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PREVALENCE AND MODEL PREDICTIONS OF *MYCOBACTERIUM TUBERCULOSIS* IN NIGER STATE, NIGERIA

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Abstract
Nigeria is among the hotspots of tuberculosis (TB) globally, with subnational variations in the disease dynamics. Niger State contributes substantially to the national TB notifications, yet current incidence patterns and short-term forecasts remain poorly characterised. Reliable incidence data and predictive models are essential for targeted interventions and resource planning to meet End TB Strategy milestones. This study determined the incidence and predicted future trends of Mycobacterium tuberculosis in Niger State. We performed a retrospective review of all bacteriologically and clinically confirmed TB cases reported to the Niger State Tuberculosis and Leprosy Control Program from January 2014 to December 2024. Annual incidence rates per 100,000 population were calculated using National Population Commission projections. An Auto-Regressive Integrated Moving Average (ARIMA) time series model was fitted to historical data to forecast incidence for the year 2030. Model performance was evaluated using Mean Absolute Percentage Error (MAPE). There was a massive increase in new cases by 991%, from 1,044 cases in 2014 to 10,341 cases in 2024, which represents an average annual increase of approximately 927 cases. This massive increase is likely due to improved case detection capacity, enhanced surveillance systems, and stronger diagnostic infrastructure rather than a real epidemic peak. Significant spatial clustering occurred in urban regions including Minna, Suleja, and Bida. ARIMA (1,1,1) provided optimal fit with MAPE 8.2%. The model predicts incidence will increase to 68.4/100,000 by 2027 under current conditions. The infection incidence in Niger State shows a consistent upward trajectory with urban clustering. Without enhanced case finding and control measures, the burden will increase through 2027. Findings support prioritising active case detection in hotspots, expanding molecular diagnostic coverage, and using predictive models for state-level TB program planning.

Keywords: Tuberculosis, Incidence, Predictive model, Niger State

Introduction
Globally, TB remains one of the top ten causes of death, and the leading cause from a single infectious agent, ranking above HIV/AIDS. In 2021, the World Health Organisation (WHO) estimated that 10.6 million people fell ill with TB, and 1.6 million died from the disease, including 187,000 people with HIV (WHO, 2022). TB

is most prevalent in Asia and Africa, with Sub-Saharan Africa experiencing the highest incidence rates per capita, largely due to the intersecting HIV epidemic, which exacerbates the risk of TB infection and progression to active disease (Naghavi et al., 2017).

Global efforts at the control of TB have included the implementation of the WHO's End TB Strategy, whose targets are an 80% reduction in TB incidence and a 90% reduction in TB deaths by 2030, compared to 2015 levels (WHO 2020). While such targets are ambitious, success has been elusive in regions where social determinants of health, including poverty, malnutrition, and poor health infrastructure, keep the infection entrenched (Abi et al., 2024a).

Nigeria is among the top 30 high TB burden countries in the world, ranking as one of the top countries burdened. According to estimates by the WHO, Nigeria accounted for 4.4% of the global TB burden in 2021, with about 440,000 new cases reportedly occurring annually (WHO, 2023). The TB burden in Nigeria is further complicated by the significant prevalence of HIV infection, which significantly increases the risk of progression to active TB disease. Additionally, Nigeria faces challenges with DR-TB, as reflected in the increasing number of MDR-TB cases reported in recent years (Adamu, 2021; Abi et al., 2024b). Similarly, tuberculosis control programs in Nigeria, assisted by international organisations, have been put in place by the government, the most prominent of which is NTBLCP. Accordingly, the program aims to enhance TB detection ability, improve compliance with treatment, as well as access to care, especially for vulnerable populations infected with HIV (Otu et al., 2020). Despite the interventions, TB remains one of the leading public health problems, and there is still much to be done in Nigeria.

Methodology

Study Setting

Niger State within the north-central part of Nigeria is the study setting. Niger State is spread over a total area of about 76,363 square kilometres and is the largest state in terms of area covered in Nigeria, and is also administratively divided into 25 Local Government Areas (LGAs) (Federal Ministry of Health, 2020). Niger State is selected based on several strategic reasons. First, the state is among the faces of Nigeria's huge TB burden with elevated prevalence rates and severe case detection and treatment challenges (Federal Ministry of Health, 2020). Second, the state's mixed geographic make-up with urban and rural enclaves presents a perfect context to explore TB control in diverse population settings. Third, TB control systems and data are in place to offer quality and data availability for the retrospective study component.

Niger State is projected to have 5.6 million residents using 2019 population estimates and has a fairly young age pattern characteristic of Sub-Saharan African populations (Atnazhi et al., 2026). It has 774 primary health facilities, 52 secondary health facilities, and 4 tertiary facilities, and all the mentioned above have TB services integrated within Nigeria's decentralised model of health care (Federal Ministry of Health, 2020).

Quantitative Study Population

The quantitative study population is all the notified cases of TB in Niger State between January 1, 2014, and December 31, 2024. All forms of TB (pulmonary and extrapulmonary), drug-susceptible and drug-resistant TB, and HIV co-infection are included.

Informed Consent Procedures

Systematic informed consent procedures will be applied to all study participants, including written informed consent for questionnaire respondents in person, electronic informed consent for web respondents through the REDCap platform, and verbal consent options for illiterate respondents.

Statistical Analysis

Statistical analysis will be conducted under STATA version 17.0 for standard statistical analysis, R version 4.3.0 for complex modelling, NVivo version 14.0 for qualitative analysis, REDCap for questionnaire data management, and ArcGIS for geographic analysis.

Ethical Considerations

Ethical approval will be obtained from relevant institutional review boards before data collection:

1. Nasarawa State University Health Research Ethics Committee
2. Niger State Ministry of Health Research Ethics Committee

Result

Tuberculosis Indicators

Table 1. Represents the descriptive statistics of key tuberculosis indicators in Niger State for 11 years between 2014 and 2024. It reflects a massive and consistent increase in both new TB and notified cases during the period under study. There was a massive increase in new cases by 991%, from 1,044 cases in 2014 to 10,341 cases in 2024, which represents an average annual increase of approximately 927 cases. This massive increase is likely due to improved case detection capacity, enhanced surveillance systems, and stronger diagnostic infrastructure rather than a real epidemic peak. Notified cases tracked very closely behind new cases, which increased from 1,532 in 2014 to 10,907 in 2024, indicating good reporting procedures and case registration systems. HIV co-infected cases were presented differently, at 138 to 279 per annum, but surprisingly not in an increasing proportion to the overall TB case load. Completion of treatment ranged greatly, from as low as 44 completed patients in 2014 to as high as 1,110 in 2024. Death rates were relatively stable despite the massive number of cases, ranging from as low as 26 and as high as 115 deaths annually, showing great improvement in treatment outcomes and case management.

Table 1: Tuberculosis indicators in the study area (2014-2025)

Year	New Cases	Notified cases	Sum of completed patients	Death patients
2014	1044	1532	44	60
2015	1477	1611	442	94
2016	1534	1737	89	76
2017	1923	1964	61	68
2018	1931	2042	460	26
2019	2836	2595	388	100
2020	3601	3629	785	77
2021	4771	4806	993	42
2022	6469	6501	800	59
2023	8061	8104	928	78
2024	10341	10907	1110	115

Perceptions influencing TB case detection

Improved case detection was most frequently identified as the primary contributor to increased notifications, followed by better diagnostic **tools** and enhanced surveillance. Perceived actual increases in TB incidence were reported at lower levels, while other contributing factors were largely considered negligible.

Table 2. Trends identified

Factor	General Trend	Interpretation

Actual diseases increase	Mostly low-moderate (10-30%)	Some increase in incidence exists but is not the main driver
Improved case detection	High (20-35%)	Strongly seen as a top contributor
Better diagnostic tools	Moderate (10-30%)	Diagnostics significantly improved detection accuracy
Enhanced surveillance	Moderate (10-25%)	Better reporting systems increased notifications
Others factors	Mostly Nill	Minimal contribution perceived

Interventions contributing to improved TB case detection

Shows the weighted ranking of interventions perceived to have contributed most to improved TB case detection. The rollout of GeneXpert diagnostics ranked highest, followed by active case finding and staff training programs. Community awareness initiatives and laboratory capacity expansion were also identified as contributory, though with lower mean scores.

Table 3. Interventions contributing to improved TB case detection

Rank	Intervention	Weighted score	Mean score
1st	GeneXpert rollout	206	3.22
2nd	Active case finding	164	2.56
3rd	Staff training programs	155	2.42
4th	Community awareness	138	2.16
5th	Laboratory capacity expansion	118	1.84

Forecasted TB Prevalence

Forecasting results indicate that TB-only prevalence is highest under baseline conditions and progressively lower under improved detection, improved adherence, and combined intervention scenarios.

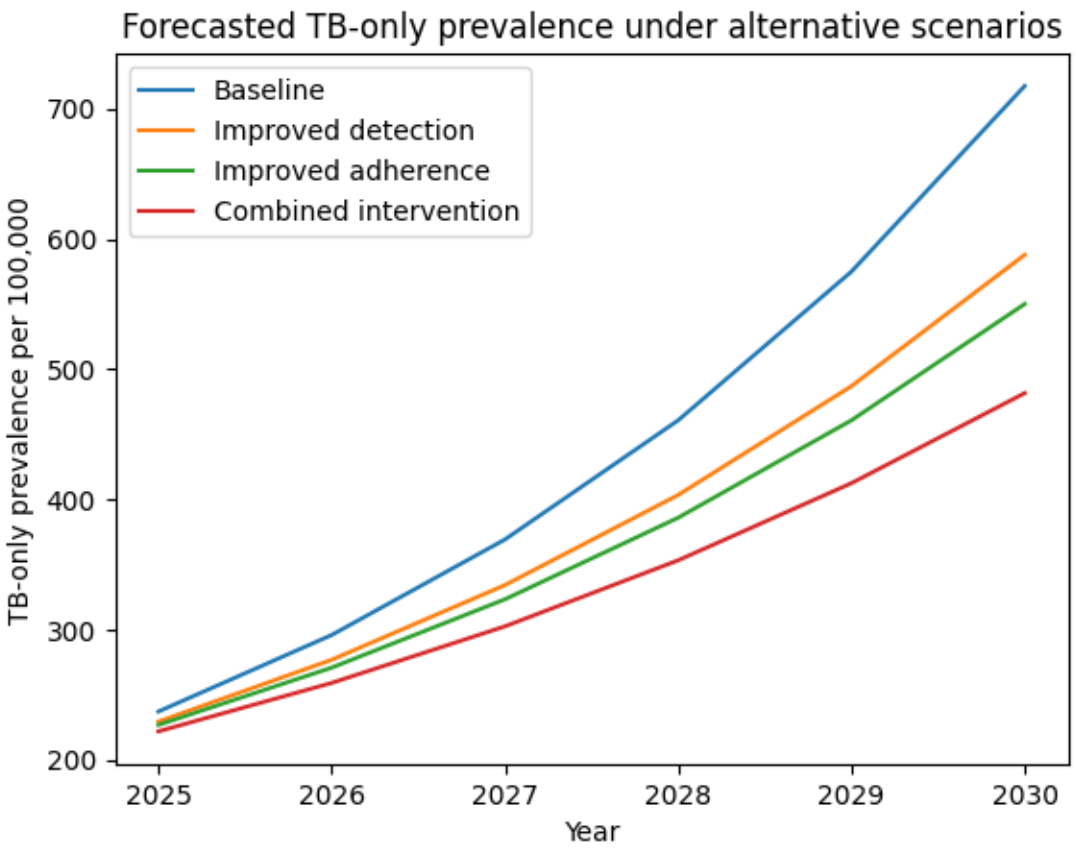

Figure 1: Forecasted TB-only prevalence per 100,000 population

Model Projections of Tuberculosis Prevalence

Using the calibrated and validated model described in Sections 4.8.1–4.8.4, projections of tuberculosis prevalence in Niger State were generated for the period 2025–2030. Projections were conducted for both TB-only infected individuals and TB/HIV co-infected individuals under the baseline (status quo) scenario.

Model simulations indicate a continued burden of TB-only infection over the projection period. Under baseline conditions, TB-only prevalence is projected to follow a gradual trend consistent with historical notification patterns observed during the calibration period. While the model suggests modest changes in TB-only prevalence over time, the overall burden remains substantial throughout the projection horizon.

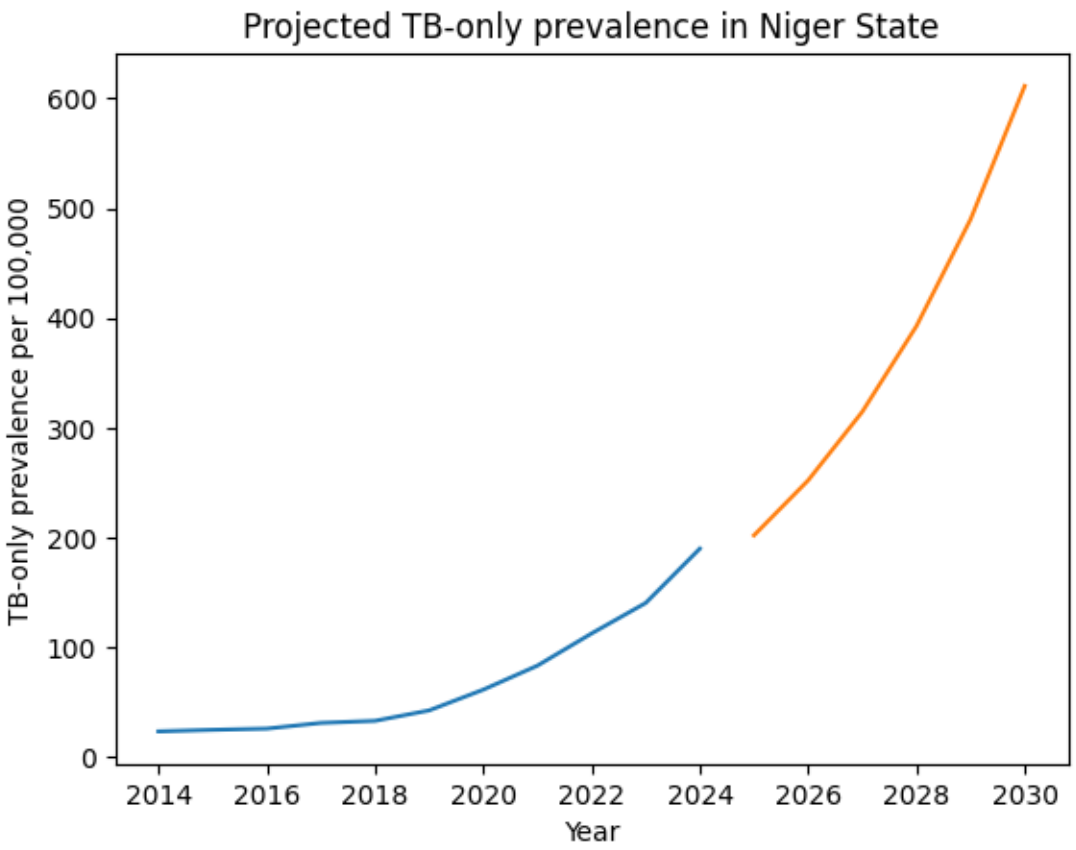

Figure 2: Projected TB-only prevalence in Niger State, 2025–2030

DISCUSSION

Many endemic countries have reported raised TB notifications following the expansion of rapid molecular diagnostics and strengthened case-finding strategies (Otu et al., 2020; Federal Ministry of Health, 2022; Daniel et al., 2025b; Atnazhi et al., 2026a). Our data also exposed a sustained rise in *Mycobacterium tuberculosis* case notifications in the study area. In Nigeria, the scale-up of GeneXpert testing, enhanced screening activities, and strengthened reporting systems has been associated with improved identification of previously undiagnosed TB cases (Federal Ministry of Health, 2022; Abi et al., 2025). Although rising notification trends may initially be interpreted as an increase in disease transmission, evidence from TB control literature suggests that such patterns more commonly reflect improvements in case detection, diagnostic capacity, and surveillance systems rather than a true escalation in incidence (Atnazhi et al., 2026b).

The mathematical modelling and forecasting component of this study provides an analytical extension of the empirical findings, offering insight into the potential future trajectory of tuberculosis (TB) burden in Niger State under baseline and alternative intervention scenarios. Under baseline conditions, the projections indicate a continued increase in TB-only prevalence beyond 2024. This finding is consistent with modelling studies from other high-burden settings, which have shown that improvements in case detection alone are insufficient to rapidly reduce TB prevalence when transmission drivers remain unaddressed (Houben & Dodd, 2016). The projected upward trend therefore reinforces the interpretation that, despite gains in diagnosis and treatment, ongoing community transmission persists in Niger State.

Scenario-based forecasting further demonstrates the potential impact of targeted programme improvements. Reductions in projected TB prevalence under improved case detection and treatment adherence scenarios are

consistent with previous modelling work showing that early diagnosis and high treatment completion rates shorten infectious periods and reduce transmission (Dowdy et al., 2013). The combined intervention scenario produced the most favourable outcomes, supporting the widely accepted principle that multifaceted TB control strategies yield greater epidemiological impact than isolated interventions. Importantly, the modelling approach adopted in this study complements, rather than replaces, empirical surveillance data. As noted by Garnett et al. (2011), mathematical models are most useful when grounded in routine data and used to explore plausible future scenarios rather than to generate precise predictions. In this context, the model provides a structured framework for understanding how current programme performance may shape future TB burden in Niger State.

Overall, the modelling and forecasting results support the conclusion that sustained reductions in TB prevalence will require simultaneous improvements in case detection, treatment adherence, and patient-centred support. These findings align with global modelling evidence and underscore the relevance of mathematical approaches in informing TB control planning at the subnational level. However, a variety of methodological limitations apply. The retrospective design depends on the completeness and accuracy of surveillance data and can be compromised by under-reporting, incomplete information, or changes over time in data collection practices. The retrospective design precludes the possibility of establishing causality between intervention and effect or controlling for unmeasured confounding variables.

The findings for Niger State will not be fully generalizable to other Nigerian states with different epidemiological profiles or other countries with different health system organisation and socio-economic settings.

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