n - 1$. Therefore, the payments are made at the beginning of each year, starting immediately and continuing until the end of the term n, or until the death of the policyholder—whichever comes first. The EPV of this annuity reflects the weighted sum of the present values of these payments, accounting for the likelihood of survival of the policyholder at each payment period and the effect of discounting future payments to their present value. Mathematically, the EPV is expressed as the sum of the present values of each individual payment, weighted by the probability of the policyholder surviving to the corresponding time t.

If we denote the present value of this annuity by Y, the calculation is governed by the following equation(David, Hardy, & Waters, 2009):

$$Y = \begin{cases} \ddot{a}_{\overline{K_x+1}|} & \text{if } K_x = 0,1,\dots,n-1 \\ \ddot{a}_{\overline{n}|} & \text{if } K_x \geq n \end{cases} \tag{1}$$

That is

$$Y = \ddot{a}_{\overline{\min(K_x+1,n)}|} = \frac{1 - v^{\min(K_x+1,n)}}{d} \tag{2}$$

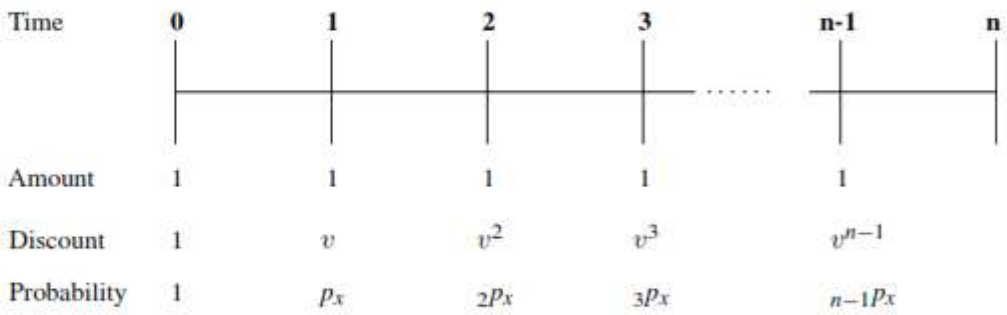
The time-line diagram in Figure 1 visually illustrates the cash flow structure of a term annuity-due. Payments are made at the start of each period, beginning immediately at $t = 0$ and continuing annually for up to n years. The payments stop either upon the policyholder's death or at the end of the n-year term. A significant aspect of the diagram is the absence of a payment at $t = n$, as the payments are made in advance and the term ends before the n-th payment. This structure simplifies cash flow calculations while reflecting the realistic boundaries of an annuity contract.

The Expected Present Value (EPV) of this annuity is derived by summing the discounted values of individual payments, weighted by the probabilities of the policyholder surviving to each payment period. The formula for the EPV is expressed as(Promislow, 2011):

$$\ddot{a}_{x:\overline{n}|} = 1 + vp_x + v^2 \, {}_2p_x + v^3 \, {}_3p_x + v^4 \, {}_4p_x + ... + v^{n-1} \, {}_{n-1}p_x \quad (3)$$

where $v = (1+i)^{-1}$ is the discount factor, and ${}_tp_x$ represents the probability that a policyholder aged x will survive for t years. The initial payment at $t = 0$ is not discounted, as it is paid immediately, while subsequent payments are discounted to account for the time value of money. The survival probabilities ensure that the calculation incorporates the mortality risk, making the formula an accurate and reliable tool for valuation.

Figure 1. Time-line diagram for term life annuity-due



The combination of discounting and survival probabilities highlights the dual influences on the EPV: the time value of money and the uncertainty of human longevity. This integration ensures that the model aligns with real-world conditions, where future payments are inherently less valuable and depend on the survival of the individual. The time-line diagram effectively demonstrates this interaction by breaking down each payment into its corresponding amount, discount factor, and survival probability, offering a clear visual framework for understanding the calculations. EPV can be compactly be expressed as(David et al., 2009);

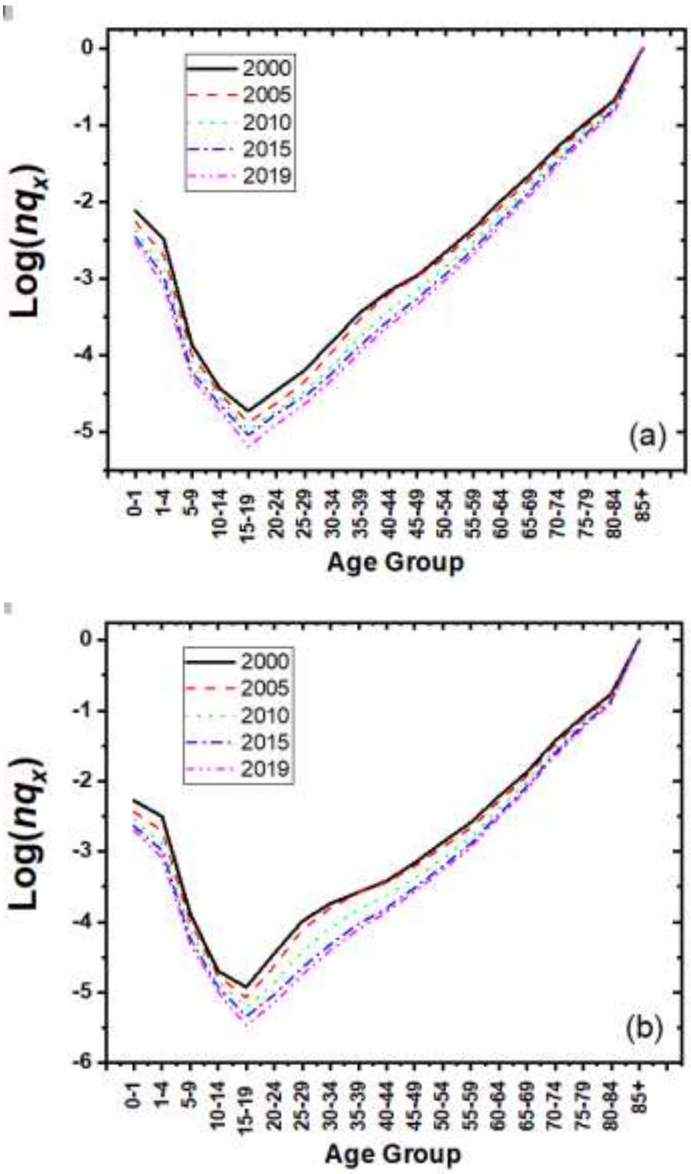
$$\ddot{a}_{x:\overline{n}|} = \sum_{t=0}^{n-1} v^t \, {}_tp_x \quad (4)$$

Using these probabilities, the Expected Present Value (EPV) of an annuity-due was calculated using Equation (4). This EPV was then analyzed to assess the impact of longevity risk on both male and female populations by examining variations across age groups and payment periods. For this purpose, policyholders ages 15, 40, 60 and 80 were considered in determining the EPV of the annuity. In this work, 5% is assumed as effective rate of return.

4. RESULTS AND DISCUSSION

In this study, we analyzed the trends in mortality probabilities for the Nigerian population and their implications for actuarial calculations, including the Expected Present Value (EPV) of life annuities. Using data obtained from the WHO, we identified distinct patterns in mortality rates across age groups and genders. Figure 2 depicts the mortality rates (logarithm of ${}_nq_x$) for Nigerian males and females from 2000 to 2019. The graph demonstrates a decline in mortality rates for several age groups over time, indicating improvements in public health and living conditions in Nigeria. Specifically, mortality is highest during infancy and early childhood, decreases significantly in adolescence (10–14 years), and then rises steadily with age. This trend highlights the effect of ongoing efforts in healthcare, such as immunization programs and maternal health improvements. However, the mortality rate for older age groups shows an upward trend, reflecting the impact of aging on health outcomes. The assumption that mortality probability reaches 1 beyond the age of 85 suggests limited longevity data for Nigeria. These findings emphasize the importance of projecting future mortality trends to address longevity risk and its implications for pension and insurance programs.

Figure 2. Gender-Specific Mortality Rates for the Nigerian Population: (a) Male and (b) Female



Source: WHO data repository

Figure 3. Observed and Projection of probability of death for age 15-19 in Nigeria

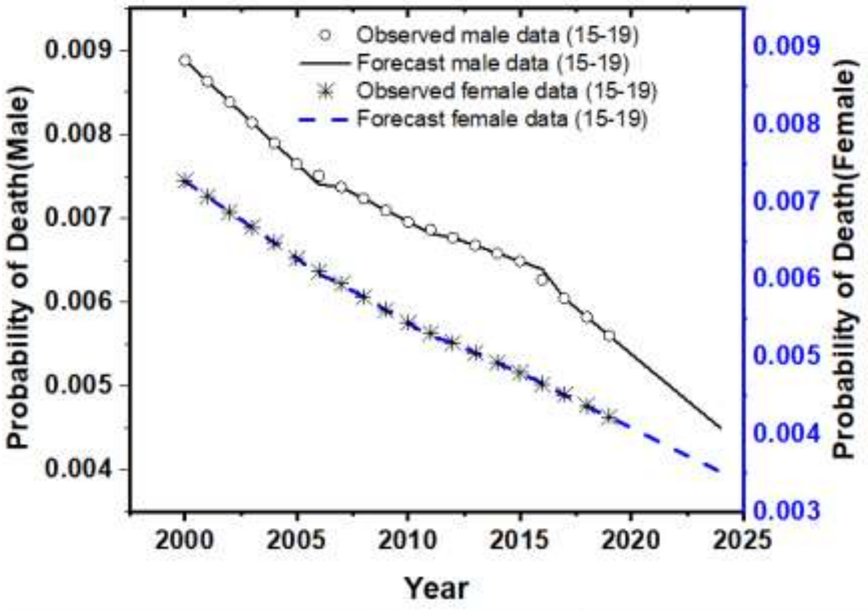


Figure 3 illustrates the observed and forecasted probabilities of death for males and females aged 15–19 years in Nigeria from 2000 to 2025. The observed data for both genders shows a decreasing trend in the probability of death over time, reflecting improvements in healthcare, nutrition, and living conditions during the observed period (2000–2019). Males consistently exhibit higher probabilities of death compared to females, which is a typical pattern in mortality studies, often attributed to biological, behavioral, and social factors(Chang & Shi, 2023; Fatusi, Adedini, & Mobolaji, 2022). The forecasted probabilities from 2020 to 2024 continue the declining trend for both genders. The model used predicts sustained improvements in mortality rates. However, the rate of decline appears to slow down, indicating that further reductions in mortality may require more significant or targeted interventions, particularly for males, who maintain a higher risk. Table 1 shows the comprehensive result for the other age groups. It is noticeable that we use this data to obtain the Abridged Life Table in the projection years which will later be used for the calculation of the EPV of term-life annuity due.

Table 1 presents the projected probabilities of death (denoted as q_x) over a five-year period beginning in 2020. These probabilities represent the likelihood that an individual, alive at the start of a specific age interval, will pass away within that interval $(x, x+n)$. The data highlights a general decline in the probability of death for both men and women in certain age groups, reflecting improvements in mortality rates. This trend suggests advancements in healthcare, lifestyle, or other contributing factors that influence longevity. The information in Table 1 serves as the basis for constructing the Abridged Life Table for the projected years. This table is an essential tool used to calculate the Expected Present Value (EPV) of a term-life annuity-due. The probabilities of death are integral in determining survival rates and associated payment structures, which are critical in actuarial science and financial planning for annuities. These projections enable a more accurate assessment of future liabilities and premiums, ensuring a robust foundation for further analysis.

Table 1. Age-Specific Projections of the Probability of Death (nq_x) for the Nigerian Population: Focus on Ages 15-19, 40-44, 60-64, and 80-84

	15-19		40-44		60-64		80-84	
Year	male	female	male	female	male	female	male	female
2020	0.005381	0.004083	0.026475	0.020898	0.10004	0.079832	0.433079	0.408
2021	0.00516	0.00394	0.025964	0.02061	0.098335	0.078573	0.428655	0.404909
2022	0.004939	0.003798	0.025454	0.020322	0.09663	0.077314	0.424231	0.401819
2023	0.004717	0.003656	0.024943	0.020034	0.094925	0.076055	0.419808	0.398728
2024	0.004496	0.003513	0.024432	0.019747	0.09322	0.074796	0.415384	0.395638

Table 2. Linear Interpolation of Age-Specific Projections of the Probability of Death (nq_x) for the Nigerian Population: Focus on Ages 15-19, 40-44, 60-64, and 80-84

	15-19		40-44		60-64		80-84	
Year	male	female	male	female	male	female	male	female
2000	0.00888	0.00727	0.032782	0.032782	0.138751	0.109138	0.511428	0.46738
2001	0.008633	0.007071	0.032652	0.032652	0.136917	0.107672	0.508219	0.464745
2002	0.008387	0.006871	0.032522	0.032522	0.135082	0.106206	0.50501	0.46211
2003	0.00814	0.006672	0.032392	0.032392	0.133247	0.10474	0.501801	0.459475
2004	0.007894	0.006472	0.032262	0.032262	0.131413	0.103274	0.498591	0.45684
2005	0.007648	0.006273	0.032131	0.032131	0.129578	0.101808	0.495382	0.454205
2006	0.00751	0.006106	0.031031	0.031031	0.127198	0.09971	0.491341	0.450813
2007	0.007371	0.005939	0.02993	0.02993	0.124817	0.097611	0.4873	0.447422
2008	0.007233	0.005772	0.02883	0.02883	0.122436	0.095512	0.483259	0.44403
2009	0.007095	0.005605	0.027729	0.027729	0.120056	0.093413	0.479218	0.440639
2010	0.006957	0.005439	0.026628	0.026628	0.117675	0.091314	0.475177	0.437248
2011	0.006863	0.00531	0.02577	0.02577	0.115853	0.090012	0.471181	0.434488
2012	0.006769	0.005181	0.024912	0.024912	0.114031	0.088709	0.467185	0.431729
2013	0.006675	0.005052	0.024054	0.024054	0.112209	0.087406	0.46319	0.42897
2014	0.006581	0.004923	0.023195	0.023195	0.110387	0.086103	0.459194	0.426211
2015	0.006486	0.004794	0.022337	0.022337	0.108565	0.084801	0.455198	0.423452
2016	0.006265	0.004652	0.022049	0.022049	0.10686	0.083847	0.450775	0.420362
2017	0.006044	0.00451	0.021761	0.021761	0.105155	0.082894	0.446351	0.417271
2018	0.005823	0.004367	0.021474	0.021474	0.10345	0.081941	0.441927	0.414181
2019	0.005602	0.004225	0.021186	0.021186	0.101745	0.080988	0.437503	0.41109
2020	0.005381	0.004083	0.026475	0.020898	0.10004	0.079832	0.433079	0.408
2021	0.00516	0.00394	0.025964	0.02061	0.098335	0.078573	0.428655	0.404909
2022	0.004939	0.003798	0.025454	0.020322	0.09663	0.077314	0.424231	0.401819
2023	0.004717	0.003656	0.024943	0.020034	0.094925	0.076055	0.419808	0.398728
2024	0.004496	0.003513	0.024432	0.019747	0.09322	0.074796	0.415384	0.395638

Tables 3 and 4 illustrate the Expected Present Values (EPVs) of term life annuities paid at the beginning of each year for term lengths of $n = 5$ and $n = 10$, respectively. The data is segmented by gender and age (x = 15,40,60,80) and spans the years 2020 to 2024. EPVs are critical metrics in actuarial science, serving as the foundation for pricing and managing life annuities and related insurance products. These calculations reflect the time value of money, mortality rates, and other key actuarial assumptions.

The EPVs demonstrate a clear inverse relationship with age, as they decrease significantly for older insured individuals. This pattern aligns with actuarial principles, as older individuals have shorter life expectancies and, consequently, fewer expected annuity payments. For example, in 2024, the EPV for a male aged 15 with $n = 5$ is 4.5234, whereas for a male aged 80, it drops to 2.1939. Such trends emphasize the impact of age on the expected value of annuities, helping insurers design age-appropriate pricing structures.

Gender differences are also evident across all age groups and terms, with females consistently having higher EPVs than their male counterparts. This disparity reflects actuarial assumptions about the longer life expectancy of females, resulting in a higher probability of receiving annuity payments over an extended period(Mirowsky, 1999). For instance, in Table 3 for 2024, the EPV for a female aged 40 is 4.5286, slightly higher than the 4.5234 recorded for a male of the same age. These gender-specific variations are fundamental to ensuring equity and sustainability in insurance pricing. The differences in EPV values arise due to varying life expectancies, health profiles, and risk exposures between genders(Crimmins, Shim, Zhang, & Kim, 2019). Women, on average, tend to live longer than men, which translates to longer payout periods for certain insurance products, such as annuities. Conversely, for term life insurance policies, men often represent higher risk due to their shorter life expectancy, leading to higher premiums. Incorporating these variations allows insurers to balance fairness with financial stability(Ayanore et al., 2019).

The length of the annuity term significantly affects the EPVs, with longer terms (n = 10) producing higher values compared to shorter terms (n = 5). This is due to the increased duration over which annuity payments are expected to be made. For instance, in 2024, the EPV for a male aged 60 with n = 5 is 4.1059, while for n = 10, it rises to 7.2462. Insurers leverage these distinctions to provide flexible products tailored to the varying needs of policyholders.

Finally, a slight upward trend in EPVs from 2020 to 2024 is observed for all ages and genders. This may be attributed to improvements in mortality rates or adjustments in actuarial assumptions such as interest rate changes. For instance, at age 60 and n = 5, the EPV for males rises from 4.0482 in 2020 to 4.1059 in 2024. These trends highlight the dynamic nature of actuarial modeling and the importance of continuously updating assumptions to reflect current realities. Together, these findings underscore the critical role of EPVs in pricing life annuities and ensuring insurers' financial stability while meeting policyholder expectations

Table 3. Actuarial Valuation of Term Life Annuities Paid at Year Commencement $\ddot{a}_{x:\overline{n}|}$ with n = 5

Year	x = 15		x = 40		x = 60		x = 80	
	Male	Female	Male	Female	Male	Female	Male	Female
2020	4.5194	4.526	4.4436	4.4482	4.0749	4.1732	2.535	2.6617
2021	4.5204	4.5267	4.4403	4.4495	4.0827	4.178	2.5551	2.6758
2022	4.5214	4.5273	4.4369	4.4508	4.0904	4.183	2.5752	2.6898
2023	4.5224	4.528	4.4335	4.4521	4.0982	4.1883	2.5953	2.7039
2024	4.5234	4.5286	4.43	4.4534	4.1059	4.1939	2.6155	2.7179

Table 4. **Actuarial Valuation of Term Life Annuities Paid at Year Commencement $\ddot{a}_{x:\overline{n}|}$ with n = 10**

Year	x = 15		x = 40		x = 60		x = 80	
	Male	Female	Male	Female	Male	Female	Male	Female
2020	8.0566	8.0692	7.9179	7.9215	7.2278	7.4178	4.4248	4.6802
2021	8.0579	8.0703	7.9187	7.926	7.2421	7.4272	4.4591	4.704
2022	8.0594	8.0714	7.919	7.9299	7.2563	7.4365	4.4937	4.7281
2023	8.0609	8.0725	7.9188	7.9334	7.2703	7.4457	4.5287	4.7525
2024	8.0626	8.0737	7.9179	7.9363	7.2843	7.4547	4.5642	4.7773

5. CONCLUSION

This study highlights the critical importance of accurate mortality projections in actuarial modeling for Nigeria's insurance and pension industries. By leveraging WHO mortality data and utilizing advanced statistical methods, we constructed projections that demonstrate a consistent decline in mortality rates. Gender-specific differences in mortality, with females exhibiting lower death probabilities, align with global patterns and underscore the need for tailored actuarial practices. The findings emphasize that the Expected Present Value (EPV) of term-life annuities varies significantly across age groups and term durations, driven by demographic and mortality trends. These results offer crucial implications for policy formulation and product design in the insurance and pension sectors, particularly in addressing longevity risks and ensuring the financial stability of annuities and pension schemes. By adopting updated life tables and integrating localized demographic insights, insurance agencies, National Pension Commission (PenCom), and policymakers can enhance risk management strategies, develop equitable financial products, and meet the needs of a rapidly evolving population. Collaboration between insurance agencies and PenCom is essential to align annuity and pension products with regulatory frameworks and ensure sustainable retirement solutions for Nigerians. Future studies should explore integrating additional variables, such as economic factors, healthcare access, and policyholder behavior, to refine mortality projections further and strengthen the actuarial modeling framework for emerging economies like Nigeria.

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DECLARATIONS AUTHOR CONTRIBUTION

The authors confirm sole responsibility for the study conception, analysis and interpretation of results, and manuscript preparation.

CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

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