Effectiveness Digital Mapping on Tuberculosis Treatment Outcomes: A Retrospective Comparative Study

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ABSTRACT:

Nabire Regency in Central Papua has a high tuberculosis (TB) burden with severe geographical challenges and high HIV prevalence. Digital mapping innovation using the Appsheet platform was expected to improve patient tracing, treatment monitoring, and ultimately treatment outcomes. This study aimed to evaluate the effectiveness of digital mapping on TB treatment outcomes. A retrospective comparative study was conducted. The sample comprised 711 respondents (387 in the digital mapping intervention group and 324 in the non-digital control group) from 16 puskesmas (8 intervention, 8 control). Analysis included univariate, bivariate (Chi-Square), and multivariate logistic regression (controlling for age and distance) with $\alpha = 0.05$. The intervention group had significantly better treatment success (79.6% vs. 70.4%; $p = 0.004$), far fewer patients lost to follow-up (0.8% vs. 13.0%; $p < 0.001$), and lower mortality (1.3% vs. 4.3%; $p = 0.013$). Multivariate analysis confirmed digital mapping as a significant factor for treatment success after controlling for age and distance (AOR = 1.760; 95% CI: 1.238–2.501; $p = 0.002$). Home distance ≥1 km was a significant risk factor for treatment failure (AOR = 0.656; 95% CI: 0.494–0.872; $p = 0.004$). HIV co-infection prevalence was high (14.2% overall). The study found that digital mapping effectively improves treatment success, reduces loss to follow-up, and reduces mortality among TB patients. Expansion of digital mapping implementation and stronger TB-HIV service integration are recommended..

Keywords: digital mapping, treatment outcomes, tuberculosis.

1. Introduction

Tuberculosis (TB) is still a major public health problem worldwide, especially in developing countries. It is caused by Mycobacterium tuberculosis and spreads through droplet infection (World Health Organization, 2017). More than 10 million new TB cases and 1.4 million deaths were recorded in 2020 (Setyaningrum et al., 2023). The highest burden is in Africa, Asia, and the Pacific, with India, the Philippines, and Indonesia among the most

affected (Aryantiningsih et al., 2020; Suganathan Soundararajan et al., 2023; Ugwu et al., 2020). Social and economic development, along with risk factors such as malnutrition, diabetes, HIV, alcohol use, and smoking, significantly influence TB prevalence (Muljo et al., 2022; Woldesemayat, 2021). In Indonesia, geographical diversity across islands complicates drug distribution and health service delivery (Alene et al., 2021; Setyaningrum et al., 2023). Undetected TB cases persist due to limited diagnostic technology and healthcare access in low- and middle-income countries (Lee et al., 2023). Despite national strategies, many regions, including Papua Tengah, face challenges such as high dropout rates and low treatment success (Charles, 2024). Digital mapping, integrating demographic and geographic data, offers a strategic solution to improve TB control by identifying high-risk areas and enhancing patient monitoring (Yuniarti et al., 2020). This study focuses on developing digital mapping to improve TB control outcomes in Nabire Regency, Central Papua Province.

Indonesia has the second-highest TB burden globally, with archipelago geography significantly affecting TB control programs (Ritonga et al., 2023). Access to healthcare is limited in remote and isolated areas, while urban overpopulation burdens existing facilities (Abdul Jalil & Abdul Rasam, 2021; Byonanebye et al., 2021). In Central Papua Province, despite new case detection reaching 91% (above national target), treatment success is only 73% compared to the 85% target (BPS, 2023). High dropout rates, relapse, drug resistance, and mortality persist (Sukatemin, 2022). Research highlighted that population density and limited health facility access increase MDR-TB risk (Bekele et al., 2023; Setyawan et al., 2023). It was found that diagnostic methods and geographic conditions affect TB prevalence (Yuniarti et al., 2020). Therefore, TB control in eastern Indonesia needs an approach that integrates both geographic and demographic data.

Previous policies from WHO and Indonesia's Ministry of Health rely on aggregate data without dynamically integrating demographic and geographic dimensions into a single analytical platform (Maja & Maposa, 2022; World Health Organization, 2017). Theories of demography and geography remain separately applied, creating a gap in complex regions like Nabire (Budi Satria, 2023; Nur'aini et al., 2021). Existing studies have not developed or tested a digital mapping system that combines hotspot mapping, accessibility analysis, and real-time dashboards to evaluate TB treatment outcomes. This study fills that gap by developing and empirically testing an Appsheet-based digital mapping intervention to improve cure rates and reduce dropout, relapse, drug resistance, and mortality.

The objective of this study is to evaluate the effectiveness of Appsheet-based digital mapping on TB treatment outcomes in Nabire Regency, Papua, Indonesia. Specific objectives are to analyze the effect of digital mapping on increasing cure rates, reducing dropout, relapse, drug resistance, and mortality. The implications are both theoretical—enriching scientific literature on integrated interventions—and practical—providing evidence-based policy recommendations for targeted resource allocation, improved healthcare access, and enhanced community engagement in TB control programs.

2. Methodology

Design

This study compared two groups: eight puskesmas with digital mapping and eight without. Data was collected retrospectively from January to February 2026 to analyze the relationships between variables.

Participants/Sample

The population included high-risk individuals for TB based on demographic characteristics (age, sex, education, employment, socio-economic status) and geographic characteristics (residence location, environmental conditions, healthcare accessibility, topography, infrastructure). The sample consisted of: (1)

individuals diagnosed with pulmonary TB via smear microscopy, chest X-ray, or GeneXpert; (2) patients undergoing intensive or continuation TB treatment; (3) program monitoring data including treatment success, dropout, relapse, drug resistance, and mortality; (4) individuals reflecting demographic variation; (5) residents (migrant or permanent) in Nabire Regency undergoing TB treatment; and (6) all patients in eight intervention puskesmas using the digital mapping application. Sampling used stratified purposive sampling, selecting 16 puskesmas (8 intervention, 8 control) based on representativeness of TB control in Nabire Regency's health department.

Instruments

Instruments included: (1) medical records and SITB (Tuberculosis Information System) reports for treatment program evaluation; (2) Appsheet-based digital mapping application with GPS and Google Maps to collect patient coordinates, produce hotspot maps, and analyze accessibility; (3) structured questionnaire Part A for demographic characteristics (age, sex, education, employment, income, migration status); (4) questionnaire Part B and field observation with GPS for geographic characteristics (distance, travel time, vehicle type, road conditions); (5) questionnaire Part D for the intervention group only, evaluating digital mapping feature utilization (coordinate collection, home visits, appointment reminders, perceived benefits).

Procedure

Data were collected from January to February 2026 across 16 puskesmas in Nabire Regency. For the intervention group, trained health workers used the digital mapping application to record patient coordinates, demographic data, and geographic barriers during initial visits and monthly follow-ups. The application provided real-time dashboard updates on patient progress. For the control group, routine personal data collection during patient visits was used. All data were entered into SITB. Outcome data (cured, dropout, relapse, drug resistance, death) were extracted from medical records and SITB at the end of treatment (December 2025 for patients enrolled January–June 2025). Questionnaire data were collected through structured interviews.

Data Analysis

Data were processed using SPSS and geographic information system software. Descriptive statistics summarized demographic and geographic characteristics. Bivariate analysis using the chi-square test compared categorical outcomes (cure, dropout, relapse, resistance, death) between intervention and control groups. Multivariate logistic regression identified independent predictors of treatment success while controlling for confounders. Spatial analysis included hotspot mapping to identify case clusters and accessibility analysis to quantify geographic barriers. All statistical tests used $\alpha = 0.05$. Results were presented as odds ratios with 95% confidence intervals and p-values.

Ethical Considerations

This study obtained ethical approval from the Health Research Ethics Committee of Universitas Strada Indonesia Kediri, Number: 0423403/EC/KEPK/I/03/2026. Permissions were sought from the Nabire Regency Health Department and all participating puskesmas. All patients were provided written informed consent after receiving an explanation of the study's purpose, procedures, risks, and benefits. Confidentiality of patient data was guaranteed; data were anonymized using unique codes. Participation was voluntary, and patients could withdraw at any time without affecting their treatment. The study follows the Declaration of Helsinki. Digital mapping data were stored on password-protected servers accessible only to the research team.

3. Results

Univariate Analysis

A total of 711 subjects were included in the analysis, consisting of 387 subjects in the digital mapping intervention group and 324 subjects in the non-digital mapping control group. Table 5.1 presents the distribution of demographic and clinical characteristics.

Table 1: Distribution of Subject Characteristics by Mapping Status (N=711)

Characteristic	Category	Digital Mapping (n=387)	Non-Digital Mapping (n=324)	Total (N=711)
Age	≤ 14 years	78 (20.2%)	69 (21.3%)	147 (20.7%)
	15–24 years	111 (28.7%)	90 (27.8%)	201 (28.3%)
	25–44 years	132 (34.1%)	103 (31.8%)	235 (33.1%)
	45–64 years	53 (13.7%)	50 (15.4%)	103 (14.5%)
	≥ 65 years	13 (3.4%)	12 (3.7%)	25 (3.5%)
Sex	Male	196 (50.6%)	164 (50.6%)	360 (50.6%)
	Female	191 (49.4%)	160 (49.4%)	351 (49.4%)
Education	Low	149 (38.5%)	96 (29.6%)	245 (34.5%)
	Secondary	208 (53.7%)	209 (64.5%)	417 (58.6%)
	High	30 (7.8%)	19 (5.9%)	49 (6.9%)
Employment	Employed	204 (52.7%)	233 (71.9%)	437 (61.5%)
	Unemployed	183 (47.3%)	91 (28.1%)	274 (38.5%)
Socioeconomic Status	Low	246 (63.6%)	242 (74.7%)	488 (68.6%)
	Middle	76 (19.6%)	34 (10.5%)	110 (15.5%)
	High	65 (16.8%)	48 (14.8%)	113 (15.9%)
Residency Status	Outside area	84 (21.7%)	32 (9.9%)	116 (16.3%)
	Within area	303 (78.3%)	292 (90.1%)	595 (83.7%)
Distance to Facility	< 1 km	161 (41.6%)	105 (32.4%)	266 (37.4%)
	1–5 km	108 (27.9%)	172 (53.1%)	280 (39.4%)
	> 5 km	118 (30.5%)	47 (14.5%)	165 (23.2%)
Coordinate Availability	Available	383 (99.0%)	0 (0.0%)	383 (53.9%)
	Not available	4 (1.0%)	324 (100.0%)	328 (46.1%)

Characteristic	Category	Digital Mapping (n=387)	Non-Digital Mapping (n=324)	Total (N=711)
Diabetes Mellitus	DM	2 (0.5%)	2 (0.6%)	4 (0.6%)
	Non-DM	385 (99.5%)	322 (99.4%)	707 (99.4%)
HIV Status	HIV-positive	83 (21.4%)	18 (5.6%)	101 (14.2%)
	HIV-negative	304 (78.6%)	306 (94.4%)	610 5.8%)

Most participants were aged 25–44 years (33.1%) or 15–24 years (28.3%). The proportion of men and women was almost equal (50.6% vs. 49.4%). More than half of subjects had secondary education (58.6%). The majority of subjects were employed (61.5%) and had low socioeconomic status (68.6%). Most subjects resided within the local area (83.7%). In the digital mapping group, the proportion of subjects living less than 1 km from a health facility (41.6%) was higher compared to the non-digital group, which was dominated by distances of 1–5 km (53.1%). All subjects in the non-digital mapping group had no coordinate points available (100%), while almost all subjects in the digital mapping group had coordinate points available (99.0%). Diabetes mellitus history was very low overall (0.6%). Notably, the proportion of HIV-positive subjects was higher in the digital mapping group (21.4%) compared to the non-digital group (5.6%). The two groups differed in distance distribution and HIV status, so multivariate analysis were used to control for these imbalances.

Bivariate Analysis

Bivariate analysis was conducted using Pearson Chi-Square tests to assess the association between mapping status (digital vs. non-digital) and treatment outcomes, including treatment success, dropout, and mortality.

Treatment Success

Table 2: Association Between Mapping Status and Treatment Success (N=711)

Mapping Status	Treatment Success (n=536)	Treatment Failure (n=175)	Total	p-value
Digital Mapping	308 (57.5%)	79 (45.1%)	387	
Non-Digital Mapping	228 (42.5%)	96 (54.9%)	324	
Total	536 (100%)	175 (100%)	711	0.004

Note: *^a^ p-value based on Pearson Chi-Square test. OR = 1.642 (95% CI: 1.164–2.314) from bivariate logistic regression.*

Of the 387 subjects receiving digital mapping, 308 (79.6%) achieved treatment success. In the non-digital mapping group, the treatment success rate was 70.4% (228 of 324 subjects).

The Pearson Chi-Square test showed a significant association between mapping status and treatment success (p = 0.004). The Odds Ratio (OR) was 1.642 (95% CI: 1.164–2.314), indicating that subjects in the digital mapping group had 1.6 times higher odds of achieving treatment success compared to the non-digital mapping group.

Dropout

Table 3: Association Between Mapping Status and Dropout (N=711)

Mapping Status	Dropout (n=45)	No Dropout (n=666)	Total	p-value
Digital Mapping	3 (6.7%)	384 (57.7%)	387	
Non-Digital Mapping	42 (93.3%)	282 (42.3%)	324	
Total	45 (100%)	666 (100%)	711	<0.001

Note: *^a^ p-value based on Pearson Chi-Square test. OR = 0.052 (95% CI: 0.016–0.171) indicates a very strong protective effect.*

Dropout events were much higher in the non-digital mapping group. Of 45 total dropout cases, 42 cases (93.3%) occurred in non-digital mapping subjects, while only 3 cases (6.7%) occurred in the digital mapping group. The dropout proportion in the non-digital mapping group was 13.0% (42 of 324), compared to only 0.8% (3 of 387) in the digital mapping group. The Chi-Square test confirmed a highly significant association between mapping status and dropout (p < 0.001). The Mantel-Haenszel Common Odds Ratio was 0.052 (95% CI: 0.016–0.171), meaning that digital mapping subjects had 0.052 times the risk of dropout compared to non-digital subjects, indicating that digital mapping was a very strong protective factor against dropout.

Mortality

Table 4: Association Between Mapping Status and Mortality (N=711)

Mapping Status	Death (n=19)	Alive (n=692)	Total	p-value
Digital Mapping	5 (26.3%)	382 (55.2%)	387	
Non-Digital Mapping	14 (73.7%)	310 (44.8%)	324	
Total	19 (100%)	692 (100%)	711	0.013

^a^ p-value based on Pearson Chi-Square test. OR = 0.290 (95% CI: 0.103–0.813).

The proportion of deaths in the non-digital mapping group (4.3% or 14 of 324) was higher compared to the digital mapping group (1.3% or 5 of 387). The Pearson Chi-Square test showed a statistically significant association between mapping status and mortality (p = 0.013). The Mantel-Haenszel Common Odds Ratio was 0.290 (95% CI: 0.103–0.813), indicating that subjects in the digital mapping group had a lower risk of death, approximately 0.29 times the risk of the non-digital mapping group.

Multivariate Analysis

Multivariate logistic regression was performed to identify factors most influencing treatment success after controlling for confounding variables. The model included mapping status (digital vs. non-digital), age, and distance to health facility.

Table 5. Factors Associated with Treatment Success (Logistic Regression Analysis)

Variable	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
							Lower	Upper
Mapping Status (Digital Mapping)	0.565	0.179	9.933	1	0.002	1.760	1.238	2.501
Age	-0.044	0.082	0.288	1	0.592	0.957	0.814	1.124
Distance (≥1 km vs. <1 km)	-0.421	0.145	8.426	1	0.004	0.656	0.494	0.872
Constant	-2.873	0.445	41.741	1	<0.001	0.057		

Note: Distance variable was recoded into binary with "<1 km" as the reference category. Exp(B) < 1 indicates a protective effect (decreasing odds of success) in the distance category.

After controlling for age and distance, mapping status remained a significant factor for treatment success ($p = 0.002$). Subjects receiving digital mapping had 1.760 times higher odds of achieving treatment success compared to subjects receiving non-digital mapping, after accounting for age and distance. Distance to health facility was also statistically significant ($p = 0.004$), with Exp(B) = 0.656. This indicates that living ≥1 km from a health facility was associated with lower odds of treatment success compared to living <1 km. Age was not significantly associated with treatment success in the model ($p = 0.592$). The overall model was significant, with Omnibus Tests of Model Coefficients showing $\chi^2 = 28.817$ ($p < 0.001$). The low R-square value (0.059) suggests that other factors not included in the model—such as medication adherence, family support, or side effects—also play an important role.

4. Discussion

In this region with difficult geography and high HIV prevalence, digital mapping was associated with better treatment success, far fewer dropouts, and lower death rates compared to conventional methods. These results align with Geographic Information Systems (GIS) theory, which states that integrating spatial data into health service delivery enables precise identification of high-risk areas and reduces geographic access barriers (Jones, 2024). In this study, the availability of coordinate points in 99.0% of the intervention group versus 0% in the control group allowed targeted home visits and emergency referrals, directly reducing

dropout from 13.0% to 0.8%. Furthermore, the finding that living ≥1 km from a health facility was a significant risk factor for treatment failure (AOR = 0.656) aligns with geographic accessibility principles, confirming that distance remains a fundamental determinant of healthcare outcomes in remote regions like Central Papua (Alene et al., 2020; Khaliq et al., 2023).

The multivariate analysis showed that digital mapping remained a significant predictor of treatment success after controlling for age and distance (AOR = 1.760; 95% CI: 1.238–2.501; p = 0.002). This finding aligns with recent studies demonstrating the effectiveness of digital health interventions in TB programs. Byonanebye et al. (2021) found that mobile phone-based interventions improved treatment outcomes in Uganda (Byonanebye et al., 2021). Similarly, Jasmine (2025) reported that digital technologies enhance TB treatment adherence through improved monitoring and patient engagement (Jasmine, 2025). The higher success rate in the digital mapping group (79.6% vs. 70.4%) is important in practice, especially since the non-digital group's rate (70.4%) falls far below the national target of 90% (Gabriel & Juliana, 2021).

The strongest finding was the protective effect of digital mapping against dropout (OR = 0.052; 95% CI: 0.016--0.171; p < 0.001). The dropout rate in the digital mapping group was only 0.8% compared to 13.0% in the non-digital group. This finding is consistent with research by Baruch Baluku et al. (2023), who found that geographic distance to TB treatment facilities was significantly associated with loss to follow-up in Africa (Baruch Baluku et al., 2023). Digital mapping likely reduces dropout through several mechanisms: (1) identification of patients in remote locations enabling efficient home visits; (2) availability of coordinate points (99.0% in the intervention group) facilitating emergency referral systems; and (3) targeted allocation of medication supervisors (PMO).

Digital mapping also demonstrated a protective effect against mortality (OR = 0.290; 95% CI: 0.103–0.813; p = 0.013), with mortality rates of 1.3% in the intervention group versus 4.3% in the control group. This finding is consistent with Pham et al. (2022), who reported high TB-HIV mortality rates in Papua New Guinea and emphasized the need for integrated, location-based approaches (Pham et al., 2022). The mortality reduction may be attributed to earlier detection of complications and faster access to emergency services enabled by patient location mapping.

The multivariate analysis confirmed that living ≥1 km from a health facility was a significant risk factor for treatment failure (AOR = 0.656; 95% CI: 0.494–0.872; p = 0.004). This finding aligns with Alene et al. (2020), who demonstrated that geographic accessibility significantly influences TB treatment outcomes in Ethiopia (Alene et al., 2020), and with Khaliq et al. (2023), who mapped TB spatial distribution in Pakistan and identified distance as a key barrier (Khaliq et al., 2023). Similarly, Scott et al. (2023) integrated molecular diagnostics with GIS mapping in South Africa and found that geographic barriers delayed diagnosis and treatment (Scott et al., 2023).

This study found a high HIV-TB co-infection rate of 14.2% overall, with 21.4% in the digital mapping group compared to 5.6% in the non-digital group. This is consistent with the HIV situation in Papua, where adult HIV prevalence exceeds 2%—much higher than the national average of 0.4%. (Setyaningrum et al., 2023). Puspita et al. (2021) documented spatial variation of TB risk in Indonesia, identifying Papua as a high-risk region requiring targeted interventions (Puspita et al., 2021).

This study has several limitations. First, the non-randomized design may introduce selection bias, as evidenced by baseline imbalances in HIV status and distance distribution between groups. Second, the small sample size of elderly subjects (n=25, 3.5%) limited statistical power for subgroup analysis (Sharma et al., 2019). Third, the low Nagelkerke R Square (0.059) indicates that other unmeasured factors (e.g., family support, medication adherence, nutritional

status) influence treatment outcomes (Burke et al., 2021; Zou et al., 2024).

Despite these limitations, this study provides strong evidence that Appsheet-based digital mapping effectively improves TB treatment outcomes in a geographically challenging, high-HIV prevalence setting. The consistency of findings across bivariate and multivariate analyses, with digital mapping remaining significantly associated with treatment success after controlling for age and distance (AOR = 1.760; 95% CI: 1.238–2.501), reinforces the robustness of these results.

The digital mapping should be widely adopted in primary health centers, particularly for patients living ≥1 km from facilities who need intensified support through home visits, dedicated medication supervisors (PMO), and emergency contact systems (Alene et al., 2020). Given the high HIV-TB co-infection rate (14.2%), integrated TB-HIV services with routine HIV screening and early ART initiation must be strengthened (Pham et al., 2022). These findings justify investment in GPS-enabled devices, mobile infrastructure, and health worker training at district and provincial levels, alongside policies supporting decentralized TB services via mobile clinics to reduce geographic barriers (Byonanebye et al., 2021). Program managers should integrate digital mapping into routine surveillance systems for targeted resource allocation and early dropout detection, as technology-enabled support can overcome socioeconomic vulnerabilities including low education, unemployment, and HIV co-infection (Jasmine, 2025; Lee et al., 2023).

These findings support the expansion of Appsheet-based digital mapping interventions in eastern Indonesia and other regions with similar geographic and epidemiological characteristics. However, successful expansion requires attention to implementation fidelity, regular monitoring of data quality, and establishment of backup mechanisms for technical failures such as poor signal or damaged devices.

5. Conclusion

This study found that Appsheet-based digital mapping significantly improved TB treatment outcomes in Nabire Regency. Specifically, it increased treatment success (AOR = 1.760), drastically reduced loss to follow-up (OR = 0.052), and lowered mortality (OR = 0.290). In contrast, living 1 km or more from a health facility increased the risk of treatment failure (AOR = 0.656; 95% CI: 0.494--0.872; p = 0.004). These findings provide strong evidence that digital mapping is an effective intervention for TB control in regions with geographic barriers and high HIV prevalence such as Central Papua. For future research, it is recommended to conduct randomized controlled trials with rigorous randomization to eliminate selection bias and confirm causality, alongside qualitative studies to explore patient and provider experiences with digital mapping to understand the mechanisms behind reduced dropout and mortality. Additionally, multicenter studies across diverse geographic and epidemiological settings are needed to enhance generalizability, as well as longitudinal studies measuring long-term outcomes including relapse rates at 12 to 24 months post-treatment, and operational research to identify optimal implementation strategies such as technology integration into routine workflows, backup mechanisms for technical failures, and cost-effectiveness analyses.

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7. Author Declaration

This study is the original work of the researchers and does not belong to, nor has it been copied from, any other individual or institution. The researchers further declare that there are no conflicts of interest, financial or otherwise, that could have influenced the design, conduct, analysis, or reporting of this study. This research was undertaken solely to generate scientific evidence regarding the use of Appsheet-based digital mapping in supporting the Pulmonary Tuberculosis Control Programme, with the aim of contributing to the advancement of scientific knowledge and improving public health services, particularly tuberculosis control in geographically challenging settings.