Journal of Carcinogenesis
Covering Genesis to Therapeutics

Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 2s, https://carcinogenesis.com/

Hematological And Socioeconomic Determinants Of Tuberculosis Diagnosis: A Cross-Sectional Analysis In Tertiary Care Hospital In Northern India

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ABSTRACT

Background:Poverty significantly amplifies the risk of Tuberculosis (TB) due to undernutrition and cramped, poorly ventilated living conditions. More than 90% of TB cases occur in people with weaker socioeconomic statuses. In low-income communities, undernutrition increases the risk of active TB. Lack of awareness among these populations exacerbates their susceptibility to various risk factors such as smoking, alcoholism, and HIV infections. Hematological indicators of systemic inflammation can aid in the early detection of Tuberculosis in environments with limited resources.

Objectives: This study aims to investigate the correlation between socioeconomic status (SES)and Tuberculosis positivity and evaluate the clinical relevance of hematological parameters as potential predictors of TB.

Methodology: A cross-sectional study was carried out with 282 individuals to evaluate the variables affecting the results of TB diagnosis. Patient information sheets were used to gather demographic, socioeconomic, and clinical data after getting consent from individual patients. GeneXpert and culture tests were used to confirm the TB diagnosis. Treatment failure predictors were found using logistic regression, and p-values and odds ratios (OR) were shown. Chi-square and Mann-Whitney U tests were used to evaluate correlations between TB status and important factors. ROC analysis was utilized to assess diagnostic accuracy, and Spearman correlation was employed to investigate the connections among biomarkers.

RESULTS: Among the 282 individuals, 190 (67.6%) were male. While 61.4% were culture-positive, 87.6% had TB identified by GeneXpert. Most patients were from the higher lower (26.9%) and lower medium (39.3%) socioeconomic groups. Gender ($p = 0.006$) and isoniazid resistance ($p < 0.01$) were substantially associated with TB. Hemoglobin ($p < 0.05$), WBC count, NLR, and ESR were key predictors. ESR (AUC = 0.776) exhibited the highest diagnostic accuracy, followed by hemoglobin, WBC count, and NLR. A mild negative correlation ($r = -0.191$) between NLR and hemoglobin and a significant positive correlation ($r = 0.278$) between ESR and NLR in TB patients were observed.

CONCLUSION: The findings highlight the dual impact of SES and inflammation markers on TB risk, emphasizing the need to incorporate these factors into routine screening and early detection strategies. Public health policies should address socioeconomic barriers while integrating hematological assessments as supplementary diagnostic tools to improve TB management, particularly in resource-constrained settings.

Keywords: *Tuberculosis predictors, Socioeconomic Status, Hematological Markers, Inflammation, Neutrophil-to-Lymphocyte Ratio (NLR).*

How to Cite: Sandeep Kumar, Santosh Kumar, Rachna, Surbhi Deshwal, (2025) Hematological And Socioeconomic Determinants Of Tuberculosis Diagnosis: A Cross-Sectional Analysis In Tertiary Care Hospital In Northern India, *Journal of Carcinogenesis*, *Vol.24, No.2s*, 1040-1050

1. INTRODUCTION

The World Health Organization's Global Tuberculosis Report 2024 states that tuberculosis (TB) was the leading infectious

disease-causing deaths in 2023. There were 8.2 million new cases, the highest number recorded since 1995. 56% of instances occur in China, India, Indonesia, the Philippines, and Pakistan [1. The number of cases with a diagnosis decreased to 2.7 million. Only 44% of cases of multidrug-resistant TB are treated, making it a crisis. WHO emphasizes that TB is preventable with current techniques and calls on nations to increase efforts to prevent, detect, and treat the illness [2].

Poverty raises the risk of tuberculosis because of overcrowding, malnourishment, and limited access to healthcare. By lowering income and raising medical costs, TB further exacerbates poverty by keeping patients in a precarious financial situation. Effective TB treatment necessitates both medical interventions and financial protective measures. Poverty and tuberculosis are closely related since the illness is more prevalent in underdeveloped areas and exacerbates financial difficulties. According to a survey of 30 studies from sub-Saharan Africa, the poorest patients had to pay up to ten times their yearly income for TB treatment, which frequently exceeded 10% of per capita income [3]. Hospitalization costs, prescription drug costs, and missed income further impoverish families. Breaking the TB poverty loop requires lowering treatment costs and offering financial assistance [4].

According to a study that examined 198,754 participants from the 2006 Demographic Health Survey in India, the prevalence of tuberculosis was lowest in the wealthiest groups (201 per 100,000) and most significant in the poorest (1100 per 100,000). Low BMI (34.2%) and indoor air pollution (28.5%) were significant factors among the poorest [5]. The most mediating factor in TB risk was malnutrition. Control measures must enhance nutrition and lower indoor pollution, especially in low-income areas, to interrupt the cycle of poverty and tuberculosis [6]. A study examined socioeconomic factors' impact on TB treatment outcomes in Karamoja, Uganda, where treatment success rates are the lowest. Low socioeconomic status was strongly linked to unsuccessful TB treatment outcomes (59.1%). While those in the informal sector (OR = 4.71, p = 0.029) and children under 15 who were not enrolled in school or working (OR = 2.71, p = 0.029) had considerably higher chances of poor outcomes, wealthier people had a 58% reduced risk of treatment failure (OR = 0.42, p = 0.047). Pre-treatment loss to follow-up was higher among females (21.7%) than males (13.5%), highlighting gender disparities. Key socioeconomic barriers included food insecurity, migration, stigma, lack of social protection, drug stock-outs, and transport challenges, underscoring the need for multi-sectoral interventions to improve TB care [7]. Another study examined the relationship between Koreans over 40's socioeconomic level (SES) and their adherence to health examinations, including blood testing. Increased screening participation was linked to higher income, education, and office-based employment. Access was low for manual laborers and those with lower incomes, most likely due to job restrictions, lack of information, and budgetary limitations [8]. In order to ensure early illness identification and management for all socioeconomic groups, the results emphasize the necessity of equitable healthcare policies that enhance access to routine blood testing and preventative care [9, 10].

Owing to the importance of early TB prediction, we designed this study to evaluate data from government hospitals in northern Indian states. We aim to identify the importance of biochemical parameters and socioeconomic status in early TB diagnosis.

2. MATERIALS AND METHODS

Study Design and Setting

The cross-sectional observational study was conducted at Government Tuberculosis (TB) diagnostic and treatment centers in Palwal, Haryana, India, between June 2024 – January 2025. The study sought to evaluate several hematological and sociodemographic characteristics as possible predictors of tuberculosis, with culture-positive acting as the gold standard for diagnosis.

Ethical Approvals

The Institutional Ethics Committee (IEC) of NIMS University approved the study with an approval number NIMSUR/IEC/2022/315 dated 10/06/2022. The study complied with good clinical practice (GCP) standards by following globally accepted ethical principles like the Declaration of Helsinki. The participants were duly informed about the study in their language, and written consent was obtained in English and Hindi to participate.

Study Population

Inclusion Criteria

The study included individuals aged 18 years or above who are suspected of having pulmonary tuberculosis. These patients receive standard diagnostic procedures, such as culture testing for Mycobacterium tuberculosis, GeneXpert, and sputum microscopy. All the individuals enrolled in the study gave their written informed permission.

Exclusion Criteria

Patients diagnosed with extrapulmonary tuberculosis and other immunocompromising diseases or other persistent infections (except HIV, which was documented separately) were not included in the study. Patients with incomplete medical records were also excluded.

Data Collection and Laboratory Procedures

The study employed a structured data record form (DRF) to collect laboratory, clinical, and demographic data in an organized manner. Age, sex, occupation, and educational attainment are among the sociodemographic and lifestyle factors used to evaluate TB patients' socioeconomic patterns. The modified Kuppuswamy scale, which combines household income, occupation, and education to divide people into various socioeconomic strata, was used to classify socioeconomic status (SES) [11]. Lifestyle factors such as alcohol use, smoking history, and prior TB exposure were also documented to investigate any risk linkages. Clinical assessments were performed on the participants, which included diagnostic imaging, symptom history, and physical examinations. In order to evaluate inflammatory markers, blood samples were examined for hemoglobin (Hb) levels, erythrocyte sedimentation rate (ESR), total leukocyte count (TLC), neutrophil-to-lymphocyte ratio (NLR), and platelet count. GeneXpert, sputum microscopy (Ziehl-Neelsen staining) for acid-fast bacilli (AFB), and culture tests (solid and liquid techniques) as the gold standard were used to confirm the tuberculosis diagnosis.

Statistical Analysis

An extensive statistical analysis was carried out with SPSS version 26. The Shapiro-Wilk test was used to determine whether the data was normal after being entered into Microsoft Excel and cross-checked for accuracy. The Chi-square test was used to evaluate categorical data, while the Mann-Whitney U test was used to compare non-normally distributed variables. TB positivity predictors were found using binary logistic regression. Hematological markers' diagnostic performance was assessed using ROC curve analysis, which provided AUC values along with 95% CIs. Spearman's rank correlation evaluated the connections between TB outcomes and hematological markers.

3. RESULTS

This cross-sectional study assessed 282 suspected TB patients. It aimed to determine the hematological and socioeconomic predictors of culture-positive TB patients. All the patients underwent clinical evaluation, hematological investigations, and confirmation of TB using culture.

Descriptive Statistics

Table 1 shows the descriptive statistics of the cohort. The mean age of study participants was 39.22 ± 17.58 years. Hematological parameters recorded were as follows: WBC count 13,716.87 ± 3199.16 cells/mm³, hemoglobin 10.45 ± 1.59 g/dL, platelet count 269,535.38 ± 67,639.62, ESR 62.84 ± 22.09 mm/hr, and NLR 4.19 ± 1.04. The mean duration of cough was 6.55 ± 2.86 weeks.

Table 1: Descriptive Statistics of Hematological Parameters (n = 282)

Parameter	Mean ± SD	Median (IQR)
Age (in years)	39.22 ± 17.58	28.0 (24.0 – 52.0)
WBC Count	13,716.87 ± 3199.16	13,500 (11,000–15,000)
Hemoglobin	10.45 ± 1.59	10.3 (9.4–11.5)
Platelet Count	269,535.38 ± 67,639.62	270,000 (220,000–320,000)
ESR	62.84 ± 22.09	60 (48–75)
NLR	4.19 ± 1.04	4.1 (3.5–4.9)

Distribution of Socioeconomic and Clinical Variables

Table 2 represents the enrolled TB patients' socioeconomic distribution and other clinical variables. Of 282 patients, 190 subjects were males (67.4%) and 92 were females (32.6%). Socioeconomic status was assessed using the Modified Kuppuswamy Scale. Most (74.8%) patients were classified under the upper-lower class, while only 3.8% belonged to the lower-middle class. No participants were reported in the upper or upper-middle categories. A significant proportion of the cohort reported previous TB history (80.7%), TB family history (30.3%), smoking (29.3%), and alcohol use (17.6%). HIV positivity was noted in 12.1% of the sample. Approximately 61.0% belonged to the lowest income group (income category 5). Fever, night sweats, weight loss, and prolonged cough (>2 weeks) were the most frequently reported symptoms.

Table 2: Distribution of Socioeconomic and Clinical Variables

Variable	N	Percentage (%)
Gender (Male)	190	67.4
Gender (Female)	92	32.6
Upper Lower SES Class	210	74.8
Lower Middle SES Class	10	3.8
Smoking	82	29.3
Alcohol Consumption	50	17.6
HIV Positive	34	12.1
History of Previous TB	227	80.7
Family History of TB	85	30.3
Income Category 5	172	61.0

Comparison of Hematological Markers by TB Culture Status

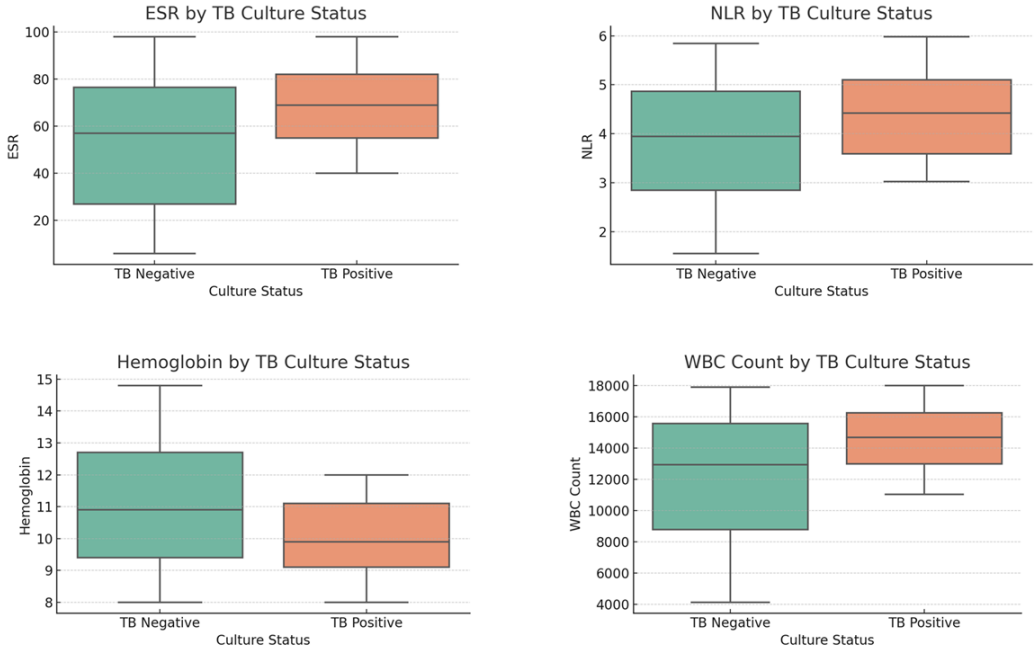
Table 3 presents the results of the Mann-Whitney U test applied to assess the difference in different hematological variables between culture-negative and culture-positive TB patients. Statistically significant differences were observed in WBC count ($U = 6910.5$, $p < 0.001$), hemoglobin level ($U = 7009.0$, $p < 0.001$), ESR ($U = 6969.0$, $p < 0.001$), and NLR ($U = 7240.5$, $p < 0.001$), with higher WBC, ESR, and NLR, and lower hemoglobin values noted in TB-positive participants. In contrast, platelet count, cough duration, and SES score did not differ significantly between the two groups ($p > 0.05$). Fig. 1 shows the comparative Box plots of WBC count, Hemoglobin, ESR and NLR among TB-positive and TB-negative individuals.

Table 3: Mann-Whitney U Test Results for Hematological Variables

Variable	U Value	Z Score	p-value
WBC Count	6910.5	-4.397	0.000*
Hemoglobin	7009.0	-4.257	0.000*
ESR	6969.0	-4.314	0.000*
NLR	7240.5	-3.923	0.000*
Platelet Count	9138.0	-1.194	0.233^{ns}
Cough Duration	8972.0	-1.440	0.150^{ns}
SES Score	9673.0	-0.431	0.667^{ns}

*Mann-Whitney U test was applied for non-normally distributed variables. p-value < 0.05 was considered statistically significant. * p-value < 0.05, ^{ns} p-value > 0.05*

Fig. 1: Boxplots of WBC count, Hemoglobin, ESR and NLR among TB-positive and TB-negative individuals.



Association of Categorical Variables with TB Status

Chi-square test results for categorical variables are summarized in Table 4. A significant association was found between TB positivity and gender ($p = 0.006$), with a higher prevalence among males. Similarly, isoniazid resistance statistically correlated with TB status ($p < 0.01$). Other variables, including SES class, HIV status, smoking and alcohol use, did not show statistically significant differences. There was also no significant association between TB positivity and previous TB history, family TB history, or classic symptoms such as fever, weight loss, and night sweats.

Table 4: Chi-square Test with TB Positive and Negative Counts

Variable	TB Positive (n)	TB Negative (n)	p-value
Gender	130	102	0.006*
SES Class	175	143	0.633^{ns}
HIV Status	12	23	0.358^{ns}
Smoking	40	45	0.628^{ns}
Alcohol	25	26	0.393^{ns}
Isoniazid Resistance	38	23	0.01*
Rifampicin Resistance	5	6	0.569^{ns}

Chi-square test was used for association between categorical variables and TB status. p-value < 0.05 was considered statistically significant. * $p < 0.05$, ns $p > 0.05$

Predictors of Culture – positive TB: Logistic Regression Analysis

Binary logistic regression was performed to identify independent predictors of TB positivity (Table 5). The model showed good fit (Hosmer-Lemeshow $p = 0.763$) and explained 45.8% of the variance (Nagelkerke $R^2 = 0.458$). WBC count (OR = 1.34, $p = 0.014$), NLR (OR = 1.81, $p = 0.009$), ESR (OR = 1.05, $p = 0.031$), and hemoglobin (OR = 0.68, $p = 0.026$) were significant independent predictors of TB positivity. Higher levels of inflammatory markers and lower hemoglobin levels

increased the odds of a TB-positive diagnosis.

Table 5: Binary Logistic Regression – Predictors of TB Positivity

Variable	OR (Exp(B))	95% CI	p-value	
WBC Count	1.34	1.06–1.71	0.014*	Significant
NLR	1.81	1.17–2.79	0.009*	Significant
Hemoglobin	0.68	0.49–0.94	0.026*	Significant
ESR	1.05	1.01–1.10	0.031*	Significant

Hosmer-Lemeshow test p = 0.763; Nagelkerke R^2 = 0.458. OR = Odds Ratio; CI = Confidence Interval. *p-value < 0.05 was considered statistically significant.

Diagnostic Performance of Hematological Parameters

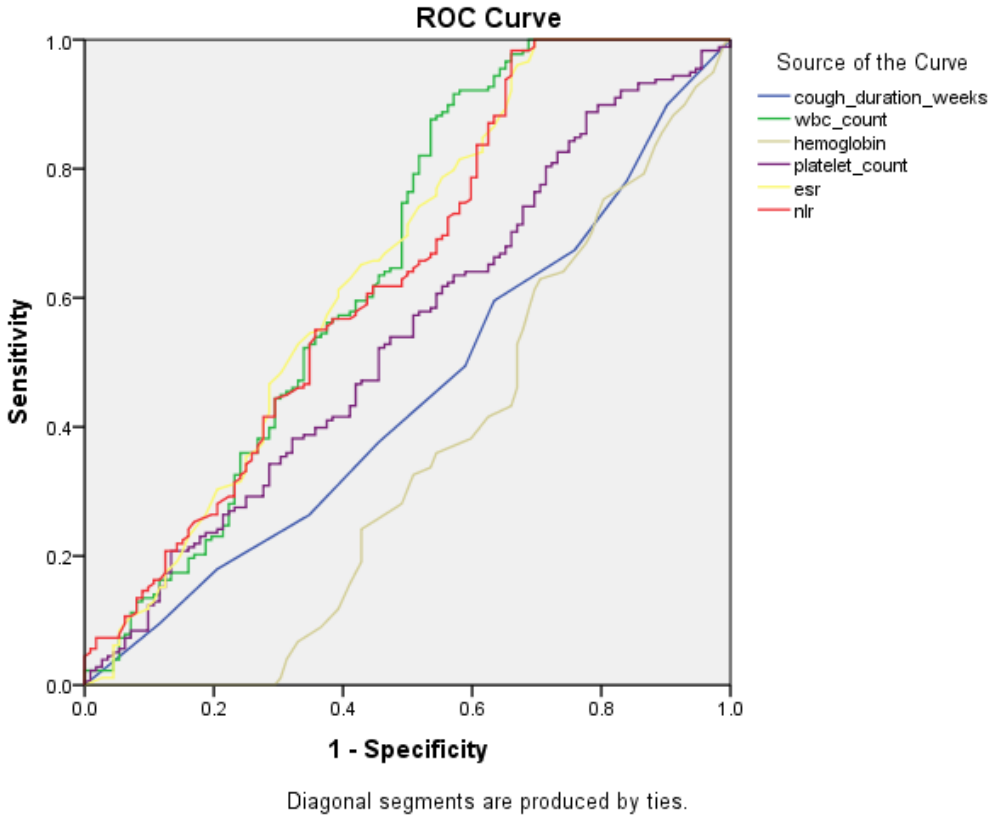
ROC curve analysis was conducted to assess the diagnostic accuracy of the hematological markers (Table 6). ESR had the highest area under the curve (AUC = 0.776, 95% CI: 0.717–0.835), followed by NLR (AUC = 0.752), hemoglobin (AUC = 0.732), and WBC count (AUC = 0.707). These findings indicate that ESR demonstrates the best discriminative performance among the variables tested. Fig. 2 also represents the pictorial representations of ROC curve of all the biomarkers.

Table 5: ROC Curve Analysis – Diagnostic Accuracy of Biomarkers

Marker	AUC	95% CI	p-value
ESR	0.776	0.717–0.835	0.001*
NLR	0.752	0.691–0.813	0.001*
Hemoglobin	0.732	0.667–0.798	0.001*
WBC Count	0.707	0.642–0.772	0.001*

ROC curve analysis used TB culture positivity as the reference standard. p-value < 0.05 was considered statistically significant. * $p < 0.05$

Fig. 2: ROC curve



Correlation between Inflammatory and Hematological Parameters

Spearman correlation analysis (Table 7) revealed a moderate positive correlation between ESR and NLR ($r = 0.278$, $p < 0.001$), and a weak negative correlation between NLR and hemoglobin levels ($r = -0.191$, $p = 0.003$), suggesting that as inflammation increases, hemoglobin tends to decrease.

Table 7: Spearman Correlation Among Hematological Parameters

Variables	Spearman r	p-value	Interpretation
ESR vs NLR	0.278	<0.001	Positive Correlation
NLR vs Hemoglobin	-0.191	0.003	Negative Correlation

Spearman's correlation coefficient was used for non-parametric correlation. p-value < 0.05 was considered statistically significant.

4. DISCUSSION

Our study's findings offer important new information about TB patients' hematological, clinical, and demographic traits. Males made up the majority of the study population (67.6%), which is in line with global epidemiological patterns [12] that indicate men are more likely than women to have tuberculosis. Biological vulnerability, variations in healthcare access, and increased exposure to risk factors, and this includes smoking and job risks, could all be contributing factors to this gender gap [13-15]. Prior research has consistently shown that men are more likely than women to get tuberculosis (TB) ($p = 0.006$), with a global incidence ratio of 1.6:1 [16-19]. Similar to the results of our study, this discrepancy is ascribed to biological susceptibility, variations in healthcare access, and elevated exposure risks in men [20]. Our analysis did not detect a statistically significant association between SES class and TB positivity despite previous research that linked TB with socioeconomic status (SES). This is probably because our study sample had a generally lower socioeconomic distribution [21].

Significant variations in inflammatory markers between TB-positive and TB-negative individuals were found by hematological analysis. Systemic inflammation and anemia which are linked to TB infection were shown by considerably lower hemoglobin levels ($p < 0.001$) and significantly higher WBC count, ESR, and NLR in TB-positive patients ($p < 0.001$) [22]. These results are consistent with previous research that indicates leukocytosis, high ESR, and anemia are frequently associated with tuberculosis (TB) as a result of immune response changes and nutritional deficits which are caused by long-term infection [23-27]. Our investigation found no significant changes in platelet counts between TB-positive and TB-negative groups ($p > 0.05$) despite prior research reporting variability in platelet counts in TB patients. Cough duration and SES score did not change significantly ($p > 0.05$) [28].

Previous research has shown that individuals with tuberculosis have much lower hemoglobin levels ($p < 0.001$) and mild anemia (50%) to severe anemia (13%) [29]. Additionally, they have heightened neutrophil-to-lymphocyte ratios ($p < 0.001$), which suggests immunological imbalance, as well as raised WBC counts and ESR ($p < 0.001$), which indicate systemic inflammation [30]. Some research reveals thrombocytosis (11.6%) or thrombocytopenia (9.8%) in platelet counts, whereas other studies find no significant difference ($p > 0.05$) [31]. Furthermore, there was no statistically significant difference in cough duration or socioeconomic position between the TB-positive and TB-negative groups ($p > 0.05$). Our investigation results agree with these patterns, supporting the link between TB and changes in the hematological and inflammatory systems [32].

Furthermore, TB-positive and isoniazid resistance were substantially correlated ($p < 0.01$), which shows the crucial role of isoniazid resistance in treatment difficulties. Other categorical characteristics, including smoking ($p = 0.628$), alcohol use ($p = 0.393$) and HIV status ($p = 0.358$), did not, however, significantly correlate with TB positivity [33]. Although they might increase general TB susceptibility, the lack of a meaningful correlation with these risk factors indicates minimal influence within this specific research population.

Hemoglobin levels (OR = 0.68, $p = 0.026$), ESR (OR = 1.05, $p = 0.031$), NLR (OR = 1.81, $p = 0.009$), and WBC count (OR = 1.34, $p = 0.014$) were all found to be independent predictors of TB positivity using binary logistic regression analysis [33]. The high correlation between NLR and TB raises the possibility that it could be used as a diagnostic biomarker. The significance of systemic inflammation in TB pathogenesis was further shown by the finding that a unit rise in WBC count was linked to a 34% increased risk of TB [34-36]. The negative link between hemoglobin levels and TB risk emphasizes the necessity of nutritional therapies as part of TB management [37].

ESR had the highest diagnostic accuracy (AUC = 0.776), according to ROC curve analysis, followed by hemoglobin (AUC = 0.732), NLR (AUC = 0.752), and WBC count (AUC = 0.707). Including these parameters in standard TB screening procedures may improve early diagnosis and disease monitoring [38]. Our analysis focuses on objective hematological indicators rather than socio-demographic characteristics like smoking and socioeconomic status. Because inflammatory resolution correlates with TB clearance, following these markers may assist in evaluating treatment response. Combining NLR, WBC, and hemoglobin may improve early TB diagnosis in resource-constrained situations [39].

ESR and NLR exhibit a somewhat positive connection ($r = 0.278$, $p < 0.001$), and this means both markers rise simultaneously as systemic inflammation does. Furthermore, a weak negative connection ($r = -0.191$, $p = 0.003$) between NLR and hemoglobin levels suggests that inflammation-associated anemia results from increased inflammation. These results support our research and it shows how systemic inflammation affects hematological parameters and establishes NLR as a valuable biomarker for tracking inflammatory conditions [40].

5. CONCLUSION

This study emphasizes the relevance of economic disparities in disease susceptibility and highlights the substantial association between low socioeconomic status (SES) and tuberculosis (TB). People from lower socioeconomic backgrounds are more likely to get TB because of several risk factors, such as overcrowding, malnutrition, and restricted access to healthcare. These results demonstrate the critical need for focused public health initiatives to reduce the risk of tuberculosis in susceptible groups. The study also shows how hematological markers, including higher white blood cell count, erythrocyte sedimentation rate, and neutrophil-to-lymphocyte ratio, are clinically relevant in identifying tuberculosis. These inflammatory markers, which are frequently changed in TB-positive people, may be helpful and affordable screening tools, particularly in environments with limited resources. Routine TB risk assessments incorporating hematological screening could improve illness outcomes by enabling early detection and treatment. Since SES and inflammatory markers significantly influence TB risk, including them in thorough risk-screening models may improve early detection initiatives. Public health initiatives that integrate hematological evaluations with socioeconomic interventions may provide a more comprehensive approach to TB control, and this may lower the disease burden in high-risk regions.

6. ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Institution for providing the necessary facilities and resources

to carry out this work.

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