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Case Study

Rapid Diagnostic Testing and Healthcare Accessibility in Rural Bundelkhand: A Case Study from Uttar Pradesh, India

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Abstract

Background: Rural healthcare systems in resource-limited regions face significant challenges in disease diagnostics and timely testing.

Objective: This study evaluates rapid diagnostic testing practices and disease testing trends in selected villages of the Banda district, Bundelkhand region, Uttar Pradesh, India.

Methods: Survey-based observational data were collected from July to October 2022 from a pathology center serving nearby gram panchayat villages. Diagnostic trends for malaria, dengue, HIV, HBsAg, HCV, and COVID-19 were analyzed.

Results: Malaria testing represented the largest diagnostic burden during the monsoon season. Rapid antigen card methods improved accessibility and turnaround time in rural settings, though throughput remained limited.

Conclusion: Point-of-care rapid diagnostics can improve disease screening and healthcare accessibility in underserved rural regions; however, integration with reliable sample preparation and validation systems remains necessary.

Introduction

Effective management and control of the rampant and pandemic diseases, including the Covid-19 outbreak, is always an ongoing challenge for the developing economies with a huge load of sample population. Possible solutions to enhance testing rates while improving turnaround time remain a major research focus. Although the cumulative records from ICMR show 886 million COVID-19 samples were tested till Feb 2022, which has now reached around 916 million samples till Feb 2023 [1]. Talking particularly about the resource-limited rural areas of the countries that house up to 70% of India's population, including Tier-3 to Tier-6 cities, the rate of testing, as compared to the percentage of actually infected population,

is drastically low. The reason is their remote locations, significantly far from the community health centers (CHC), roughly 20–30 km; limited means of conveyance; and poor infrastructural and virtual connectivity. The pathologies and CHCs also face various technical problems, including sample storage and an upper limit to test the samples with high priority to release the reports on the same day. The cumulative effect of all these may sometimes result in poor disease control and management. Rural areas are the country's backbone, not only for India but throughout the globe, as they connect us with the main food supply chain. A disease-free rural population with better health services could directly act as a catalyst to suppress the rampant and pandemic diseases. This article includes some factual information covering the rural part of the country's

lesser-developed Bundelkhand Region under District “Banda”; we have identified certain limitations, elaborated on some lab-on-chip devices, and proposed an idea to correlate with the present situation and suggested a possible solution to improve the rate of testing.

The objective of this study is to evaluate disease diagnostic patterns, rapid testing practices, and operational limitations in rural pathology settings of the Bundelkhand region while assessing the potential role of rapid point-of-care diagnostic technologies in improving healthcare accessibility. This study highlights real-world diagnostic practices and operational healthcare limitations in rural Bundelkhand while correlating them with emerging point-of-care and lab-on-chip technologies for future healthcare accessibility.

Background

Rapid biosensing card testing

Rapid biosensing card testing has gained significant popularity since the COVID-19 outbreak and has demonstrated promising diagnostic utility. They are now being implemented in the Gram Panchayat CHC to provide sustainable disease testing for village people, parallel to the conventional diagnosis mechanism, to boost the testing rate. Although lateral flow immunoassay-based detection has an old history, as it evolved sixty-four years ago due to the pioneering work of Yellow and Berson [2], Abbott Laboratories commercialized the first HIV antibody detection late in the year 1985. Since then, this field has been emerging for the detection of a variety of Ab and Ag specific to many diseases, such as Dengue, Malaria, HCV, HBsAg, and SARS-CoV-2, to name a few (Figure 1).

Card testing is a semi-automated method to process the pre-processed sample, either whole blood (for *P. Falciparum* and *Plasmodium* species), serological extracts from whole blood (for HIV, HCV Ab, and HbsAg), nasopharyngeal secretions/oropharyngeal fluid from a throat swab (for SARS-CoV-2), or immunoglobulin/antibody secretion in terms of plasma extracts (for Dengue). The biosensing cards that contain only a sample well (S) are specifically designed to detect the surface antigens, while those with sample and buffer wells (B) more specifically detect the IgM/IgG antibodies, as shown in Figure 2. Generally, 2 drops of the sample (70 µl) are needed, which need to be prepared before processing it through the LFA strip. Centrifuge tube-based sedimentation-assisted centrifugation is required for efficiently extracting the pure sample out of whole blood (roughly 4 ml of starting volume). The whole process requires 15–20 min/cycle and 3–4 repeated cycles for RBC-free plasma/serum [3]. Nowadays, more advancements in the field of plasma extraction are noticeable through a variety of microfluidics CD-based centrifugations [4]. The advancement from CD-based microfluidics towards slanted-spiral microchannels and multiplexed slanted spirals [5] assists ultra-fast, rapid extraction, improving the flow rates from 1.5 ml/min to 24 ml/min [6–8].

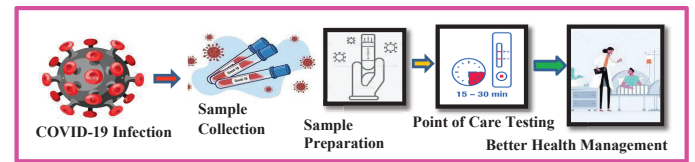


Figure 1: Schematic showing health management and disease control through Rapid Antigen POCT.

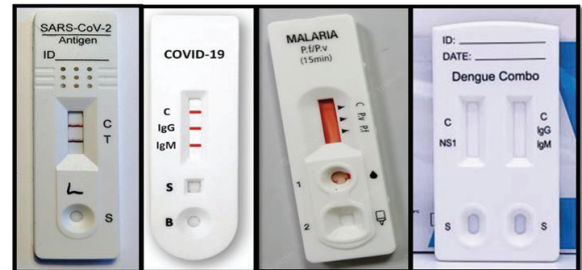


Figure 2: Commercially available Rapid Antigen Testing Kits (not recommended for self-testing).

Materials and methods

Study design

This study was conducted as a descriptive observational case study focusing on disease diagnostic practices and rapid testing trends in selected rural regions of Bundelkhand, Uttar Pradesh, India. The study aimed to evaluate the accessibility and utilization of rapid point-of-care diagnostic methods in resource-limited rural healthcare settings.

Study area

The survey and data collection were conducted in Naraini Tehsil, District Banda, Uttar Pradesh, India, which forms part of the agro-climatic Bundelkhand region. The selected area predominantly consists of rural villages with agricultural dependency and limited healthcare accessibility. According to the Census of India 2011, Naraini Tehsil comprises approximately 187 villages with a population of nearly 2.95 lakh residents.

The pathology center included in this study receives patient samples from nearby villages, including Pachokhar, Lahureta, Haraha, Kalhara, and Kabauli.

Study duration

The observational data were collected over four months from July 2022 to October 2022.

Data source and collection

The study utilized cumulative laboratory diagnostic records obtained from a privately operated pathology laboratory functioning under the Gram Panchayat Naraini, Banda district. The data included disease testing records prescribed by registered medical practitioners for infectious diseases commonly prevalent in the region.

The collected data were categorized month-wise for the following target diseases:

- Malaria Parasite (MP)
- Dengue
- HIV
- Hepatitis B Surface Antigen (HBsAg)
- Hepatitis C Virus (HCV)
- COVID-19

Only aggregated numerical diagnostic records were analyzed, and no personal patient identifiers were collected or disclosed.

Sampling strategy

A convenience-based observational sampling strategy was adopted in this study. Diagnostic records from patients visiting the selected pathology center during the study duration were included for analysis. The study focused primarily on rural populations accessing healthcare services from nearby villages surrounding Naraini Tehsil.

Inclusion criteria

The following criteria were used for inclusion in the study:

1. Patients were prescribed diagnostic testing for the selected infectious diseases during the study period.
2. Patients whose samples were processed using rapid antigen card methods or conventional diagnostic procedures.
3. Diagnostic records available in a complete monthly cumulative form.

Exclusion criteria

The following records were excluded:

1. Incomplete or duplicate laboratory records.
2. Non-target disease diagnostic tests unrelated to the study objective.
3. Records lacking month-wise categorization.

Diagnostic methods

Rapid biosensing card methods and point-of-care testing approaches were analyzed in this study. Depending upon the disease condition and prescribed diagnosis, whole blood, plasma extracts, serological samples, and nasopharyngeal swabs were processed using commercially available lateral flow immunoassay-based rapid diagnostic kits.

COVID-19 diagnosis was performed through government-authorized rapid antigen and/or RT-PCR testing methods, whereas several routine infectious disease screenings at the

selected pathology center were conducted using semiautomated rapid card-based methods.

Statistical analysis

The collected data were analyzed using descriptive statistical methods. Month-wise cumulative distributions and percentage-based comparisons were performed to identify disease testing trends and diagnostic burden during the study duration. The results were graphically represented for comparative interpretation.

Ethical considerations

This study utilized anonymized cumulative laboratory records without involving direct patient intervention or disclosure of personal identity. The study was conducted solely for academic and healthcare research purposes.

Findings

The cumulative record of conventional and rapid antigen card testing for serological/plasma samples and whole blood for MP only is given in Figure 3, showing maximum cases for mosquito-borne infectious disease MP, spiking during August, and dengue is the least widespread. The reason being the nearby villages to Tehsil Naraini largely consist of irregular uplands with outcrops of rocks intermingling with mostly lowlands, frequently underwater during the rainy season. Figure 4 presents the statistics for sample diagnosis. The data reflects the number of diagnosed patients, which could be much lower than the actual number of infected individuals unable to access healthcare facilities at the tehsil owing to multiple factors and scarcity of resources.

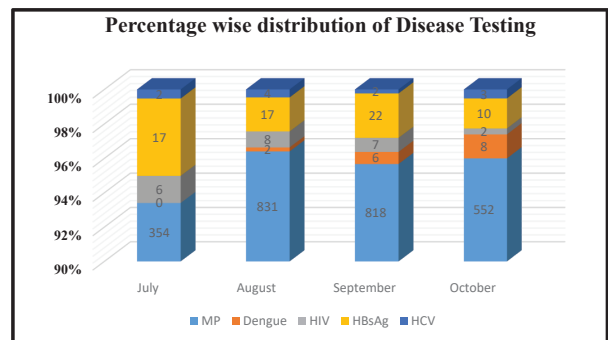


Figure 3: The month-wise cumulative record of Laboratory Diagnosis of Target Diseases.

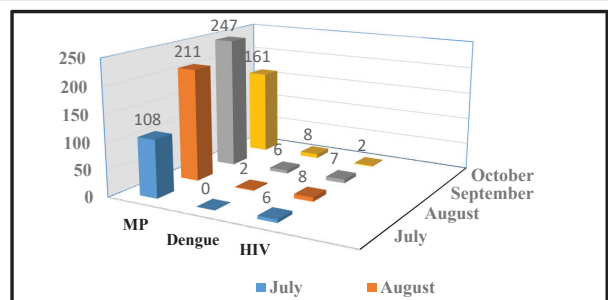


Figure 4: Month-wise breakthrough of Diagnosis based on Card Methods.

Discussion on findings

The selected survey area appropriately represents rural populations with limited healthcare accessibility, as it mostly covers the rural population vulnerable to the medical practitioners suggesting antigen testing and other routine tests. The lab throughput is poor if we analyze the data on a per-day basis, limiting diagnostic report generation to only 22–25 cases per day, and most specifically, only 6–7 diagnostics based on card methods. This limited throughput becomes concerning during widespread vector-borne disease outbreaks, such as malaria, when the pathology center serves multiple surrounding villages.

The observed increase in malaria diagnostic burden during the monsoon months aligns with previously reported epidemiological trends in rural tropical and semi-arid regions, where stagnant water accumulation during rainy seasons promotes mosquito breeding and vector-borne disease transmission. The geographical conditions surrounding Naraini Tehsil, including lowlands frequently affected by seasonal water accumulation, may contribute significantly to the increased prevalence of malaria cases observed during August and September.

The findings of this study further highlight the importance of decentralized point-of-care diagnostic systems in geographically dispersed rural communities with limited access to centralized healthcare infrastructure. Rapid diagnostic testing methods may help reduce diagnostic delays, improve preliminary disease screening, and support timely healthcare intervention in resource-limited settings where conventional laboratory accessibility remains limited.

Reforms to speed up the testing grounds may meet the required sample detection rate to effectively control the rampant and pandemic diseases. Point-of-care testing approaches should be further strengthened and integrated with conventional diagnostic systems to improve healthcare accessibility and diagnostic efficiency in underserved rural regions [Table 1].

Lab-on-chip plasma separation

The plasma separation using passive techniques covers membrane technology [9], microfluidics [10], and microfilters [11]. Membrane-based plasma separators embed an asymmetric polymer, fiber, or glass membrane for selective immobilization of erythrocytes and leukocytes, while pure plasma could be extracted from the downstream by applying a slight negative pressure to the micropipette. The separation time is almost 15 minutes, followed by sample transfer for the analysis. The prototypes of the membrane-based passive separation devices are shown in Figure 5 and Figure 6. Both devices work on a common principle of binding the erythrocytes on the surface of the membrane for extracting the plasma, but the latter is a more compact and portable self-pressurized device for a layperson to detect the biomarkers with multiple LFAs, along with pre-separation within the same chip. The prototype device based on microfluidics is shown in Figure 7. This device

Table 1: Month-wise Distribution and Peak Diagnostic Burden of Target Infectious Diseases in Rural Bundelkhand Region (July–October 2022).

Disease	Peak Month	Highest Cases Observed
Malaria (MP)	August	831
Dengue	September	8
HIV	September	8
HBsAg	September	22
HCV	August	4

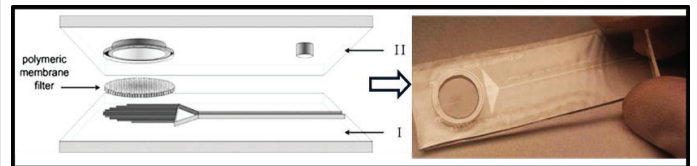


Figure 5: Membrane-based Passive Blood Plasma Separator Device; 3D Schematic (left); and An Assembled PDMS/Glass Plasma Separator (right). Image is reproduced with the prior Permissions from the Authors through email via proper correspondence [12].

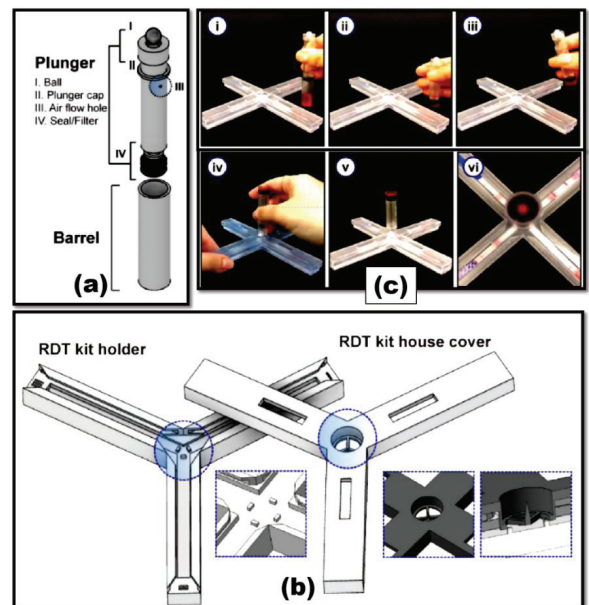


Figure 6: Design and Operation of Membrane-based Self-Pressure Driven Portable Passive Plasma Separator. (a) Exploded view of the Plunger containing the internal parts, including Ball, Plunger Cap, Air Flow Hole, and Seal/ Filter; (b) Y-Shaped Holder and house cover for Multiple LFAs; (c) (i) to (vi) Plasma Extraction along with subsequent Biomarkers detection via LFAs. Image is reproduced with the prior permission from the Author through email via proper correspondence [13].

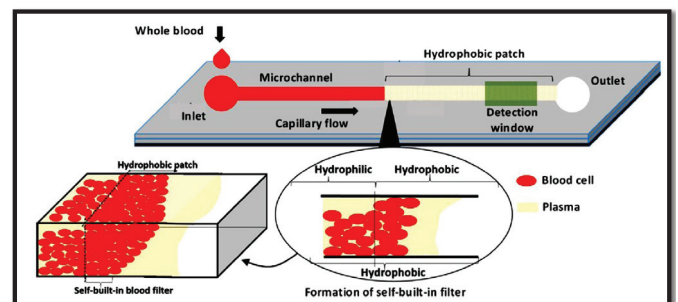


Figure 7: Schematic of a capillary-driven PDMS microchannel acting as a built-in self-filter for the extraction of plasma along the hydrophobic channel and subsequent detection of glucose biomarker. Image is reproduced with the prior permission from the authors via proper correspondence [14].



takes into account the differential wetting of the main channel to induce self-resistance against the whole blood flow near the input stream, while a more hydrophobic surface allows plasma to stream down towards the output port.

Proposed idea and suggestions

Rapid antigen and point-of-care testing methods provide faster preliminary screening and operational advantages in resource-limited settings, although RT-PCR and conventional laboratory methods remain essential for confirmatory diagnosis and higher analytical sensitivity. Such a type of testing, however, is considered to be partially lab-free, compatible with resource-limited rural areas, and preferred when presence or screening is prioritized upon a descriptive report. The demand for rapid diagnostic systems is increasing drastically; they help in better health management, mass detection, and disease control in pandemic situations like COVID-19; early detection and control for rampant disease at the very first acute stage of infection; POCT; and economical and reduced death rates.

However, such methods still rely on conventional laboratory methods for sample preparation. We are therefore emphasizing and researching the fully automated LOC, the key targets being (1) integrating the separation and detection mechanism into a single compact chip, (2) exploring methods and materials to reduce the fabrication and testing cost, (3) in-situ fabrication and on-site testing to improve the testing rate, and (4) exploring passive means to overcome the dependence on electricity for resource-limited remote areas. Despite their operational advantages, rapid antigen and biosensing card methods possess limitations, including lower analytical sensitivity compared to molecular methods, the possibility of false positive/negative results, operator dependency, environmental storage sensitivity, and reduced quantitative capability. Further comparative validation studies are required.

We have discussed a few devices that are still not commercialized owing to the higher cost per chip and complex fabrication methods. Both of these challenges must be addressed to increase their accessibility for resource-limited rural areas. Totally circumventing the laboratory-dependent sample preparation for plasma testing can promote rapid POCT and LOCT, along with early detection of rampant and pandemic diseases.

Conclusion

Rapid point-of-care diagnostic technologies demonstrate strong potential for improving disease screening accessibility in resource-limited rural regions such as Bundelkhand. However, challenges associated with sample preparation, diagnostic sensitivity, and large-scale implementation remain important considerations. Further integration of low-cost lab-on-chip technologies with validated diagnostic systems may support improved healthcare delivery in underserved populations.

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References

1. India Census. Indian Council of Medical Research. SARS-CoV-2 (COVID-19) testing status[Internet]. 2023 [cited 2026 May 25]. Available from: <https://www.icmr.gov.in>
2. Pavia CS, Plummer MM. The evolution of rapid antigen detection systems and their application for COVID-19 and other serious respiratory infectious diseases. *Journal of Microbiology, Immunology and Infection.* 2021;54(5):776-786. Available from: <https://doi.org/10.1016/j.jmii.2021.06.003>
3. Mabey D, Peeling RW, Ustianowski A, Perkins MD. Diagnostics for the developing world: tropical infectious diseases. *Nature Reviews Microbiology.* 2004;2(3):231-240.
4. Amasia M, Madou M. Large-volume centrifugal microfluidic device for blood plasma separation. *Bioanalysis.* 2010;2(10):1701-1710. Available from: <https://doi.org/10.4155/bio.10.140>
5. Rafeie M, Zhang J, Asadnia M, Li W, Warkiani ME. Multiplexing slanted spiral microchannels for ultra-fast blood plasma separation. *Lab on a Chip.* 2016;16(15):2791-2802. Available from: <https://doi.org/10.1039/C6LC00713A>
6. India Census. Ministry of Human Affairs, Government of India. State-wise population in rural area . 2011 [cited 2026 May 25]. Available from: <https://rbidocs.rbi.org.in/rdocs/Publications/PDFs/2TABLE2DC39B399D51426C9BDED7E89E546CC8.PDF>
7. Roy R, Ahmad H. State agricultural profile of Uttar Pradesh (2011-2012). Agro-Economic Research Centre, University of Allahabad [Internet]. 2012 [cited 2026 May 25]. Available from: <https://allduniv.ac.in/ckfinder/userfiles/files/2013-State-Agri-Profile.pdf>
8. India Census. Ministry of Human Affairs, Government of India. Naraini Tehsil population - Banda, Uttar Pradesh [Internet]. 2011 [cited 2026 May 25]. Available from: <https://www.censusindia2011.com/uttar-pradesh/banda/naraini-population.html>
9. Lopresti F, Keraite I, Ongaro AE, Howarth NM, La Carrubba V, Kersaudy-Kerhoas M. Engineered membranes for residual cell trapping on microfluidic blood plasma separation systems: a comparison between porous and nanofibrous membranes. *Membranes.* 2021;11:680. Available from: <https://doi.org/10.3390/membranes11090680>
10. Li X, Popel AS, Karniadakis GE. Blood-plasma separation in Y-shaped bifurcating microfluidic channels: a dissipative particle dynamics simulation study. *Physical Biology.* 2012;9(2):026010. Available from: <https://doi.org/10.1088/1478-3975/9/2/026010>
11. Crowley TA, Pizziconi V. Isolation of plasma from whole blood using planar microfilters for lab-on-a-chip applications. *Lab on a Chip.* 2005;5(9):922-929. Available from: <http://dx.doi.org/10.1039/B502930A>
12. Thorslund S, Klett O, Nikolajeff F, et al. A hybrid poly(dimethylsiloxane) microsystem for on-chip whole blood filtration optimized for steroid screening. *Biomedical Microdevices.* 2006;8:73-79. Available from: <https://doi.org/10.1007/s10544-006-6385-7>



13. Kim H, Park H, Chung DR, Kim T, Park E, Kang M. A self-pressure-driven blood plasma-separation device for point-of-care diagnostics. *Talanta*. 2022;247:123562. Available from: <https://doi.org/10.1016/j.talanta.2022.123562>

14. Maria MS, Rakesh PE, Chandra TS, Sen AK. Capillary flow of blood in a microchannel with differential wetting for blood plasma separation and on-chip glucose detection. *Biomicrofluidics*. 2016;10(5):054108. Available from: <https://doi.org/10.1063/1.4962874>

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