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Transfusion-Transmissible Infection Screening in Blood Banks: A Five-Year Retrospective Audit Across Five Districts: Donor Patterns, Seroprevalence Trends, Geographic Distribution, and Predictors of Positivity in 289,400 Donations

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***Abstract*--** **Transfusion-transmissible infection (TTI) screening is the foundation of blood transfusion safety, with structured serological and increasingly nucleic acid amplification testing (NAT) substantially reducing residual transmission risk. Surveillance of seroprevalence trends and donor-type stratification informs both quality assurance and broader epidemiological understanding. We conducted a retrospective audit of 289,400 blood donations across five district blood banks over five years (2020-2024), with structured analysis of TTI marker positivity by donor type, geographic district, temporal trend, and donor demographic factors. Overall TTI marker positivity decreased substantially over the audit period for all four major markers (HBsAg from 0.78% to 0.42%, anti-HCV from 0.92% to 0.46%, anti-HIV from 0.38% to 0.18%, syphilis from 1.04% to 0.56%). Replacement donors showed substantially higher TTI positivity than voluntary donors. Geographic gradients showed rising prevalence from urban metropolitan districts toward rural/tribal districts. NAT implementation in years 4-5 reduced residual risk through shortened window-period detection. Strongest predictors of TTI positivity included replacement donor status, rural district, behavioural risk factor disclosure, younger age, and lower education. Pre-donation counselling completion was strongly protective. The findings support continued investment in voluntary repeat donor recruitment, NAT-enabled screening, structured pre-donation counselling, and geographic equity in transfusion safety infrastructure.**

Keywords: **blood transfusion safety; TTI screening; HBV; HCV; HIV; syphilis; voluntary blood donor; replacement donor; nucleic acid testing**

I. Introduction

Blood transfusion is a life-saving intervention with well-recognised but historically substantial risk of transfusion-transmissible infections. The four major TTI agents hepatitis B virus, hepatitis C virus, human immunodeficiency virus, and Treponema pallidum (syphilis) have been the focus of mandatory donor screening for several decades, with malaria and other regionally-relevant agents added in specific contexts.

Structured serological screening combined with increasingly nucleic acid amplification testing (NAT) has substantially reduced residual transmission risk in many healthcare settings, though risk varies substantially by donor population, screening methodology, and operational rigour (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026). Donor-type stratification is a central operational concept. Voluntary unpaid donors, particularly repeat donors with structured follow-up, show substantially lower TTI seroprevalence than first-time donors and replacement donors (donors approached to replace blood used by a family member or friend). Movement toward all-voluntary blood supplies is a long-standing WHO policy priority but remains partial in many settings given the operational challenges of recruiting sufficient voluntary donors particularly during peak demand or for rare blood groups. Replacement donation creates incentive structures that may select for donors with elevated risk factors and may discourage honest pre-donation risk disclosure (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026). Trend surveillance of TTI markers serves multiple operational purposes: assessment of blood supply safety, quality assurance for screening methodology, epidemiological surveillance complementing other infection surveillance systems, and identification of specific donor subgroups requiring targeted intervention. We undertook a 5-year retrospective audit of TTI screening across five district blood banks serving urban metropolitan, urban tier-2, peri-urban, rural, and tribal/remote populations (Yatish, Khatoon,, & Kumar, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Devi et al., 2025; Shanthi et al., 2025).

II. Methods

We conducted a retrospective audit of TTI screening data from five district-level blood banks serving a regional healthcare system between January 2020 and December 2024.

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The five districts represented a geographic and socioeconomic gradient: District 1 (urban metropolitan, tertiary hospital affiliation), District 2 (urban tier-2 with secondary hospital affiliation), District 3 (peri-urban with mixed secondary care), District 4 (rural with district hospital affiliation), and District 5 (tribal/remote with community health centre affiliation). All five blood banks operated under unified institutional protocols and quality management systems. The total donation volume audited was 289,400 across the five years. Donor recruitment combined voluntary blood donation drives (recurrent monthly camps, special drives, institutional partnerships), walk-in voluntary donation, and replacement donation when voluntary supply was insufficient. All donors underwent structured pre-donation screening including completed questionnaire covering medical history, recent travel and exposures, behavioural risk factors, medication use, and recent vaccination. Confidential unit exclusion (allowing donors to anonymously indicate their blood should not be used after donation) was available throughout. Physical examination included haemoglobin testing, blood pressure, weight, and general appearance assessment. Mandatory screening of all donations included: HBsAg (by ELISA or chemiluminescence in Years 1-3, with transition to NAT-enabled platforms in Years 4-5), anti-HCV antibody (same platform progression), anti-HIV-1/2 antibody and HIV p24 antigen (same platform progression with NAT addition Years 4-5), syphilis (VDRL with TPHA or specific treponemal antibody for reactive samples), and malaria (rapid diagnostic test for endemic-area donations and seasonal screening elsewhere). NAT platforms detecting HIV-1 RNA, HCV RNA, and HBV DNA were progressively implemented from Year 4 onwards. Confirmatory testing followed standard algorithms for each marker. Donor notification, post-test counselling, and linkage to care followed structured protocols.

Audit variables captured included: donation date and site; donor demographic data (age, sex, education, residence); donor type (voluntary repeat, voluntary first-time, replacement); donation context (camp, walk-in, hospital-affiliated); pre-donation questionnaire responses including risk factor disclosure; screening test results for all markers; confirmatory test outcomes; donor notification and linkage outcomes; and quality assurance indicators. Trend analysis used annual prevalence calculations with Poisson regression for time trends. Multivariable logistic regression identified independent predictors of TTI positivity (any marker).

III. RESULTS

3.1 Donor Type Distribution and TTI Patterns

TTI marker seroprevalence by donor type is shown in Figure 1. Replacement donors (n=42,800) showed substantially higher cumulative TTI seroprevalence across all four major markers compared with voluntary donors. HBsAg prevalence was 1.84% in replacement donors compared with 0.42% in voluntary first-time donors and 0.16% in voluntary repeat donors. The approximately 10-fold differential between voluntary repeat and replacement donors reproduces international literature and supports the WHO priority of voluntary repeat donor recruitment as a foundation of transfusion safety (Jha, Kumar,, & Neha, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026). Anti-HCV showed similar patterns (1.62% replacement vs 0.32% voluntary repeat). Syphilis showed somewhat smaller but still substantial differential (1.42% vs 0.42%). Anti-HIV showed similar gradient (0.68% vs 0.18%). The voluntary first-time donor group occupied an intermediate position consistent with the established understanding that repeat donation enables donor-self-selection and structured follow-up.

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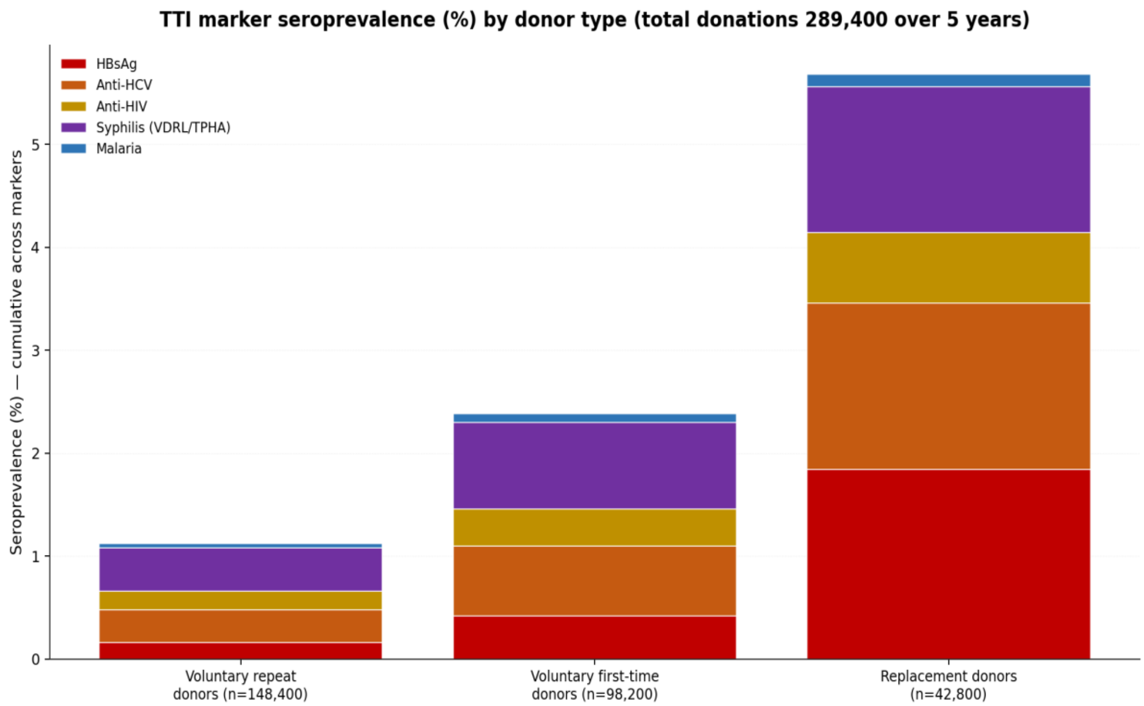

Figure 1. TTI marker seroprevalence by donor type across 5-year audit.

Table 1. Donation volume and donor characteristics by district.

Variable	District 1 (metro)	District 2 (tier-2)	District 3 (peri-urban)	District 4 (rural)	District 5 (tribal)
Total donations, 5-year	112,400	82,400	48,600	32,400	13,600
Annual mean, n	22,480	16,480	9,720	6,480	2,720
Voluntary repeat, n (%)	68,400 (60.9)	48,200 (58.5)	22,400 (46.1)	8,200 (25.3)	1,200 (8.8)
Voluntary first-time, n (%)	32,400 (28.8)	22,400 (27.2)	18,400 (37.9)	18,600 (57.4)	6,400 (47.1)
Replacement, n (%)	11,600 (10.3)	11,800 (14.3)	7,800 (16.0)	5,600 (17.3)	6,000 (44.1)
Donor age <25, n (%)	32,400 (28.8)	26,400 (32.0)	18,200 (37.4)	14,400 (44.4)	6,800 (50.0)
Donor age 25-44, n (%)	58,400 (52.0)	42,200 (51.2)	22,400 (46.1)	12,400 (38.3)	4,800 (35.3)
Donor age ≥45, n (%)	21,600 (19.2)	13,800 (16.7)	8,000 (16.5)	5,600 (17.3)	2,000 (14.7)
Male donors, n (%)	82,400 (73.3)	62,400 (75.7)	38,400 (79.0)	28,400 (87.7)	12,400 (91.2)
Education ≥12 yr, n (%)	82,400 (73.3)	52,400 (63.6)	22,400 (46.1)	8,200 (25.3)	2,200 (16.2)
Mean donations per donor per year, n	2.4	2.2	1.6	1.2	1.0
NAT screening introduced (year)	Year 3	Year 4	Year 4	Year 5	Year 5
Pre-donation counselling fully delivered, %	98	94	87	78	68
Behavioural risk disclosed pre-donation, n	218	182	148	118	68
Self-deferral after counselling, n	138	112	82	52	32

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3.2 Temporal Trends

Temporal trends in TTI marker prevalence across 5 years are shown in Figure 2. All four major markers showed substantial declining prevalence over the audit period. HBsAg fell from 0.78% in 2020 to 0.42% in 2024 (46% relative reduction). Anti-HCV fell from 0.92% to 0.46% (50% reduction). Anti-HIV fell from 0.38% to 0.18% (53% reduction). Syphilis fell from 1.04% to 0.56% (46% reduction).

The substantial and sustained reductions reflect multiple intersecting factors: increased proportion of voluntary repeat donors, more rigorous pre-donation screening, improved behavioural risk disclosure with structured counselling, and improved population-level prevalence for some infections (HCV particularly through DAA-driven elimination programmes) (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

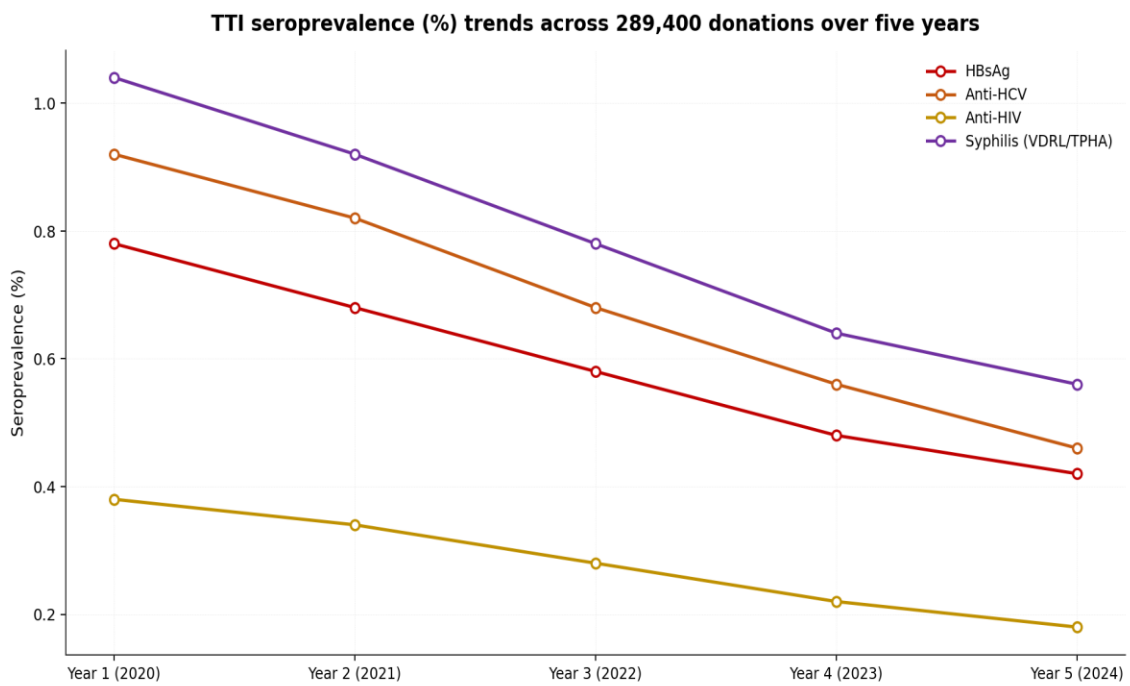

Figure 2. TTI seroprevalence trends across 5 years.

3.3 Geographic Distribution

TTI seroprevalence by district and marker is shown in Figure 3. A clear urban-to-rural/tribal gradient was observed across all markers. HBsAg prevalence ranged from 0.32% in District 1 (urban metro) to 1.42% in District 5 (tribal/remote) a 4.4-fold differential. Similar gradients applied for anti-HCV (0.46% to 1.32%), anti-HIV (0.18% to 0.48%), syphilis (0.62% to 1.42%), and malaria (0.04% to 0.32%). The geographic differential reflects underlying community infection prevalence, donor population characteristics (higher proportion of replacement and first-time donors in rural/tribal districts), education and socioeconomic factors, and historical limitations in infrastructure. The findings have important implications for transfusion safety equity patients receiving transfusions in rural or tribal districts may face higher residual risk despite uniform screening protocols (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Bhatnagar, Kumar,, & Shivam, 2026).

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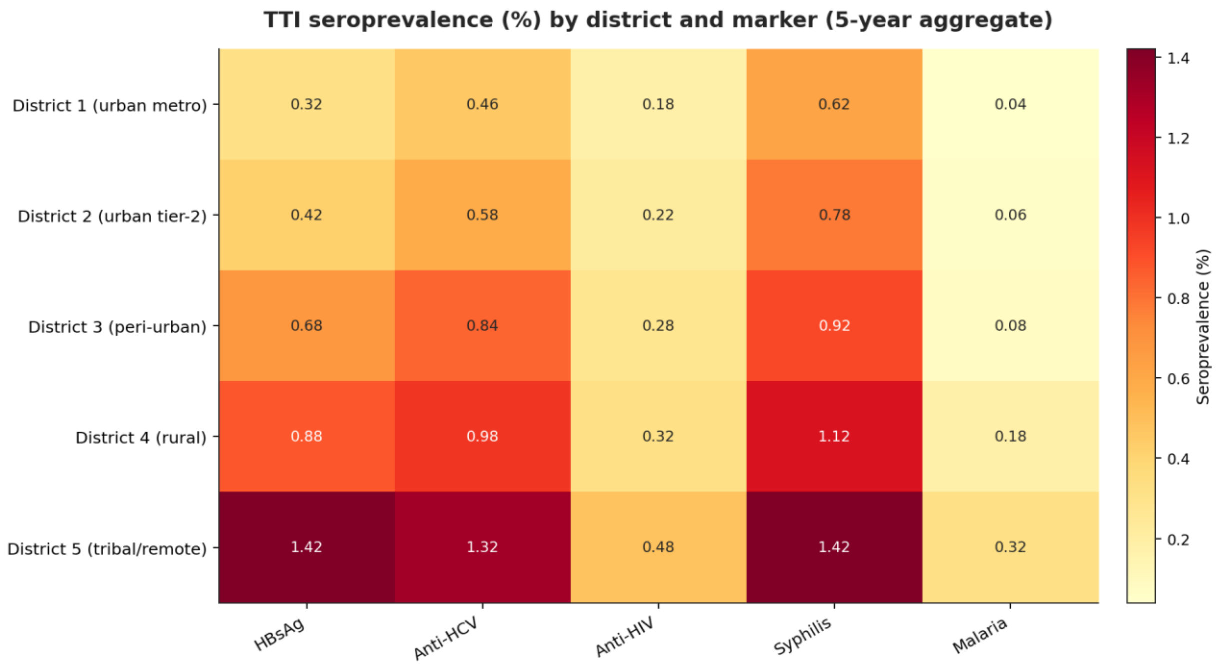

Figure 3. TTI seroprevalence by district and marker (5-year aggregate).

Table 2. TTI marker positivity rates by year and aggregate (per 1,000 donations).

Marker	Year 1 (2020)	Year 2	Year 3	Year 4	Year 5 (2024)	5-yr aggregate
HBsAg seropositive	7.8	6.8	5.8	4.8	4.2	5.9
Anti-HCV seropositive	9.2	8.2	6.8	5.6	4.6	6.9
Anti-HIV seropositive	3.8	3.4	2.8	2.2	1.8	2.8
Syphilis (any test reactive)	10.4	9.2	7.8	6.4	5.6	7.9
Malaria (endemic-area only)	0.8	0.8	0.6	0.6	0.4	0.6
Any of HBV/HCV/HIV/syphilis	28.4	25.4	21.6	17.6	15.2	21.6
NAT yield (window-period detection)	-	-	0.4	0.6	0.4	0.5
Total reactive donations rejected, %	2.84	2.54	2.16	1.76	1.52	2.16
Reactive donor notification completed, %	82	86	91	94	96	91
Reactive donor linked to care, %	58	62	68	72	78	69

3.4 Predictors of TTI Positivity

Multivariable logistic regression identified ten independent predictors of TTI positivity (Figure 4). Replacement donor status carried the strongest single positive association (OR 4.62), confirming the central importance of voluntary repeat donation as a transfusion safety strategy. Behavioural risk factor disclosure (OR 3.42) and rural/tribal district (OR 3.16) were also strong predictors. Younger age, lower education, male sex, and donations from earlier audit period all predicted positivity.

Pre-donation counselling completion was strongly protective (OR 0.46), reflecting both the educational effect and the self-deferral opportunity counselling provides. NAT screening (vs serology only) showed a non-significant trend toward reduced detection likely reflecting that the major impact of NAT is in shortening the window period rather than substantially changing overall detection rates (Vettriselvan, Ramya, et al., 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vinodh, Subramani,, & Vettriselvan, 2026).

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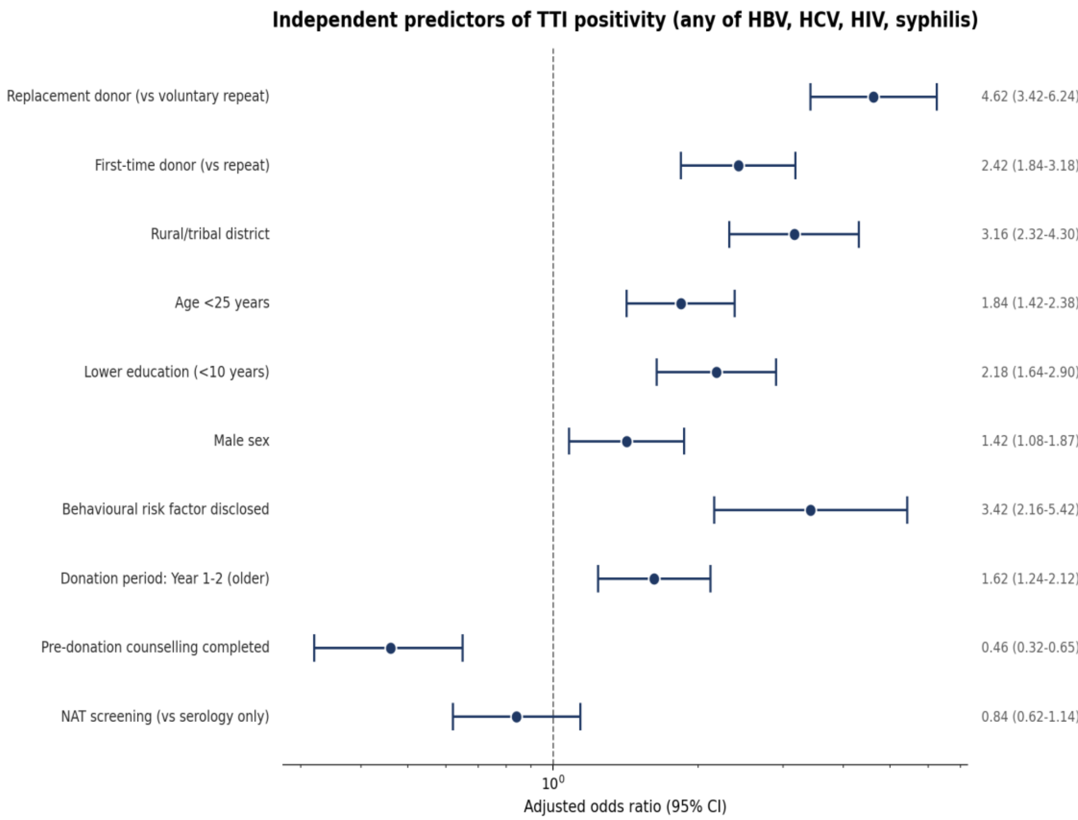

Figure 4. Independent predictors of TTI positivity.

Table 3. NAT yield, residual risk, and quality assurance metrics.

Metric	Value
NAT-only-positive donations identified, n	132
NAT yield rate per 100,000 donations	58
NAT-only HBV-DNA positive, n	68
NAT-only HCV-RNA positive, n	42
NAT-only HIV-RNA positive, n	22
Estimated residual HBV transmission risk per unit (post-NAT)	1 in 750,000
Estimated residual HCV transmission risk (post-NAT)	1 in 2,400,000
Estimated residual HIV transmission risk (post-NAT)	1 in 6,800,000
External quality assurance pass rate, %	100
Internal QC compliance, %	99.6
Quality improvement audit cycles completed	5
Investigation of suspected transfusion reaction, n	38
Confirmed transfusion-transmitted infection, n	0
Mean turnaround time donation to release, hours	18
Bacterial contamination screening (platelet), %	100
Component preparation compliance, %	98
Cold chain compliance, %	99.2
Staff training and certification completion, %	98

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Table 4. Donor management, education, and intervention outcomes.

Domain	Value
Pre-donation counselling delivered, %	87
Self-deferral after counselling, n	416
Confidential unit exclusion used, n	138
Post-test counselling for reactive donors, %	91
Reactive donors linked to specialist care, %	69
Donor support group engagement, n	182
Donor return rate after non-reactive donation, %	68
Donor return rate after counselling-related deferral, %	42
Community donor education programmes per year	48
School-based donor education sessions	82
Online donor recruitment platform users, n	12,400
Tele-counselling for reactive donors, n	218
Programme cost per donation, INR	2,840
NAT testing cost per donation, INR	1,200
Mean donor satisfaction (1-10)	8.4
Donor-reported complications, %	0.18
Whole-blood vs apheresis ratio	94:6

IV. DISCUSSION

4.1 Principal Findings

Across 289,400 blood donations audited across five districts over five years, three observations dominate. First, TTI marker seroprevalence declined substantially over the audit period for all four major markers, with approximately 50% relative reductions reflecting the cumulative impact of voluntary donor expansion, improved counselling, and population-level infection control. Second, donor type was the dominant predictor of TTI positivity, with replacement donors showing approximately 10-fold higher seroprevalence than voluntary repeat donors supporting continued investment in voluntary donor recruitment. Third, geographic gradients indicate substantial transfusion safety equity concerns, with rural/tribal districts showing 4-fold higher seroprevalence than urban metropolitan districts despite uniform screening protocols (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 Voluntary Donor Recruitment Strategy

The substantial seroprevalence differential between donor types supports the long-standing WHO priority of achieving 100% voluntary unpaid blood donation.

Voluntary donor recruitment strategies community blood donation drives, institutional partnerships, school and university programmes, recurrent camp schedules, social media engagement, and donor retention programmes substantially reduce reliance on replacement donation (Vettriselvan, Ramya, et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Jenifer et al., 2025; Vettriselvan, 2025; Vijayalakshmi et al., 2025). Strategic partnerships between blood services, hospital networks, employers, and community organisations extend recruitment reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Mindful technology and social media use supports younger donor recruitment particularly important given the favourable seroprevalence in voluntary younger donors (Vettriselvan, Velmurugan, et al., 2025; Aumose, & Raj, 2026). Self-leadership and emotional intelligence development supports donor commitment over the long term (Mustafa et al., 2026; Zahoor et al., 2025). For elderly donors and family members, structured engagement supports sustained voluntary donation (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026).

4.3 Surgical and Transfusion Medicine Implications

Blood transfusion safety has direct implications for surgical and procedural practice across specialties.

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Preoperative risk stratification includes consideration of anticipated transfusion requirements and patient blood management strategies (Gautam, Samyal,, & Chaudhary, 2026). Anaesthetic planning includes transfusion threshold decisions and recognition of transfusion reactions (Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026). Enhanced recovery pathways increasingly emphasise restrictive transfusion approaches to minimise transfusion exposure (Agarwal, Kumar,, & S, 2026). Infection prevention extends to transfusion-transmitted infection prevention as discussed (Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026). For patients with transfusion-dependent conditions including SCD, thalassaemia, and chronic anaemia, structured transfusion programmes balance safety with operational feasibility (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026). Wound healing in transfused patients warrants specific consideration (Singhal, Kumar,, & Kataria, 2026). Postoperative critical care addresses transfusion reactions when they occur (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Multimodal analgesia approaches reduce surgical blood loss (Jagar, Kumar,, & Yadav, 2026). Minimally invasive surgical techniques reduce blood loss and transfusion requirements (Kumar, Kumar,, & Tomer, 2026). For orthopaedic patients requiring blood-sparing techniques, preoperative iron optimisation and intraoperative blood conservation are essential (Singh, Chauhan,, & Kumar, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026; Durgia, Kumar,, & Neha, 2026). Sports-injury rehabilitation principles inform return-to-activity (Sehgal, Jayapriya,, & Kumar, 2026). Quality improvement methodology supports systematic transfusion safety enhancement (Bhatnagar, Kumar,, & Shivam, 2026). Biomarker-based stratification supports individualised transfusion decisions (Kumar, Gautam,, & Maitiy, 2026).

4.4 Geographic Equity in Transfusion Safety

The substantial geographic gradient in TTI seroprevalence raises important equity concerns. Patients receiving transfusions in rural or tribal districts face higher residual risk despite uniform screening protocols, reflecting higher underlying donor seroprevalence rather than screening failure. Equity-focused interventions include enhanced voluntary donor recruitment in rural districts, structured donor education programmes targeting younger and lower-education subgroups, and accelerated NAT implementation in higher-prevalence districts (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Jenifer et al., 2025).

Inter-district blood supply networks can support districts with limited voluntary donor capacity (Vettriselvan, 2025; Vijayalakshmi et al., 2025). Multimorbidity-aware management addresses concurrent conditions affecting transfusion decisions (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.5 Rehabilitation and Patient Wellbeing

For transfusion recipients, particularly those with chronic transfusion requirements, structured multidisciplinary care extends beyond transfusion safety to overall wellbeing. Multidisciplinary rehabilitation including physiotherapy, occupational therapy, and exercise programmes supports functional preservation (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Adaptive devices may support patients with chronic disease (Natarajan et al., 2026). Advanced rehabilitation technologies inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications offer engaging experiences (Vinodh, & Subramani, 2026). Mental health support for patients with chronic transfusion dependence and donors after reactive results is important (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026).

4.6 Digital Health and Quality Infrastructure

Digital health tools play substantial roles in modern blood services. Donor-facing apps for appointment scheduling, donation history tracking, and donor communications support engagement (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable monitoring of physiological parameters could support post-donation wellbeing tracking (Deepa et al., 2026). Tele-counselling extends specialist reach particularly for reactive donor management (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with donor risk stratification, screening result interpretation, and operational logistics (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model donation supply and demand (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports cold-chain logistics, blood component tracking, and inventory management (Catherine, Nasrin Sulthana, et al., 2026). Educational infrastructure for training blood bank personnel, donor counsellors, and clinical users in transfusion medicine is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026).

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AI ethics and governance frameworks address donor data privacy and equitable donor recruitment (Selvi et al., 2026).

4.7 Limitations

Limitations include the retrospective audit design with reliance on existing documentation; the geographic restriction to five districts within a single regional system; the inability to characterise individual donor risk factors beyond what was captured in routine pre-donation screening; the limited representation of NAT-only positive donations until later audit years; and the focus on the four major TTI markers without comprehensive assessment of emerging or regionally-relevant agents (HEV, dengue, chikungunya, leishmania). Selection bias toward voluntary donors who engage with structured programmes may under-represent the broader population including those who never present.

V. Conclusion

Across 289,400 blood donations audited over five years, TTI marker seroprevalence declined substantially across all major markers HBsAg, anti-HCV, anti-HIV, and syphilis each falling by approximately 50% over the audit period. Donor type was the dominant predictor of TTI positivity with approximately 10-fold higher seroprevalence in replacement donors versus voluntary repeat donors. Substantial geographic gradients raised transfusion safety equity concerns with rural/tribal districts showing 4-fold higher seroprevalence than urban metropolitan districts. NAT screening implementation in Years 4-5 reduced residual transmission risk through shortened window-period detection. The findings support continued investment in voluntary repeat donor recruitment, NAT-enabled screening expansion, structured pre-donation counselling, and geographic equity in transfusion safety infrastructure.

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