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Indexing blood banking performance in India: A retrospective cross-sectional analysis of states and districts

Gaurav M. Urs [a], Padmavathy Krishna Kumar [a,b], Yash Kamath [a,c], Siddhesh Zadey [a,d,e,*]

[a] Association for Socially Applicable Research (ASAR), Pune, Maharashtra, India
[b] Adichunchanagiri Institute of Medical Sciences, BG Nagara, Karnataka, India
[c] Seth Gordhandas Sunderdas Medical College and KEM Hospital, Mumbai, Maharashtra, India
[d] Dr. D. Y. Patil Medical College, Hospital, and Research Centre, Dr. D. Y. Patil Vidyapeeth, Pune, Maharashtra, India
[e] GEMINI Research Center, Duke University School of Medicine, Durham, North Carolina, USA

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ABSTRACT

Background: Multiple international assessments have highlighted gaps in blood banking globally. However, there is a dearth of subnational assessments. We applied a thematic framework with multiple composite indices to assess blood bank performance across Indian states and districts.

Methods: In this retrospective cross-sectional analysis, data for 2493 blood banks in 35 states/union territories (UTs) and 616 districts was extracted from the National Blood Transfusion Council for 2016. The framework involved seven themes (accreditation, ownership, safety, volume, infrastructure, regulation, and workforce) with several indicators nested under them. Composite thematic indices and an overall index (0-100, with 100 being the best performance) were constructed using the adjusted Mazziotta-Pareto index method that can provide composite indices that are partially non-compensatory and easily interpretable.

Results: The state-level median [interquartile range] value of the overall index was 59.61 [46.35, 71.67]. Chandigarh had the highest values for safety, regulation, workforce, and ownership indices, Maharashtra for volume and infrastructure indices, and Manipur for accreditation index. Districts in southern and western states performed well on the overall index with inter- and intra-state variations for themes. District-level correlations depicted positive associations among indices with the strongest correlation between ownership and accreditation indices ($n=616$, $R=0.92$, $p<0.001$).

Conclusion: Blood banking in India is fragmented, with variations in themes across geographies. The northern and northeastern states require more attention for volume, accreditation, infrastructure, and ownership. While the southern and western-central regions need to prioritize safety. The framework with thematic indices, when applied to routine data, can be useful for monitoring and evaluation to decide local policies and resource allocations.

1. Introduction

Blood banks provide a steady supply of blood for several functionalities in a health system, such as emergencies, trauma care, dialysis, routine surgical and obstetric procedures, cancer management, and the treatment of blood-related illnesses [1]. One of the most significant barriers to providing basic healthcare in resource-limited areas across the world is a lack of access to clean and dependable stored blood [2]. Issues regarding lack of blood volume and risky blood transfusions, among others, in low- and middle-income nations like India have been brought up by the Lancet Commission on Global Surgery (LCoGS) [3]. For instance, LCoGS recommended at least 15 units of blood be collected annually per 1,000 individuals.

India has made several efforts to ensure blood availability and safety. Of importance is the Indian National Blood Policy, which governs blood availability and regulation. It aims to ensure a readily available and sufficient supply of safe and reliable blood and its components, gathered from a voluntary quasi-routine blood donor in well-equipped establishments, free of transfusion-transmitted infections, and stored and distributed under ideal conditions [4]. Additionally, the National AIDS Control Organisation (NACO) has been providing safe blood in the country since 1992 [5]. NACO-affiliated blood banks must satisfy

* Corresponding author at: D2 Sai Heritage, New DP Road, Aundh, Pune, Maharashtra 411007, India.
E-mail address: sidzadey@asarforindia.org (S. Zadey).

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specific requirements and adhere to stringent rules regarding blood collection, evaluation, analysis, and storage, but non-NACO blood banks may lack the appropriate supplies or personnel.

Assessing blood banking performance is a critical component of health system evaluations. The World Health Organization (WHO) has highlighted the gaps in blood banking on a global level noting disparities in blood donation between low-, middle-, and high-income countries [6]. For instance, high-income countries account for 42% of the 120 million annual blood units donated worldwide, despite accounting for only 16% of the global population. The United States Center for Disease Control and Prevention (CDC) expanded on WHO's work [7]. It noted that only four of the 14 Sub-saharan African countries met the WHO-recommended minimum of 10 units per 1,000 population. For blood transfusion safety, six countries had an HIV prevalence of more than 1% among donated units. The CDC study also found that only two national blood transfusion services had been accredited by a standardized body.

There has been a dearth of nationwide studies on blood banking in India [8]. Studies have primarily focused on blood volumes and donation, with the aim of addressing the supply-demand mismatch. There is a lack of studies focusing on other aspects including blood banking regulation, accreditation, adequate infrastructure, and well trained workforce. Additionally, the existing studies have largely focused on single-center experiences from tertiary care facilities [9].

There exist high-caliber reports that haven't been thoroughly studied and analyzed [10]. Given the recommendations of LCoGS, our primary aim was to systematically assess various aspects of blood banking using a structured thematic framework that includes safety, accreditation, ownership, infrastructure, regulation, safety, and volume at subnational levels. For this, we propose a family of composite indices that can be used to monitor and evaluate Indian states and districts.

2. Methods

2.1. Data source and extraction

In this retrospective cross-sectional secondary data analysis, data was extracted from the 'Assessment of Blood Banks in India' reports for 616 districts within 28 states and 7 union territories (UTs) from the National Blood Transfusion Council (NBTC) website [10]. The NBTC is the apex authority in India for policy-making regarding the management of blood banks. Established in 1996, NBTC has four main objectives: encouraging voluntary donation, guaranteeing safe blood transfusion, developing facilities for blood banks, and fostering human resources [11]. The reports provide data on the evaluation of blood banks in terms of blood collection, voluntary blood donors, governance systems, and other areas for implementing quality improvement systems. The data in these reports came from self-assessment questionnaires filled out by personnel at the blood banks.

Data was manually extracted from the tables, figures, and infographics from all 35 reports to create a consolidated dataset in Google Sheets. The investigators iteratively verified each other's work. Three hundred and nine unique variables were extracted for 35 states and union territories, and thirty-nine unique variables were extracted for the 616 districts. UT of Lakshadweep had no report. The consolidated dataset, along with the data dictionary, can be found at Harvard Dataverse [12].

2.2. Data analysis

2.2.1. Descriptive analysis

For state analysis, 205 of the 309 variables were included for further analysis after removing the NBTC scoring variables. One hundred and twenty-nine unique indicators were further selected for descriptive analysis (Table 1). In the district-level analysis, of the 39 variables, 24 variables were included for further analysis after removing the NBTC scoring variables. The same 24 variables were selected for descriptive analysis (Table 2). In both levels of analysis, count and percentage variables were obtained. No variables had any missing data across the states and UTs. Variable-wise data missingness is reported for districts in Table 2. All count variables were converted to percentage variables. For continuous indicators, the mean (standard deviation) and median (interquartile range) were used to summarize distributions, while proportions (%) were used for categorical indicators.

2.2.2. Constructing indices for blood banking performance

To assess the blood banking performance systematically and comprehensively at the state and district levels, we created a thematic framework loosely based on LCoGS and the World Health Organization (WHO) report on blood safety and availability [3,13]. The seven themes included accreditation, ownership, regulation, infrastructure, safety, volume, and workforce. For state-level analysis, seven themes with 49 indicators were used (Table 3). For district-level analysis, 5 themes with 14 indicators were used for creating composite indices (Table 4). Workforce and regulation could not be included due to the absence of data.

The thematic indices were composites of multiple indicators as listed in detail in Tables 1-4. However, below we describe concisely what these themes attempt to capture. Accreditation involves information on whether the blood bank is accredited by NACO. A NACO accreditation for a blood bank ensures that enhanced infrastructure and adequate capacity building are supported by NACO to promote its functions. As of 2016, there were 1,131 NACO-accredited blood banks in India [14]. Ownership included whether the blood banks are owned and managed by public or non- or for-profit private sectors. Infrastructure included comparable indicators on blood bank availability. Safety included the presence of screening facilities to rule out different infections that hinder transfusions such as syphilis, HIV, malaria, and Hepatitis B seropositivity in collected/stored blood samples at the blood banks. Volume included annual blood collection, type of donations (replacement or voluntary), and blood used for component separation. Regulation included compliance with NBTC requirements, quality control kits availability, and the presence of a valid operating license. Workforce dealt with the availability of trained blood bank staff including medical officers, technical staff, staff nurses, counselors, and pro-donor motivators.

We used the Mazziotta-Pareto Index (MPI) as the method for index creation [15]. MPI gives composite indices that are partially non-compensatory, easily computable and interpretable, and comparable across periods and regions with a flexible weighting scheme including the non-controversial equal weights [16]. The composite thematic and overall indices were constructed following the below steps. First, the individual indicators were normalized using min-max scaling to range from 0 to 100 (Eq. (1)).

$$r_{ij} = [(\ \ - x_{\min})/(x_{\max} - x_{\min}\ )] \times 100 \quad (1)$$

where, r_{ij} = normalized indicator for unit i and indicator j

Second, these scaled indicators were combined using (Eq. (2)).

$$MPI_i = M_{ri} + (S_{ri}^{*}\ CV_i) \quad (2)$$

where, M_{ri} = mean of the normalized values of the unit i

S_{ri} = standard deviation of the normalized values of the unit i

$CV_i = S_{ri} / M_{ri,}$ is the coefficient of variation for the unit i.

The penalty term corrects for imbalance across indicators to ensure that high performance on any one indicator cannot completely compensate for low performance on another indicator. Finally, the composite index was normalized using min-max scaling to be within the range of 0 to 100. These scaled MPI-based index values were then used for comparing states and districts across individual themes and overall blood banking performance. All indices constructed here have positive polarity, i.e., a higher value depicts better or desirable performance. Index analysis was conducted using a platform built for the compind R

Table 1
Variables extracted from the NACO website that were used for index creation and analysis for states and union territories.

Variable	Variable Description	Thematic Category	Included for analysis	Included for thematic index
total_naco	Total Number of NACO Blood Banks in the State	Accreditation	YES	YES
number_nabhyes_total	Number of all BB accredited to NABH	Accreditation	YES	YES
bb_t_c	Total Number of Blood Banks which have Component Separation Facility	Infrastructure	YES	YES
total_all	Total Number of Blood Banks in the State	Infrastructure	YES	YES
reg_supply_blood_bags	Percentage of Blood Banks with regular supply of Blood Bags	Infrastructure	YES	YES
reg_supply_blood_grouping_reagents	Percentage of Blood Banks with regular supply of Blood Grouping Reagents	Infrastructure	YES	YES
reg_supply_tti_kits	Percentage of Blood Banks with regular supply of TTI Kits	Infrastructure	YES	YES
bb_working_autoclave	Percentage of Blood Banks with Functional Autoclave Machines	Infrastructure	YES	YES
bb_working_automated_pipettes	Percentage of Blood Banks with Functional Automated Pipettes	Infrastructure	YES	YES
bb_working_blood_container_weighting_device	Percentage of Blood Banks with Functional Blood Container Weighing Device	Infrastructure	YES	YES
bb_working_blood_transport_box	Percentage of Blood Banks with Functional Blood Transportation Boxes	Infrastructure	YES	YES
bb_working_centrifuge_iha	Percentage of Blood Banks with Functional Centrifuge for Serological Testing Immunohaematology	Infrastructure	YES	YES
bb_working_centrifuge_samples	Percentage of Blood Banks with Functional Lab Centrifuge for Samples	Infrastructure	YES	YES
bb_working_collection_monitor	Percentage of Blood Banks with Functional Blood Collection Monitor	Infrastructure	YES	YES
bb_working_computers	Percentage of Blood Banks with Functional Computers with Accessories and Software	Infrastructure	YES	YES
bb_working_crash_cart	Percentage of Blood Banks with Functional Crash Carts	Infrastructure	YES	YES
bb_working_donor_couches	Percentage of Blood Banks with Functional Donor Couches	Infrastructure	YES	YES
bb_working_instrument_hb	Percentage of Blood Banks with Functional Instruments for Hb Estimation	Infrastructure	YES	YES
bb_working_oxygen	Percentage of Blood Banks with Functional Oxygen Supply Equipment	Infrastructure	YES	YES
bb_working_refrigerated_centrifuge	Percentage of Blood Banks with Functional Refrigerated Centrifuge	Infrastructure	YES	YES
bb_working_refrigerator_tested_blood	Percentage of Blood Banks with Functional Refrigerator for Tested Blood with Temperature Recorder	Infrastructure	YES	YES
bb_working_refrigerator_untested_blood	Percentage of Blood Banks with Functional Quarantine BB Refrigerator for Untested Blood	Infrastructure	YES	YES
bb_working_serology_rotator	Percentage of Blood Banks with Functional Serology Rotator	Infrastructure	YES	YES
bb_working_sharps	Percentage of Blood Banks with Functional Containers for Sharp Disposal	Infrastructure	YES	YES
bb_working_water_bath	Percentage of Blood Banks with Functional Water Baths	Infrastructure	YES	YES
bb_hosp_total	Total Hospital Attached Blood Banks	Ownership	YES	YES
bb_lab_total	Total Laboratory Attached Blood Banks	Ownership	YES	YES
bb_licvalid_total	Total Blood Banks with a License under Renewal	Regulation	YES	YES
qual_kits_total_percent	Number of Blood Banks with Quality Check for Kits, Reagents and Blood Bags	Regulation	YES	YES
qual_eqas_tti_total_percent	Number of Blood Banks with External Quality Assurance Scheme for TTIs	Regulation	YES	YES
nbtc_compliance_ebloodbanking	Percentage of State Blood Banks submitting regular reports to E-Blood Banking	Regulation	YES	YES
nbtc_compliance_haemovigilance	Percentage of State Blood Banks member of National Haemovigilance Program	Regulation	YES	YES
nbtc_compliance_processing	Percentage of State Blood Banks recovering processing charges within NBTC	Regulation	YES	YES
nbtc_compliance_sdc	Percentage of State Blood Banks submitting regular reports to State Drug Controller	Regulation	YES	YES
nbtc_compliance_sims	Percentage of State Blood Banks submitting regular reports to Strategic Information Management System (SIMS)	Regulation	YES	YES
nbtc_compliance_stock	Percentage of State Blood Banks displaying stock position in their blood bank premises	Regulation	YES	YES
tti_naco_hbv	Seroreactivity Percentage for HBV of Blood Collected at NACO Supported Blood Banks in the State	Safety	YES	YES
tti_naco_hcv	Seroreactivity Percentage for HCV of Blood Collected at NACO Supported Blood Banks in the State	Safety	YES	YES
tti_naco_hiv	Seroreactivity Percentage for HIV of Blood Collected at NACO Supported Blood Banks in the State	Safety	YES	YES
tti_naco_malaria	Seroreactivity Percentage for Malaria of Blood Collected at NACO Supported Blood Banks in the State	Safety	YES	YES
tti_naco_syphilis	Seroreactivity Percentage for Syphilis of Blood Collected at NACO Supported Blood Banks in the State	Safety	YES	YES
tti_nonnaco_hbv	Seroreactivity Percentage for HBV of Blood Collected at Non-NACO Supported Blood Banks in the State	Safety	YES	YES
tti_nonnaco_hcv	Seroreactivity Percentage for HCV of Blood Collected at Non-NACO Supported Blood Banks in the State	Safety	YES	YES
bb_annual_total	Annual Units of Blood Collected at All Blood Banks	Volume	YES	YES
bb_voluntary_total	Percentage of Voluntary Donations at all Blood Banks	Volume	YES	YES
bb_manpow_counsellor	Percentage of Blood Banks with at least one Counselor	Workforce	YES	YES

(*continued on next page*)

Table 1 (*continued*)

Variable	Variable Description	Thematic Category	Included for analysis	Included for thematic index
bb_manpow_medic_officer	Percentage of Blood Banks with at least one Medical Officer	Workforce	YES	YES
bb_manpow_prodonormotivator	Percentage of Blood Banks with at least one PRO Donor Motivator	Workforce	YES	YES
bb_manpow_staff_nurse	Percentage of Blood Banks with at least one Staff Nurse	Workforce	YES	YES
bb_manpow_tech_staff	Percentage of Blood Banks with at least one Technical Staff	Workforce	YES	YES
bb_percent_counsellor	Percentage of Blood Banks with at least one trained Counselor	Workforce	YES	YES
bb_percent_medic_officer	Percentage of Blood Banks with at least one trained Medical Officer	Workforce	YES	YES
bb_percent_prodonormotivator	Percentage of Blood Banks with at least one trained PRO Donor Motivator	Workforce	YES	YES
bb_percent_staff_nurse	Percentage of Blood Banks with at least one trained Staff Nurse	Workforce	YES	YES
bb_percent_tech_staff	Percentage of Blood Banks with at least one trained Technical Staff	Workforce	YES	YES

Table 2
Variables extracted from the NACO website that were used for index creation and analysis for districts.

Variable	Variable Description	Thematic Category	Included for analysis	Included for thematic index	Percentage of districts missing data (n=616)
NACO supported	Number of NACO supported Blood Banks in the District	Accreditation	YES	YES	0.65
Non NACO	Number of Non-NACO supported Blood Banks in the District	Accreditation	YES	NO	0.81
Total support	Total Number of Blood Banks in the District	Infrastructure	YES	YES	0
bb_availaibility	Number of Blood Banks per 1 Million Population	Infrastructure	YES	YES	0
bcsu_collection_total	Annual Total Blood Units Collected by Blood Component Separation Units by District	Infrastructure	YES	NO	0.81
component_separation_percent_bcsu	Percentage of Collected Units of Blood used for Component separation District Level	Infrastructure	YES	YES	1.14
district_percent_cs_naco	Percentage of Component Separation by District	Infrastructure	YES	NO	0
bb_own_public	Number of Public Owned Blood Banks By District	Ownership	YES	NO	0.97
bb_own_nfp	Number of Not-for-profit Owned Blood Banks By District	Ownership	YES	NO	1.62
bb_own_priv	Number of Private Owned Blood Banks By District	Ownership	YES	NO	4.05
district_hiv	HIV Seropositivity Percentage by District	Safety	YES	YES	0.16
district_hcv	HCV Seropositivity Percentage by District	Safety	YES	YES	0.16
district_hbv	HBV Seropositivity Percentage by District	Safety	YES	YES	0.16
district_syphilis	Syphilis Seropositivity Percentage by District	Safety	YES	YES	0.16
district_malaria	Malaria Seropositivity Percentage by District	Safety	YES	YES	0.16
average_annual_naco	Average Annual Blood Units collected at NACO Supported Blood Banks in the District	Volume	YES	NO	0.81
average_annual_nonnaco	Average Annual Blood Units collected at Non-NACO Supported Blood Banks in the District	Volume	YES	NO	1.13
district_voluntary_collection	Annual Blood Units Collected via Voluntary Donation at District Blood Banks	Volume	YES	YES	0.16
district_replacement_collection	Annual Blood Units Collected via Replacement Donation at District Blood Banks	Volume	YES	NO	0.81
district_annual_collection	Annual Blood Units Collected via any mode at District Blood Banks	Volume	YES	NO	0.16
district_annual_per100	Blood Collection per 100 individuals in each district	Volume	YES	YES	0.16
percentage_voluntary_district	Percentage of Blood Donations that are Voluntary Donations in each district	Volume	YES	NO	0.16
percentage_voluntary_district_naco	Percentage of Blood Donations that are Voluntary Donations at NACO supported Blood Banks in each district	Volume	YES	NO	0.16
percentage_voluntary_district_nonnaco	Percentage of Blood Donations that are Voluntary Donations at Non-NACO supported Blood Banks in each district	Volume	YES	NO	3.57

package [17].

In this study, MPI was chosen over other commonly used methods such as arithmetic mean and principal component analysis (PCA) due to the advantages offered by it for reducing bias and improving interpretability. The imbalance across indicators that exists in an arithmetic mean due to better performance on one indicator compensating for poorer performance on the others is eliminated in MPI method by using the penalty term. MPI is not as computationally heavy as PCA and offers easier interpretation since it has an arithmetic mean penalized for inter-indicator imbalance. Further, PCA is typically used for high dimensional data which was not needed for the current data. However, certain drawbacks of the current implementation of MPI method should be considered. For the overall index, we scaled the values twice. The scaling was nonlinear which means that absolute magnitudes of differences between adjacent values are not retained. This can also lead to flooring and ceiling effects, which can skew interpretation. Additionally, indices created using MPI are partially compensatory, meaning that there can still be some residual imbalance.

State-wise radar plots depicted how states/UTs perform across seven thematic indices and where the imbalance lies [18]. Associations among the indices were explored using Pearson's product-moment correlations and were presented through a correlation heatmap or matrix [19]. The correlations were classified as follows: very strong (0.7 to 0.9), strong (0.4 to 0.7), moderate (0.3 to 0.4), weak (0.2 to 0.3), and negligible (0.1 to 0.2) [20]. Statistical significance was decided based on a conservative alpha threshold of 1%.

Table 3
Variable inclusion in thematic indices created to analyze the blood banks for states and union territories.

Theme	Description	Number of variables	
		For analysis	For index
Accreditation	NACO and NABH standardization of the banks.	9	2
Ownership	Ownership status and their location	18	2
Infrastructure	Equipment used at blood banks for collection, testing, storage, and transit.	23	22
Safety	Screening for transfusion infections and quality assurance	21	7
Volume	Collection of blood, donation type, and separation of components component separation.	9	2
Regulation	Compliance to NBTC requirements, quality control kits availability, and valid operating license.	39	9
Workforce	Availability of trained blood bank staff.	10	5

Table 4
Variable inclusion in thematic indices created to analyze the blood banks for districts.

Theme	Description	Number of variables	
		For analysis	For index
Accreditation	NACO and NABH standardization of the banks.	2	1
Ownership	Ownership status and their location	3	3
Infrastructure	Equipment used at blood banks for collection, testing, storage, and transit.	5	3
Safety	Screening for transfusion infections and quality assurance	5	5
Volume	Collection of blood, donation type, and separation of components component separation.	9	2

3. Results

3.1. Status of blood banking across India

Data on 2493 blood banks across 616 districts in 35 states and union territories were included in the analysis. Data on various aspects of blood banks are summarized in Table 5. This data was further disaggregated by the NACO (n=1119 or 44.8%) and non-NACO status. Of the 2493 blood banks, 949 (38.1%) were public, 597 were owned by trusts or not-for-profit, and 947 were for-profit private organizations. There were a total of 11,646,241 units of blood collected of which 8,308,692 units (71.3%) were voluntary donations. Hence, blood collected per 1000 people was 9.09 units. For safety, only 15.32% of blood banks had facilities to detect transfusion transmissible infections (TTIs). Seropositivity rates for individual TTIs in collected blood were 0.13% for HIV, 0.35% for Hepatitis C Virus (HCV), 0.85% for Hepatitis B Virus (HBV), 0.19% for syphilis, and 0.06% for malaria. 91.5% of blood banks adhered to the NBTC regulations. However, the National Accreditation Board for Hospitals and Healthcare Providers (NABH), an organization that provides standard guidelines for all blood banks to follow to ensure blood safety from the stage of collection up until transfusion to patients, had only accredited 2.93% of blood banks nationwide. As for infrastructure, the majority of blood banks had well-stocked equipment with stock levels above 90%. However, only 83.3% of blood banks had functional computers with accessories and software and only 86.44% had functional centrifuges for serological testing and immunohematology. Blood banks did well for workforce staffing of at least one medical officer (94.1% blood banks), technical staff (96.3%), staff nurses (92.6%), and counselors (92.6%). However, training for

Table 5
Indicators across NACO and non-NACO blood banks in 2016.

Variable	NACO	Non-NACO	Total
Total Number of Blood Banks	1119	1374	2493
Annual Units of Blood Collected per 1000 population	-	-	9.09
Annual Units of Blood Collected by Voluntary Donation per 1000 population	-	-	6.49
Blood Banks with Component Separation Facility	38.52	61.14	100
Blood Banks without Component Separation Facility	61.48	38.86	100
Blood Banks owned by Trusts/Not-for-profits	243	704	947
Blood Banks owned by Private Organisations	0	597	597
Blood Banks owned by Public Institutions	876	73	949
Percentage of Blood Banks with Valid Licenses	55.67	73.94	65.74
Blood Banks attached to Hospitals	86.15	69.51	1918
Blood Banks Standalone	12.15	23.8	463
Blood Banks attached to Laboratories	1.70	6.70	111.00
Annual Units of Blood Collected	6916413	4729828	11646241
Percentage of Voluntary Blood Donation	77.10	44.58	70.68
Annual Units of Blood Collected by Voluntary Donation	-	-	8308692
Percentage of HIV Seropositivity in collected Blood	0.14	0.09	0.13
Percentage of HCV Seropositivity in collected Blood	0.36	0.23	0.35
Percentage of HBV Seropositivity in collected Blood	0.92	0.58	0.85
Percentage of Syphilis Seropositivity in collected Blood	0.17	0.22	0.19
Percentage of Malaria Seropositivity in collected Blood	0.07	0.04	0.06
Percentage of Blood Banks complying with NBTC Guidelines	93.83	89.59	91.5
Percentage of Blood Banks with Document Control System Available	41.73	55.02	49.06
Percentage of Blood Banks which have SOPs for Technical Processes	94.28	97.89	96.27
Percentage of Blood Banks with Internal Quality Control for Immunohaematology	71.05	83.55	77.94
Percentage of Blood Banks with Internal Quality Control for TTIs	54.42	50.22	52.11
Percentage of Blood Banks with Quality Check for Kits, Reagents and Blood Bags	78.82	92.29	86.24
Percentage of Blood Banks with External Quality Assurance Scheme for Immunohaematology	8.13	17.1	13.08
Percentage of Blood Banks with External Quality Assurance Scheme for TTIs	9.56	13.97	11.99
Percentage of Blood Banks with NABH Accreditation	2.23	3.49	2.93
Percentage of Blood Banks with EQAS	12.24	20.16	16.73
Percentage of Blood Banks with TTI	12.69	17.47	15.32
Percentage of Blood Banks with Designated and Trained Quality Manager	21.81	51.16	37.99
Percentage of Blood Banks with Designated and Trained Technical Manager	27.52	65.07	48.22
Percentage of Blood Banks with Programme for Regular Equipment Maintenance	74.53	96	86.36
Percentage of Blood Banks with Equipment Calibration as per Regulatory Requirement	78.11	97.16	88.61
Percentage of State Blood Banks recovering processing charges within NBTC	-	-	85.2
Percentage of State Blood Banks displaying stock position in their blood bank premises	-	-	88.13
Percentage of State Blood Banks submitting regular reports to State Drug Controller	-	-	81.83
Percentage of State Blood Banks submitting regular reports to Strategic Information Management System (SIMS)	-	-	85.4

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Table 5 (*continued*)

Variable	NACO	Non-NACO	Total
Percentage of State Blood Banks submitting regular reports to E-Blood Banking	-	-	40.91
Percentage of State Blood Banks member of National Haemovigilance Program	-	-	11.79
Percentage of Blood Banks with at least one Medical Officer	-	-	94.06
Percentage of Blood Banks with at least one Technical Staff	-	-	96.31
Percentage of Blood Banks with at least one Staff Nurse	-	-	92.58
Percentage of Blood Banks with at least one Counselor	-	-	47.61
Percentage of Blood Banks with at least one PRO Donor Motivator	-	-	39.11
Percentage of Blood Banks with at least one trained Medical Officer	-	-	30.08
Percentage of Blood Banks with at least one trained Technical Staff	-	-	45.05
Percentage of Blood Banks with at least one trained Staff Nurse	-	-	22.42
Percentage of Blood Banks with at least one trained Counselor	-	-	13.36
Percentage of Blood Banks with at least one trained PRO Donor Motivator	-	-	4.37
Percentage of Blood Banks with regular supply of Blood Bags	-	-	92.46
Percentage of Blood Banks with regular supply of TTI Kits	-	-	90.13
Percentage of Blood Banks with regular supply of Blood Grouping Reagents	-	-	90.37
Percentage of Blood Banks with Functional Donor Couches	-	-	96.15
Percentage of Blood Banks with Functional Instruments for Hb Estimation	-	-	90.21
Percentage of Blood Banks with Functional Blood Collection Monitor	-	-	93.1
Percentage of Blood Banks with Functional Quarantine BB Refrigerator for Untested Blood	-	-	94.79
Percentage of Blood Banks with Functional Containers for Sharp Disposal	-	-	92.54
Percentage of Blood Banks with Functional Oxygen Supply Equipment	-	-	95.15
Percentage of Blood Banks with Functional Computers with Accessories and Software	-	-	83.31
Percentage of Blood Banks with Functional Lab Centrifuge for Samples	-	-	90.17
Percentage of Blood Banks with Functional Centrifuge for Serological Testing Immunohaematology	-	-	86.44
Percentage of Blood Banks with Functional Blood Transportation Boxes	-	-	90.29
Percentage of Blood Banks with Functional Crash Carts	-	-	93.1
Percentage of Blood Banks with Functional Autoclave Machines	-	-	91.01
Percentage of Blood Banks with Functional Water Baths	-	-	89.45
Percentage of Blood Banks with Functional Refrigerator for Tested Blood with Temperature Recorder	-	-	96.79
Percentage of Blood Banks with Functional Automated Pipettes	-	-	85.96
Percentage of Blood Banks with Functional Refrigerated Centrifuge	-	-	58.36
Percentage of Blood Banks with Functional Blood Container Weighing Device	-	-	82.63
Percentage of Blood Banks with Functional Serology Rotator	-	-	83.31

specific blood banking functions was limited among medical officers (30.1%), technical staff (45.1%), nurses (22.4%), and counselors (13.4%).

3.2. NACO vs non-NACO

In terms of ownership, 876 of the 949 public blood banks had NACO accreditation, while only 243 of the 947 trusts/not-for-profit blood banks did. There were no private blood banks that were NACO accredited. NACO-accredited blood banks performed better in terms of volume and safety. For instance, non-NACO blood banks collected 3442 units per blood bank while NACO-accredited blood banks collected 6181 units per blood bank. Out of the total units collected, the NACO blood banks received more voluntary blood donations (77.10%) than non-NACO blood banks (44.58%) (Table 5).

3.3. Variations in indices across states and districts

For 35 states and union territories, median [interquartile range] index values were 27.66 [17.02, 39.01] for accreditation, 61.26 [5.00, 70.78] for ownership, 86.412 [75.38, 89.29] for infrastructure, 44.48 [34.13, 79.23] for safety, 32.58 [20.33, 40.28] for volume, 37.32 [19.17, 50.46] for regulation, 43.99 [28.84, 56.91] for workforce and 59.61 [46.35, 71.67] for overall index. State-wise radar plots depict the skew in performance across different indices for the states (Fig. 1). All states depicted skew, i.e., performance on some indices was better than that on others. Additionally, the skews varied across states. Chandigarh had the highest value of the overall index while Sikkim had the lowest (Fig. 2). Blood banks in the southern and western states had better overall index values compared to those for central, eastern, and north-eastern states. Chandigarh had the highest values for safety, regulation, workforce, and ownership indices, Maharashtra had the highest values for volume and infrastructure indices, and Manipur for the accreditation index. The northeastern state of Sikkim had the lowest value for the infrastructure index, Mizoram for safety and ownership, and Meghalaya for the volume index. Chhattisgarh had the lowest workforce index value while Dadra & Nagar Haveli had the lowest values for the regulation index.

For 616 districts, median [interquartile range] index values were 7.16 [3.64, 10.64] for accreditation, 4.17 [2.17, 8.56] for ownership, 4.69 [1.36, 20.49] for infrastructure, 7.39 [3.22, 12.26] for safety, 36.21 [29.85, 44.31] for volume and 32.45 [27.31, 40.63] for overall indices. The low median values point to skewed distributions where most districts did not perform well on multiple indices. The majority of the NACO-accredited blood banks were in south India followed by districts in the west with the remaining zones showing a scattered accreditation presence (Fig. 3A). Blood banks in the northeast and some pockets of North India were publicly owned or run by nonprofits, while those in South Indian districts were mostly privately owned (Fig. 3B). Districts in southern and western states and some districts in north India performed well on the infrastructure index while those in the north, northeast, and parts of central India showed poorer infrastructure (Fig. 3C). Mumbai in Maharashtra had the highest value for the accreditation index and Bangalore in Karnataka for the ownership and infrastructure indices. Manipur's Bishnupur, Tamenglong, and Ukhru districts, as well as Meghalaya's East-Jaintia-Hills, North-Garo-Hills, South-Garo-Hills, and South-West-Khasi-Hills districts, had some of the lowest values for accreditation, ownership, and infrastructure indices.

Low safety index values were found to be concentrated in pockets across all the zones but mostly seen in the north, northeast, and southernmost parts of India with several districts in south-central and west India doing better (Fig. 4A). Even so, the highest value for safety index was found for Tawang in the northeastern state of Arunachal Pradesh with 61 districts having a zero value. Most districts in southern states and pockets of north India had high volume index values while those in northeast, central, and large parts of north India had lower values (Fig. 4B). Kolkata in West Bengal had the highest value while Ramanagara in Karnataka had the lowest value for volume index. Several districts in southern and western states performed well on the overall index. Kolkata in West Bengal had the highest value while Mahasamund

Fig. 1. Thematic indices for 35 Indian states and union territories. The gray polygon in the background is formed by the median index values and depicts a reference for comparison. Abbreviations: A = Accreditation, S = Safety, R = Regulation, V = Volume, W = Workforce, I = Infrastructure, and O = Ownership.

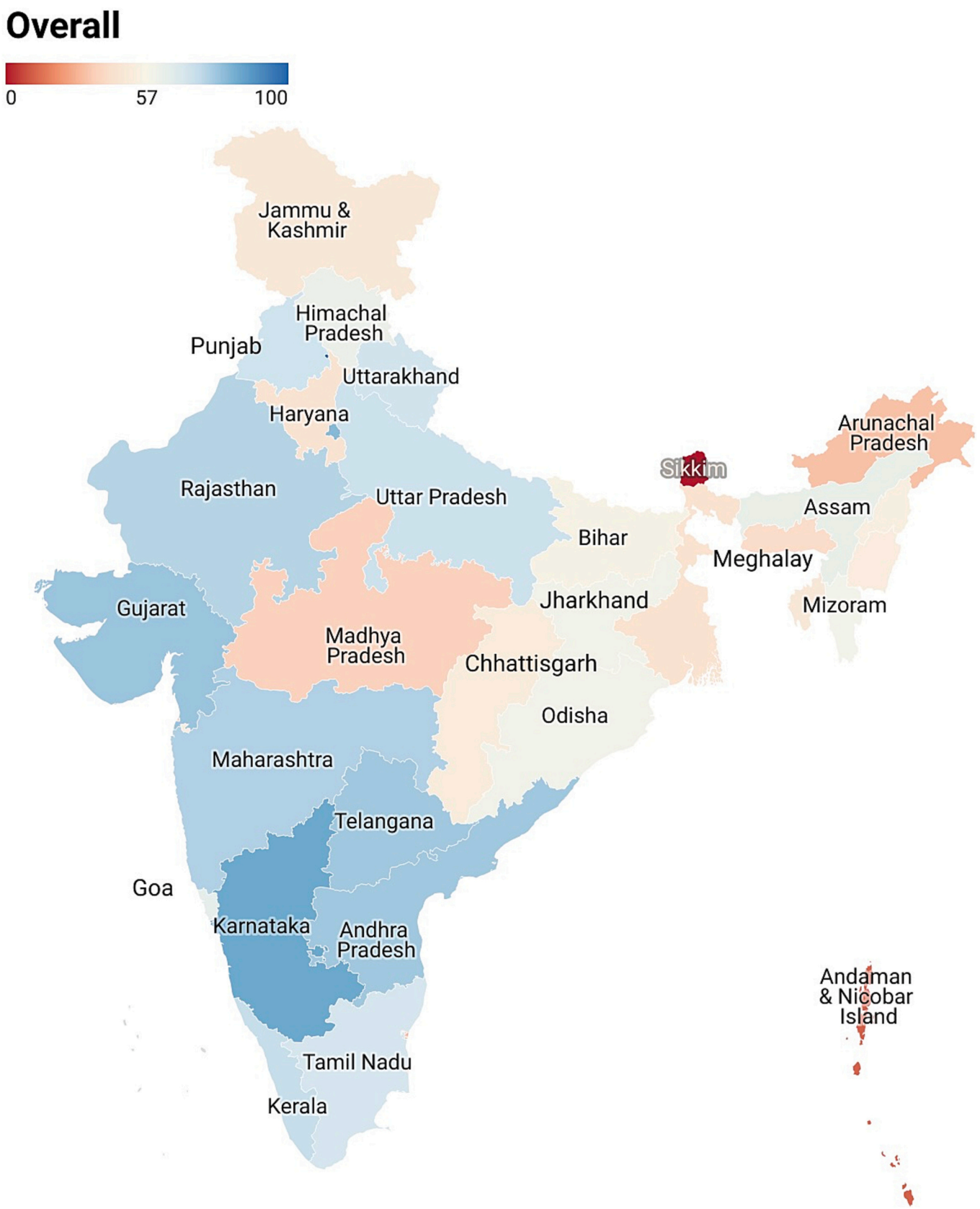

Fig. 2. Overall index values based on seven themes capturing blood banking performance for 35 states and union territories.

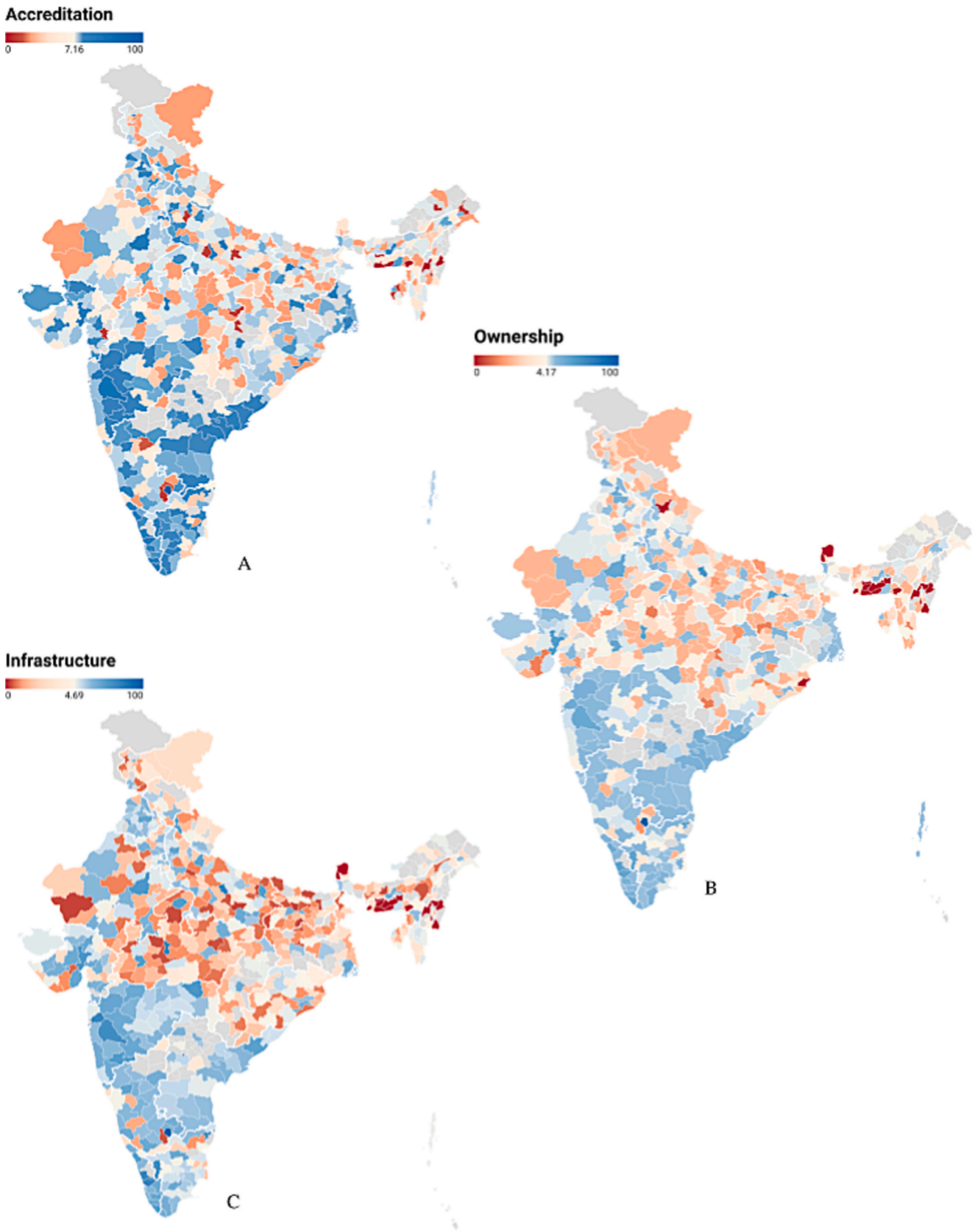

Fig. 3. Thematic index values for 616 districts measuring different aspects of blood banking performance including - A) accreditation, B) ownership, and C) infrastructure.

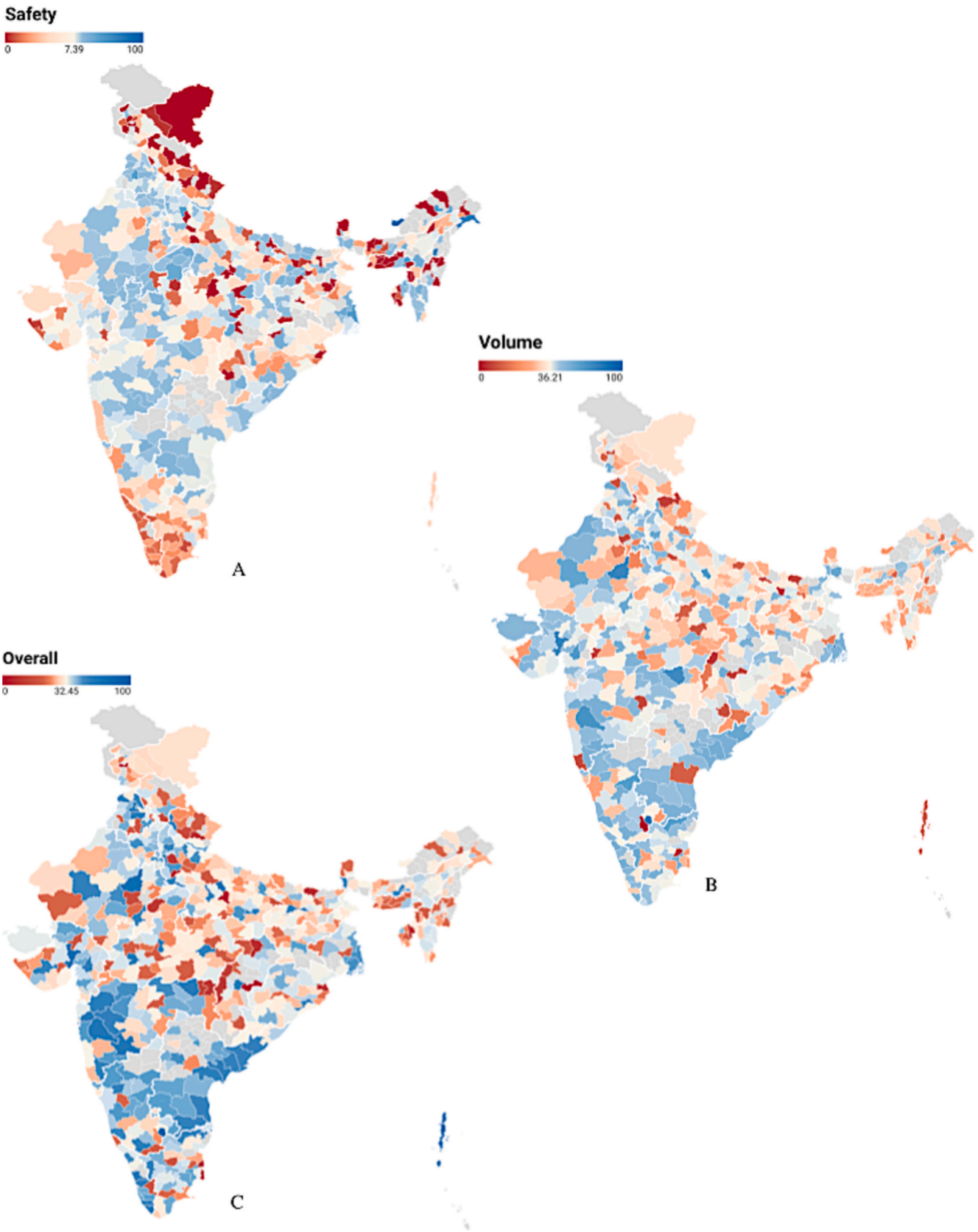

Fig. 4. Thematic index values for 616 districts measuring different aspects of blood banking performance including- A) safety, B) volume, and C) overall blood banking performance.

in Chhattisgarh had the lowest value (Fig. 4C).

3.4. Correlations among indices

For 616 districts, we found very strong positive correlations between ownership and accreditation (R=0.92, p<0.001), infrastructure and accreditation (R=0.76, p<0.001), and infrastructure and ownership (R=0.79, p<0.001). Volume index had strong correlations with accreditation (R=0.61, p<0.001), infrastructure (R=0.64, p<0.001), and ownership indices (R=0.64, p<0.001). The safety index did not have significant correlations with other thematic indices (p>0.05) but depicted a weak but significant association with the overall index (R=0.19, p<0.001). Correlations among other indices were of smaller or negligible strength but still a positive direction (Fig. 5).

4. Discussion

4.1. Summary of findings

The primary objective of the study was to understand the performance of blood banks through indices at state and district levels. The framework of indices used here relates closely to themes brought out by LCoGS [3]. Our analysis found that blood banks in central and south central India performed better than the other regions in the country, with low median scores and a skewed distribution across all blood banks. The infrastructure and ownership indices had lower median values than the other indices, indicating low performance in these areas. Thematic indices had strong positive correlations across districts.

4.2. Previous studies and relevance of findings

The World Health Organization's latest report on blood safety and availability uses cross-national data for 2014-2018 to note stark differences in blood volume collection, blood safety screening, and unnecessary transfusions among low, middle, and high-income countries [6]. The WHO report provides information at the country level based on data directly obtained from the national records of a country or based on WHO's imputation calculations in certain cases. Extending such assessment to sub-national levels to understand within-country differences is critical. In the current study, we have attempted to fill this gap by conducting district and state-level analyses for India, which is the most populous country.

The data used here has been previously used by Asirvatham and colleagues in an analysis that assessed blood bank functioning under the following criteria - licensing, sufficient number of blood banks, annual blood volume collection, voluntary non-replacement blood donation, safety screening facilities, component separation, adequately trained staff, availability of reagents and testing kits, participation in hemovigilance program, presence of e-blood banking, and compliance with NBTC rules [21]. Using weighted scores, blood banks were categorized as low, medium, or high functioning. This study only provided regional aggregate data. In the current study, we focus on individual states and districts to understand high-resolution geographic differences. In the previous paper, clarity around the categorization of blood banks based

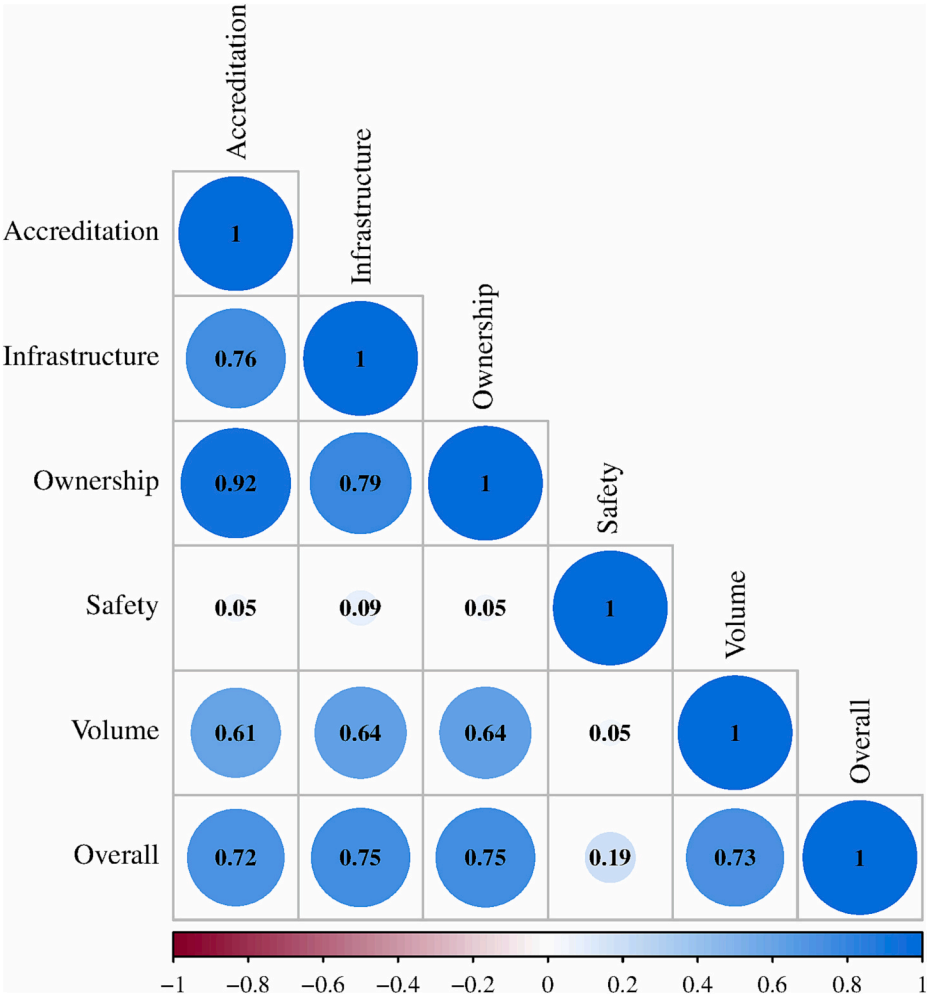

Fig. 5. Correlations among different thematic indices at the district level.

on component separation facility was missing. Our work uses thematic indices that are in line with LCoGS to evaluate blood bank performance under accreditation, ownership, safety, volume, and infrastructure. Asirvatham and colleagues used the NBTC cut-off of 10,000 units to assess annual blood volume collection but there is no evident rationale for it. Contrastingly, we used an LCoGS-recommended cut-off blood collection volume of 1500 units per year per 1000 people. This was based on a cross-country analysis of the relationship between average life expectancy and blood collection [3]. Finally, the score computation method - especially the weighting scheme has not been transparent. We used MPI methodology, which is an easy, transparent, and non-compensatory approach for creating composite indices that can be tracked and compared across multiple periods and regions [15].

Previously, obstetric care providers in Bihar mentioned long distances between blood banks and healthcare facilities, lack of pre-transfusion testing facilities, and disparity in access to blood among private and public facilities that force the public health facilities to rely on replacement donation from patients' family among reasons for blood shortage that impact the quality of care received by the patients [22]. These providers also suggested the legalization of unbanked direct blood transfusion, and better decentralization initiatives for smooth blood bank functioning such as partnerships with civil society organizations to educate the communities and curbing misinformation related to blood donations as relevant policy changes. The indices proposed here capture some of these issues. These indices when applied to routine quantitative data can help in health system monitoring and evaluation of policy impact. Further, the family of indices can be expanded to include indicators relevant to the acceptability of blood donations and community-level preferences.

4.3. Policy implications

Accreditation and infrastructure had lower median scores than the other indices, indicating the need for more attention to these themes in future policies directed toward strengthening blood banking. Extant geographical variations note that the northern and northeastern states require more attention for volume, accreditation, infrastructure, and ownership. While the southern and western-central parts of India need to focus on safety. Attention to specific themes in specific regions can ensure appropriate investments and the allocation of human and instructional resources in a needs-based manner ensuring equitable improvements [23].

Limited access to safe and timely banked blood is a significant impediment to universal SOTA care. In resource-constrained settings, blood acquisition is significantly delayed because of poor protocol and coordination. This can be improved by the accreditation of blood banks under national regulations [23]. In terms of infrastructure and ownership, private and nonprofit organizations typically have better management and practices than the public sector, which may be one of the key factors in the timely donation and adequate availability of blood [22].

There are multiple potential uses of the proposed thematic framework and family of indices. They can comprehensively be used for comprehensive and routine assessment to enhance resource availability and capacity building and for strengthening regulations related to blood banks in the long run. It can also help understand blood bank accessibility among populations in different parts of the country and thus guide local policy formulation to explore alternate routes to ensure immediate blood access during emergencies. Currently, eRaktKosh is a government-authorized website that provides real-time information on blood units collected and the number of donors registered across India. eRaktKosh also helps a person locate a blood bank near them, find a suitable donor, and allows individuals or organizations to register and organize blood donation camps [24]. Hence, future analyses could adapt the proposed indices and utilize data from eRaktKosh for monitoring blood banking performance. Finally, the proposed indices can be included in the high-level health and policy indices for decision-making.

4.4. Strengths and limitations

Our study provides a systematic assessment of blood banking in India across multiple geographic levels. Additionally, the family of thematic indices provides a way, in the future, to monitor and evaluate blood banking performance across districts. The findings have direct policy relevance with regard to the regions and themes that should be focused on for resource allocation. Our methodological framework is transparent and easy to implement. It can be extended to other administrative levels in India and other LMICs.

There are several limitations to the study. First, the data used here is from 2016 and not recent. However, this is the most recent data publicly available in NBTC reports. The availability of more recent and particularly post-pandemic data can help to better understand the current state of blood banking in India. Second, as noted in the methods, several districts had missing data on some variables and/or did not participate in the original data collection. The current analysis did not impute any such data and suffers from the missingness of the original dataset. However, it should be noted that some districts did not enter any data in the assessment while others did not have blood banks to report about. In the future, data from these locations, combined with timely reporting, would help to strengthen the findings. Third, the current analysis did not compare the indexes against other health system indicators, hence, their construct validity is pending for future studies.

5. Conclusion

In this study, we applied a thematic framework of indices to capture various aspects of blood banking performance in India to find geographic differences at state and district levels. These findings can be used to decide resource allocation for improving performance for specific themes at specific locations, hence, supporting localized policy making and planning. Future studies will adapt and extend the proposed methods using real-time data for monitoring and evaluation. Ensuring an adequate and safe supply of blood is crucial for universal health coverage achievement among LMICs.

Author contributions

Gaurav M Urs (GMU), Padmavathy KK (PKK), Yash Kamath (YK), Siddhesh Zadey (SZ)

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Ethics approval and consent to participate

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Availability of data and materials

All data used and created in the manuscript can be found at Harvard Dataverse (https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PODSOU).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author did not use any such tool. The author takes full responsibility for the content of the publication.

CRediT authorship contribution statement

Gaurav M. Urs: Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **Padmavathy Krishna Kumar:** Data curation, Software, Writing – original draft. **Yash Kamath:** Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **Siddhesh Zadey:** Conceptualization, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

Siddhesh Zadey reports a relationship with Nivarana that includes: board membership. Siddhesh Zadey reports a relationship with Maharashtra State Mental Health Policy Drafting Committee that includes: committee membership. Siddhesh Zadey reports a relationship with G4 Alliance South Asia SOTA Care Working Group that includes: group membership.

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