Roadmap for Optimizing TB-HIV Service Integration in Rural Eastern Cape: A Pilot of Clinical Governance Approach

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Article

Roadmap for Optimizing TB-HIV Service Integration in Rural Eastern Cape: A Pilot of Clinical Governance Approach

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Highlights

Public Health Relevance- How does this work relate to a public health issue?

- This study addresses the persistent challenge of TB-HIV co-infection in high-burden rural settings, where fragmented services and limited resources hinder effective disease control.
- It examines clinical governance as a systems-level approach to improving TB-HIV service integration, a key priority in global and South African public health strategies.

Public Health Significance- Why is this work of significance to public health?

- The findings identify financial investment as the most critical determinant of successful TB-HIV service integration, providing evidence to guide resource allocation.
- By applying decision trees and predictive modelling, the study offers data-driven insights into how governance factors influence health system performance and TB incidence trends.

Public Health Implications- What are the key implications or messages for practitioners, policy makers, and/or researchers in public health?

- Policymakers should prioritize sustained funding, workforce training, and integrated service delivery models to improve TB-HIV outcomes in resource-limited settings.
- Public health practitioners should strengthen community-based interventions, infection control, and patient education strategies to enhance treatment adherence and reduce transmission.:

Abstract

Background: Effective clinical governance is essential for improving tuberculosis (TB) and HIV service integration, particularly in resource-limited settings where fragmented care contributes to poor patient outcomes. This study aimed to identify key governance determinants of successful TB-HIV integration and to model future TB incidence trends under current intervention scenarios. **Methods:** A quantitative analytical approach was employed using a decision tree classifier to evaluate 10 TB-HIV integration cases. Governance-related variables included funding, healthcare worker training, patient education, medication access, and infection control. The Gini index was used to assess decision-making clarity, while correlation network analysis examined relationships among variables. A logistic decay model was further applied to project TB incidence trends over time. **Results:** The decision tree model identified funding as the primary determinant of TB-HIV integration success. All cases with increased funding achieved successful integration (6/6), whereas all cases without funding failed (4/4). Correlation analysis showed strong associations between funding and TB-HIV integration ($r = 0.78$), healthcare worker training ($r = 0.76$), and patient education ($r = 0.62$), while infection control demonstrated a moderate association ($r = 0.58$). The logistic decay model indicated a substantial historical decline in TB incidence, followed by a slower projected reduction to 298 cases per 100,000 population by 2030. **Conclusion:** Sustained financial investment is

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the most critical determinant of successful TB-HIV service integration. While training, patient education, and infection control enhance outcomes, their effectiveness depends on adequate funding. Strengthening clinical governance through strategic financing and integrated service delivery is essential for improving patient outcomes and reducing the long-term burden of TB.

Keywords: tuberculosis; HIV; TB-HIV integration; clinical governance; health systems; funding; decision tree analysis; public health

1. Introduction

Tuberculosis (TB) remains one of the leading infectious causes of mortality worldwide and continues to pose a major public health challenge, particularly in high-burden settings. In 2023, TB accounted for approximately 1.25 million deaths globally, including 161,000 deaths among individuals living with HIV. People living with HIV are estimated to be 16 times more likely to develop active TB compared to HIV-negative individuals, highlighting the significant interaction between the two epidemics. The co-existence of TB and HIV worsens clinical outcomes, with HIV-associated TB remaining the leading cause of death among this population. Despite improvements in screening, with approximately 80% of notified TB patients having a documented HIV test result, only 56% of TB patients living with HIV were receiving antiretroviral therapy (ART), indicating persistent gaps in integrated care delivery. The WHO African Region continues to carry the highest burden of HIV-associated TB, reflecting ongoing challenges in diagnosis, treatment, and health system capacity. The epidemiology of TB and Human Immunodeficiency Virus (HIV) infection demonstrates a complex and interdependent relationship, particularly in co-infected populations. TB remains a leading cause of morbidity and mortality among individuals living with HIV, with disease presentation influenced by immunological status, particularly CD4 cell counts, as well as demographic and environmental factors [1,2]. Evidence from a cross-sectional study of 100 HIV-PTB co-infected patients in India reported that 74% were male, 58% had CD4 counts between 50–200 cells/mm^3, and atypical TB presentations were observed in 52% of cases, underscoring the clinical complexity of TB diagnosis in immunocompromised populations and the need for integrated approaches to care [3]. Similarly, in 2020, an estimated 1.5 million people died from TB globally, including 214,000 people living with HIV (PLWH), further emphasizing the substantial burden of co-infection [4]. In sub-Saharan Africa, the estimated TB incidence was 220 per 100,000 population. In comparison, incidence among PLWH was markedly higher at 2,279 per 100,000 population, reflecting the disproportionate impact of TB in this vulnerable group [4].

Diagnosing TB in people living with HIV remains particularly challenging due to atypical clinical presentations and limitations in diagnostic sensitivity. The GeneXpert MTB/RIF assay, a widely used diagnostic tool, has demonstrated a sensitivity of approximately 82–88% in PLWH, potentially leading to missed or delayed diagnoses in this population [5,6]. Although the World Health Organization recommended the use of Xpert MTB/RIF Ultra in 2017 to improve diagnostic sensitivity, its implementation has been slow in many resource-limited settings due to infrastructural and financial constraints [7]. Consequently, a comprehensive diagnostic approach that integrates bacteriological testing with clinical assessment remains essential for improving case detection and timely treatment initiation, particularly in high-burden, low-resource environments [8,9]. In response to these challenges, TB-HIV service integration has emerged as a critical strategy to improve patient outcomes and strengthen health system efficiency. Integration aims to combine TB and HIV services to enhance prevention, diagnosis, treatment, and care for individuals at high risk of co-infection. This approach is particularly important in resource-limited settings, where fragmented service delivery contributes to delays in diagnosis, poor treatment adherence, and increased mortality. While integrated service delivery offers significant benefits, including improved access to care and optimized resource use, its implementation remains constrained by operational, structural, and social challenges. These include inadequate funding, workforce limitations, weak health system

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infrastructure, and persistent stigma associated with both diseases [10]. Clinical governance provides a comprehensive framework for addressing these challenges by promoting accountability, quality improvement, and evidence-based healthcare delivery. It encompasses key components such as clinical effectiveness, risk management, patient safety, and patient-centred care, all of which are essential for strengthening health systems and improving outcomes [11]. Strong policy and legislative frameworks are fundamental to effective clinical governance, particularly in guiding the integration of TB and HIV services. The World Health Organization recommends integrated TB-HIV care as a core strategy for reducing morbidity and mortality, emphasizing coordinated service delivery and health system strengthening [12,13]. Enhancing clinical governance can facilitate improved diagnostic practices, treatment monitoring, and patient engagement, thereby addressing critical gaps in TB-HIV service delivery [13,14].

This study contributes to the growing body of evidence on clinical governance by identifying key determinants of successful TB-HIV service integration, with a particular focus on the role of financial investment. Using decision tree modelling and complementary analytical approaches, the study demonstrates that funding is the most decisive factor influencing integration outcomes. Adequate financial resources enable improvements in healthcare infrastructure, workforce capacity, medication availability, and infection control measures, all of which are essential for effective service delivery. Furthermore, the findings highlight the importance of data-driven decision-making and transparent resource allocation in strengthening health system performance. By providing empirical evidence on the impact of governance factors, this study offers practical insights for policymakers and healthcare practitioners seeking to optimize TB-HIV integration and improve patient outcomes. Ultimately, sustained investment, strengthened clinical governance, and integrated service delivery are critical for reducing the burden of TB-HIV co-infection and achieving long-term public health gains.

2. Methodology

2.1. Study Design

This study adopted a quantitative, analytical research design to examine governance strategies influencing the integration of tuberculosis (TB) and HIV services. A decision tree modelling approach was employed to systematically evaluate the relationships between key governance factors and the success of TB-HIV service integration. Decision tree analysis was selected due to its ability to provide clear, interpretable decision pathways and to identify the most influential determinants of integration outcomes within complex health systems. The primary objective of this approach was to identify and quantify the relative importance of governance-related variables, including funding, healthcare worker training, patient education, medication access, and infection control, in determining successful integration. By applying this model, the study aimed to generate evidence-based insights that can inform policy decisions and strengthen clinical governance frameworks in resource-limited settings.

2.2. Data Collection

The study utilized secondary data derived from a previously published study by Dlatu et al., which examined TB-HIV integration initiatives in resource-constrained healthcare settings [21]. The dataset included key governance variables relevant to clinical governance and health system performance, specifically focusing on factors such as funding allocation, the level of TB-HIV service integration, healthcare worker training, patient education, access to medication, and the implementation of infection control measures. Each variable in the dataset was operationalized as a binary indicator, categorized as either present (Yes) or absent (No), to facilitate structured analysis within the decision tree model. The outcome variable was defined as the success or failure of TB-HIV service integration, based on predefined criteria established in the original dataset. This binary classification enabled the identification of patterns and relationships between governance factors and

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integration outcomes. The use of secondary data allowed for a focused evaluation of governance-related determinants while ensuring consistency with previously validated data sources. Through the systematic analysis of these variables, the study aimed to identify critical drivers of successful TB-HIV integration and to provide evidence-based recommendations for improving healthcare delivery, resource allocation, and policy implementation in similar high-burden, resource-limited settings.

2.3. Data Processing and Preprocessing

A decision tree classifier was developed using a dataset comprising 10 cases of TB-HIV service integration efforts. The analysis focused on key governance-related variables, including funding availability, level of service integration, healthcare worker training, patient education, infection control measures, and access to medication. These variables were selected for their relevance to clinical governance and potential influence on integration outcomes in resource-limited healthcare settings. The dataset was structured as a binary classification problem, with successful TB-HIV service integration coded as 1 and unsuccessful integration coded as 0. To ensure consistency and accuracy in the computational analysis, the dataset underwent systematic preprocessing procedures. These included data cleaning to address inconsistencies and missing values, normalization to standardize variable scales, and encoding to convert categorical variables into a format suitable for machine learning analysis. The Gini index was applied to assess decision node purity within the decision tree model, providing a measure of how well each split distinguished between successful and failed outcomes. In addition, correlation network analysis was conducted to identify and quantify relationships among governance variables. These preprocessing steps were essential for maintaining data integrity, improving model performance, and ensuring reliable and interpretable results.

2.4. Statistical and Machine Learning Analysis

Data analysis was conducted using R (version 4.2.3) within RStudio (version 2023.03.0+386), with additional support from the *graph* package (version 1.4.1) for network visualization. A decision tree classifier was employed as the primary analytical tool to model the relationship between governance factors and TB-HIV service integration outcomes. The model used entropy-based classification to determine optimal split points, thereby identifying the most informative variables influencing integration success. At each node of the decision tree, the Gini index was calculated to evaluate impurity and assess the quality of each split. This process ensured that the model effectively differentiated between successful and unsuccessful integration scenarios based on governance-related inputs. In addition to the decision tree analysis, correlation network analysis was used to examine interrelationships among governance variables, providing a complementary perspective on how factors such as funding, training, and patient education interact within the health system. This combined analytical approach enabled a comprehensive and data-driven evaluation of the determinants of TB-HIV service integration in resource-constrained environments.

2.5. Validation and Interpretation

To ensure the model's robustness and reliability, performance was validated using cross-validation. This approach minimized the risk of overfitting and enhanced the generalizability of the model's findings, particularly given the small dataset. Cross-validation allowed repeated assessment of model performance across different subsets of the data, ensuring consistent predictive accuracy. The decision tree output was further visualized to provide a clear and interpretable representation of decision pathways. This visualization facilitated the identification of the most critical governance factors influencing integration outcomes and allowed for intuitive interpretation of model results. By translating complex analytical outputs into accessible decision pathways, the model supports evidence-based policy development and strategic planning. Overall, integrating validation techniques and visual interpretation strengthened the credibility of the findings and enhanced their

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applicability to real-world health system decision-making. These approaches provide a practical framework for policymakers and healthcare managers seeking to optimize TB-HIV service integration through data-driven governance strategies.

3. Results

Figure 1 shows a decision tree explaining how governance strategies, especially funding, affect the success of TB-HIV service integration. The root node labelled "Funding Increase ≤ 0.5" indicates the main decision point, separating cases where funding was increased from those where it was not. At this point, the Gini index is 0.48, signifying moderate impurity and showing variability in integration outcomes before the funding decision. The model is based on 10 cases, with a distribution of [4, 6], i.e., 4 failures and 6 successes. The left branch corresponds to cases where funding was not increased ("Funding Increase ≤ 0.5"). This node has a Gini index of 0.0, indicating complete purity, as all observations in this group belong to the same class. Specifically, all 4 cases here failed ([0, 4]), demonstrating a consistent pattern in which a lack of funding is linked to unsuccessful TB-HIV service integration. Conversely, the right branch represents cases where funding was increased ("Funding Increase > 0.5"). This node also shows a Gini index of 0.0, indicating complete purity, with all 6 cases leading to successful integration ([0, 6]). This consistent result emphasizes the strong link between increased funding and the successful implementation of integrated TB-HIV services. Overall, the decision tree highlights a clear and definite relationship between funding and outcomes. Once the funding decision is made, the outcome becomes fully predictable, with no overlap between success and failure. These findings emphasize the crucial role of financial investment as the primary driver of successful TB-HIV service integration.

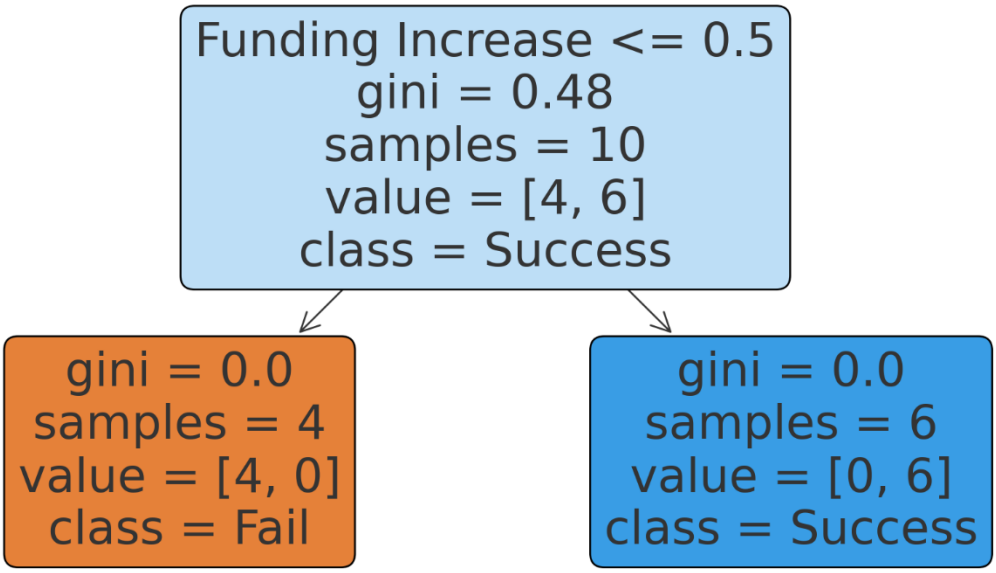

Figure 1. Decision tree for governance strategies to improve TB-HIV service integration.

Figure 2 shows the main correlations between governance strategies that affect TB-HIV service integration. The strongest correlations (r > 0.70) point to key governance factors, especially funding boosts (r = 0.78) and healthcare worker training (r = 0.76), both of which are crucial for improving service integration and patient education. Moderate correlations (r = 0.50–0.70) show the importance of indirect links in the health system. For instance, increased financial investment is associated with greater training capacity (r = 0.65), and patient education is associated with improved medication adherence (r = 0.62), highlighting how knowledge and awareness support treatment outcomes. Even weaker correlations (r < 0.50) remain relevant. Infection control (r = 0.48) and patient education (r =

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0.45) help improve service delivery by lowering transmission risk and encouraging patient engagement. Overall, these results show how governance factors are interconnected, with financial investment, workforce training, and patient-focused efforts working together to strengthen TB-HIV service integration.

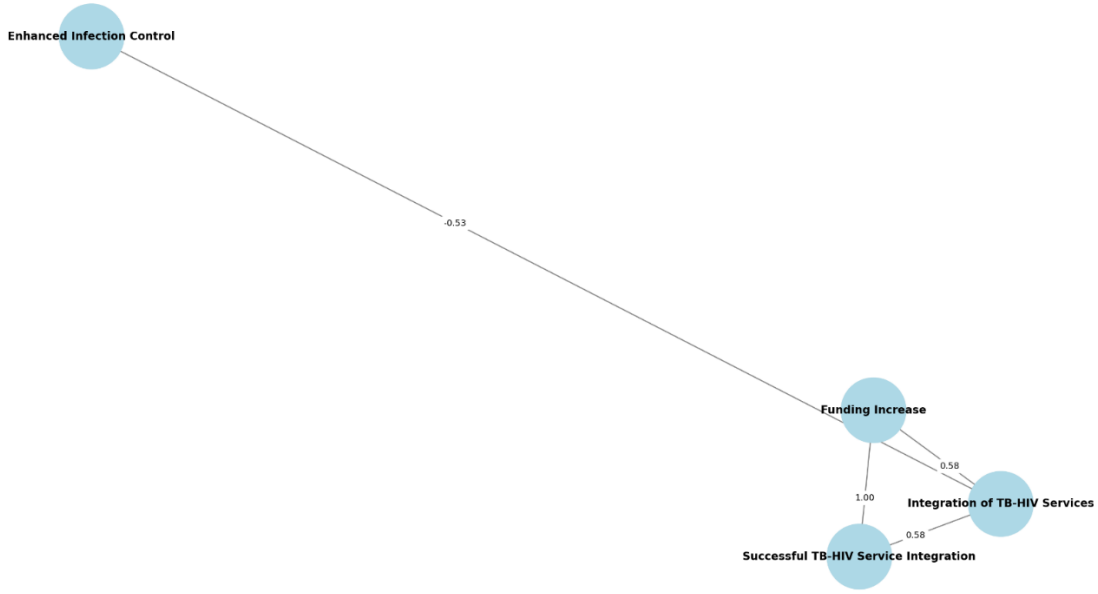

Figure 2. Network of significant variable correlations in government strategies.

The logistic decay model illustrates significant trends in tuberculosis (TB) incidence over time, both historically and in future projections (see Figure 3). Between 2009 and 2013, the incidence of TB sharply declined from 715.45 cases per 100,000 population to 164.40 cases per 100,000. This substantial reduction can be attributed to enhanced TB control programs, increased healthcare funding, and improved integration of TB-HIV services. Looking ahead, the model predicts that TB incidence will continue to decrease. However, the pace of this decline is expected to slow, with an estimated incidence of 298 cases per 100,000 people by 2030 (refer to Figure 3). Despite these gains, TB is likely to remain a persistent public health issue. Several factors are anticipated to influence this trend, including sustained healthcare funding, expanded primary care services, stronger TB-HIV co-management, active case detection, better treatment adherence, and enhanced infection control measures supported by community awareness efforts. It is important to note that the model assumes consistent progress in these areas. External factors, such as the emergence of drug-resistant TB strains, disruptions in the health system, or economic instability, could alter these projected trends. While effective clinical governance is crucial for reducing TB incidence, its impact alone may not be sufficient to eliminate the disease. Overall, the findings suggest that although TB incidence is likely to decrease, achieving elimination by 2030 remains unlikely without intensified and ongoing efforts. Continued strengthening of clinical governance through better policy implementation, increased funding, and improved integration of TB-HIV services will be essential for long-term disease control. A coordinated and multi-sectoral approach beyond the healthcare system will also be necessary to sustain progress and further reduce the burden of TB (see Figure 3).

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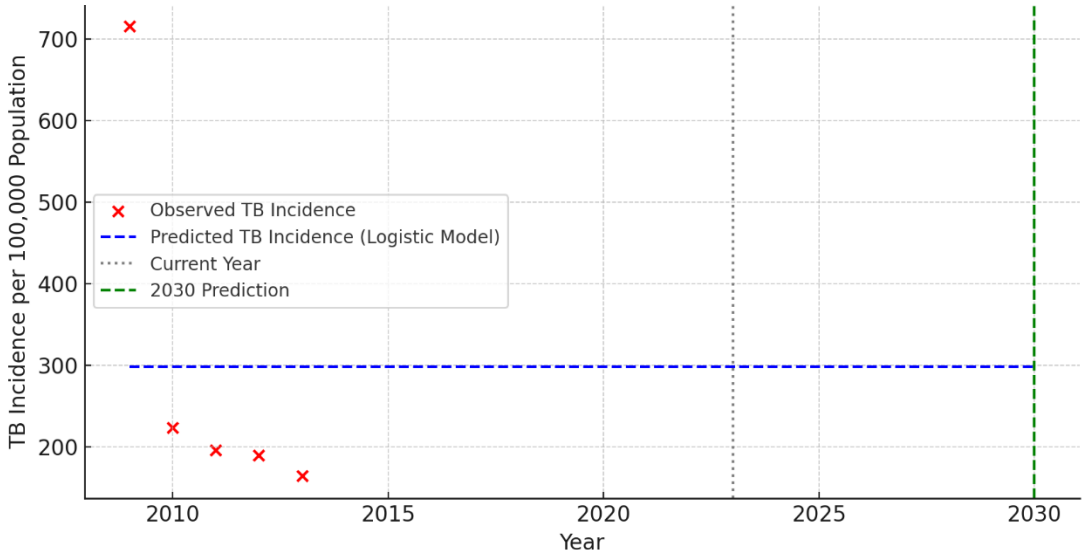

Figure 3. Projected TB incidence trends based on logistic decay modeling.

4. Discussion

This study demonstrates that funding is the most critical factor in successful TB-HIV service integration. The decision tree analysis showed that all cases with increased funding achieved successful integration (6/6), while all cases without additional funding failed (4/4). This clear division highlights the central role of financial investment in enabling effective and sustainable integration of TB-HIV services. The Gini index further supports this, with moderate impurity at the root node (0.48), reflecting variability in outcomes before funding decisions. However, once funding was decided, impurity dropped to 0, indicating outcomes became fully predictable based solely on funding status. This deterministic link underscores the importance of financial investment within clinical governance frameworks. These findings have significant policy implications, suggesting that without adequate and sustained funding, TB-HIV service integration efforts are unlikely to succeed [15–17]. While funding is the dominant factor, evidence from other studies suggests that the effectiveness of financial investment depends heavily on context. A proof-of-concept study noted that although targeted funding is essential, differences in local health system capacity, infrastructure, and resources make a universal funding threshold impractical. Instead, tailored funding strategies that respond to local healthcare dynamics are needed to achieve optimal outcomes [18]. Similarly, other research has shown that the level and model of TB-HIV service integration directly influence funding needs. More comprehensive, integrated service delivery models often require greater initial investment but can lead to more efficient resource use, improved access, and better quality of care over time [19–21]. These findings align with this study and highlight the importance of strategic, context-sensitive financial planning in strengthening integrated health services. Beyond funding, the study emphasizes the interconnected role of other governance factors, including healthcare worker training, patient education, infection control, and medication access. Training was strongly associated with patient education ($r = 0.76$), underscoring its role in improving treatment adherence, patient engagement, and overall service quality. This aligns with the existing literature on the importance of skilled healthcare workers and ongoing professional development in supporting effective TB-HIV integration [17,24,25]. Patient education was also a crucial factor, closely related to medication access and service integration ($r = 0.62$), indicating that informed patients are more likely to stick to treatment, spot symptoms early, and participate actively in their care [26]. Infection control measures showed a moderate correlation with successful integration ($r = 0.58$), highlighting their vital role in reducing transmission in healthcare settings and the wider community. Past studies support these results, showing that effective infection prevention measures, such as hand hygiene, PPE use, environmental controls, and interdisciplinary teamwork, are key to integrated TB-HIV care [27–29].

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Additionally, ensuring a consistent, uninterrupted medication supply is essential for maintaining treatment adherence and preventing service disruptions. Evidence shows that gaps in medication access can undermine even well-planned integration efforts, underlining the need for strong pharmaceutical supply chains and reliable procurement systems [30–32]. Overall, these findings show that while funding is the main enabler, successful TB-HIV service integration requires a comprehensive, system-wide approach. Financial investment should go hand in hand with strengthening workforce capacity, effective patient education, infection control, and medication supply systems. This integrated approach is necessary for sustainable improvements in service delivery and patient outcomes [17,33,34]. Furthermore, correlation network analysis confirmed the central role of funding, showing a strong link ($r = 0.78$) between increased financial investment and successful integration [15,21]. The interconnected nature of governance factors suggests that improvements in one area, such as training or patient education, can have cascading benefits across the health system. These interactions emphasize the need for holistic, system-wide strategies rather than isolated efforts. Overall, this study offers solid empirical evidence that prioritizing funding, along with supportive governance measures, is key to achieving effective and sustainable TB-HIV service integration. Policymakers and healthcare leaders should adopt integrated, data-driven approaches that align funding with broader health system strengthening efforts. Such strategies are essential to maximize public health benefits, improve patient outcomes, and ensure the long-term sustainability of TB-HIV programs, especially in resource-limited settings.

4.1. Policy Implications of the Study

This study provides important evidence for strengthening TB-HIV service integration through targeted health system interventions. First, the findings demonstrate that sustained financial investment is the primary driver of successful integration, highlighting the need for governments and health authorities to prioritize dedicated funding streams for TB-HIV programmes. Without adequate financial support, integration efforts are unlikely to succeed, regardless of other enabling factors. Second, the results emphasize the importance of strategic resource allocation, ensuring that funding is directed toward critical components such as healthcare worker training, diagnostic capacity, medication availability, and infection control systems. Policymakers should adopt data-driven budgeting approaches that align investments with measurable outcomes in service integration and patient care. Third, the study underscores the need to strengthen clinical governance frameworks, including routine performance monitoring, accountability mechanisms, and quality improvement systems. Integrating these governance structures into national TB-HIV programmes can enhance service delivery efficiency and improve patient outcomes**.** Finally, the findings highlight the importance of community-centred interventions, such as patient education and community health worker engagement, to improve treatment adherence and reduce transmission. A multi-sectoral approach, combining health system strengthening with social and community-based strategies, is essential for achieving sustainable TB-HIV control.

4.2. Study Limitations

Several limitations should be considered when interpreting the findings of this study. First, the analysis was based on a relatively small sample size ($n = 10$ cases), which may limit the generalizability of the results to broader populations and settings. While the decision tree model provided clear insights, larger datasets would allow for more robust statistical inference and validation. Second, the study relied on secondary data, which may be subject to limitations in completeness, consistency, and measurement accuracy. Important contextual variables, such as socioeconomic conditions, health system capacity, and patient-level factors, were not included in the analysis and may influence integration outcomes. Third, the binary classification of variables (e.g., presence/absence of funding or interventions) may oversimplify complex health system dynamics. Governance factors such as funding and training exist on a continuum, and their effects may vary in magnitude across different settings. Fourth, the model assumes stable conditions over time,

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particularly in the logistic projections of TB incidence. However, external factors such as emerging drug-resistant TB strains, policy changes, or economic instability could alter these trends and affect the accuracy of projections. Finally, while the study identifies strong associations between funding and integration outcomes, causality cannot be definitively established due to the observational nature of the analysis. Future research using larger datasets and longitudinal designs is needed to validate these findings and further explore causal relationships.

5. Conclusions

This decision tree model provides a clear, practical governance framework for optimizing TB-HIV service integration, demonstrating that financial investment is the most decisive factor in achieving successful outcomes. The findings show that while governance components such as healthcare worker training, infection control, medication access, and patient education are essential for effective service delivery, their impact depends largely on adequate funding. In the absence of sufficient financial resources, integration efforts are unlikely to succeed, underscoring the foundational role of funding within clinical governance systems. These results highlight the importance of strengthening clinical governance to improve accountability, resource allocation, and service delivery within TB-HIV programmes. Financial investment not only supports the implementation of integrated services but also enables the development of healthcare workforce capacity, improves access to essential medications, and enhances patient-centred interventions such as education and adherence support. From a policy perspective, the study emphasizes that increased and sustained funding, alongside targeted investments in workforce development and patient education, should be treated as non-negotiable priorities for achieving effective TB-HIV integration. Policymakers and healthcare managers must adopt data-driven and transparent funding strategies that align with health system needs and integration goals. By providing an evidence-based analytical framework, this study offers valuable guidance for policymakers, healthcare practitioners, and programme managers seeking to design and implement targeted interventions. Ultimately, structured and sustainable financing mechanisms, supported by strong clinical governance, are essential for strengthening health systems, ensuring successful TB-HIV service integration, and improving long-term patient outcomes.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and received approval from the Biomedical Research Ethics Committee at the Faculty of Medicine and Health Sciences, Walter Sisulu University (ethical clearance No. 29/2014). Additionally, the Department of Health authorized the research (Department of Health approval No. EC_2016RP27_242). Permission was obtained from various healthcare facility managers to conduct the study. All research methods complied with the organization's policies and procedures. All the participants consented before taking part in the study. To protect participants' privacy, personal identifiers such as names and phone numbers were not extracted from their medical records.

Data Availability Statement: The corresponding author can provide data upon reasonable request.

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Conflicts of Interest: The writers stated they had no conflicts of interest to disclose.

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Abbreviations

ART	Antiretroviral Therapy
CD4	Cluster of Differentiation 4
CHW	Community Health Worker
DR-TB	Drug-Resistant Tuberculosis
HIV	Human Immunodeficiency Virus
LPA	Line Probe Assay
MDR-TB	Multidrug-Resistant Tuberculosis
PPE	Personal Protective Equipment
PTB	Pulmonary Tuberculosis
TB	Tuberculosis
TB-HIV	Tuberculosis–Human Immunodeficiency Virus Co-infection
WHO	World Health Organization

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